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Stirling Economics Discussion Paper 2010-14
November 2010

Online at http://www.economics.stir.ac.uk

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Abstract
Recent decades have witnessed substantial losses of biodiversity in Europe, partly driven by the ecological changes associated with intensification of agricultural production. These changes have particularly affected avian (bird) diversity in marginal areas such as the uplands of the UK. We developed integrated ecological-economic models, using eight different indicators of biodiversity based on avian species richness and individual bird densities. The models represent six different types of farms which are typical for the UK uplands, and were used to assess the outcomes of different agricultural futures. Our results show that the impacts of these future agricultural scenarios on farm incomes, land use and biodiversity are very diverse across policy scenarios and farm types. Moreover, each policy scenario produces un-equal distributions of farm income changes, and gains and losses in alternative biodiversity indicators. This shows that generalisations of the effects of land use change on biodiversity can be misleading. Our results also suggest that a focus on umbrella species or indicators (such as total richness) can miss important compositional effects.

Keywords: policy scenarios, ecological-economic models, farm models, biodiversity, agri-environmental policy.

1. Introduction

Recent decades have witnessed substantial losses of biodiversity in Europe, partly driven by the ecological effects of changes to systems of agricultural production (Benton *et al.* 2002; Donald *et al.* 2006). Marginal agricultural areas such as uplands in the UK have been particularly affected, experiencing widespread habitat change to a greater degree than in lowland agricultural zones (Haines-Young *et al.* 2003). The ecological consequences have been striking, with substantial and on-going declines in upland breeding bird populations (Sim *et al.* 2005). Farming is the dominant land-use in the UK uplands, even though it operates on the margins of agricultural productivity (Donald *et al.* 2006). Recently, upland farm incomes in the UK have fallen dramatically (Defra 2005) and the viability of upland farms now often depends on core subsidy support such as the Single Payment Scheme of the Common Agricultural Policy and on agri-environment payments (Peak District Rural Deprivation Forum 2004; National Trust 2005; Acs *et al.* 2010).

The aim of this paper is to investigate the likely future impacts of agricultural change in the UK uplands on biodiversity, using a range of indicators of avian diversity and richness. Farmers change their behaviour in response to both market prices and government interventions. We include both "drivers" in a set of scenarios of future agricultural markets and policies, and investigate likely outcomes under each scenario using simulation models. Such scenarios attempt to map out the boundaries of what may happen, using "the best evidence from science and other areas to provide visions of the future"[1]. They are acknowledged as a useful way of developing understanding of qualitative changes in outcomes under uncertainty. For instance, many modelling exercises of climate change impacts make use of scenarios for changes in greenhouse gas concentrations and weather

[1] http://www.foresight.gov.uk/index.asp

patterns (IPCC, 2007). Similarly, the World Bank's recent work on adaptation costs in developing countries makes use of scenarios for climate change and socio-economic phenomena such as economic growth rates (World Bank, 2010). For biodiversity, the Millennium Ecosystem Assessment ([MEA] 2005) made use of four scenarios for the global economy in order to examine possible impacts on ecosystem services. In doing so, the MEA explicitly pointed out that the actual future would not be the same as any of scenarios considered. Instead, the scenarios were designed to capture the range of uncertainty about important drivers and settings. Scenario analysis, when combined with simulation modelling, provides insights into the relative strength and direction of key outcome variables, and is thus a means of scoping uncertainty when precise predictions are not available or particularly meaningful.

A number of previous studies have developed scenarios to describe upland futures in the UK, eight of which were reviewed by Reed et al.(2009). Reed et al also assessed the perceptions of stakeholders of the relative likelihood and desirability of alternative upland futures. The most desirable and likely scenario appeared to be a continuation of hill farming (albeit at reduced levels of intensity) based on cross compliance combined with agri-environmental measures. Stakeholders considered that a withdrawal of government financial support for hill farming was the least desirable scenario, but argued that it warranted attention because of the serious implications for the rural economy and livelihoods. Furthermore, Reed et al., (2009) also concluded that environmental implications were the least well developed aspects of scenario analysis, a comment of particular relevance to the research reported here.

The scenarios used in this paper are referred to as "Foresight Scenarios", and derive from an on-going UK government exercise (DTi, 2002). The Foresight programme was launched by the UK government in 1994 as a way of looking ahead and preparing for the future. It "..brings together the voices of business, government, the science base and others to identify the threats and opportunities that we are likely to face over the next ten to twenty years or more" (DTi, 2002: more information is available at http://www.foresight.gov.uk). In the Foresight Scenarios, it is assumed that in one dimension, social values range from individual consumerism to community conservationism, whilst in the second dimension, governance ranges from local autonomy to global interdependence. This gives rise to four scenarios which are termed "World Markets" (WM), "Global Sustainability" (GS), "National Enterprise" (NE), and "Local Stewardship" (LS) - as shown in Figure 1. We use these scenarios as a means of thinking about future agricultural and environmental outcomes for farming in the uplands, based on a range of future world market conditions, trade arrangements and Common Agricultural Policy designs.

The Foresight Scenarios were developed for UK farming in the Agricultural Futures project (Morris et al., 2005; Sylvester Bradley and Wiseman, 2005) and include assumptions regarding the direction and extent of change of key external drivers, such as the global demand for livestock products, as well as differences in livestock and grassland technologies.
A review of historic trends combined with expert opinion suggested that the primary drivers of agricultural change are external macro-economic factors, agricultural trade and policy, consumers and markets, and climate change. Secondary drivers arising partly in response to primary drivers include changes in agricultural structure, systems and technology, farmer motivation, rural development regulation, and environmental and agri-environmental policy. A narrative to reflect these changes was developed by Morris et al., (2005a) and from these, drawing on expert judgement, stakeholder consultation, and model simulations in the Silsoe Whole Farm Model (Annetts and Audsley, 2005), a set of indices giving the relative value of

key selected indicators for each scenario (e.g. level of crop and livestock production; level of policy support) against a baseline was developed. These indicators reflect changes in input and output prices, and in the Common Agricultural Policy and UK government agri-environment policies, under each of the future scenarios (Table 1).

The impacts of these possible future agricultural policies and market conditions on long term upland farm incomes and biodiversity were then analysed using integrated ecological-economic models of upland farming and biodiversity in the Peak District National Park in the UK. We combine behavioural modelling with statistical regression, to capture important responses of the farm system to changes in prices and policies and the likely responses from different biodiversity indicators. The models were developed using seven alternative indicators of biodiversity based on total avian species diversity and richness and individual bird densities (Dallimer et al, 2009). The models were based on different types of farms which are typical for the UK uplands, in order to capture heterogeneity in response to future scenarios due to differences in farm structure and resources (Acs et al, 2010).

2. Methodology

2.1 Farm model data

We based the economic components of farmer behaviour on data collected on upland farming in the Peak District National Park. The survey was designed and carried out with the help of experienced farm business researchers through the winter months of 2006/2007. It comprised 44 farm visits. Farms were chosen on the basis of their location and on access to moorland grazing. The survey included questions on land area, land types and land use, production activities and subsidy payments received during the reference year of 2006. All surveys were carried out at the farm, and each took around three hours to complete.

Sheep, dairy and beef cattle production were found to be the dominant activities in the uplands of the Peak District, utilising two main types of land: moorland and "inbye" land. Moorland is defined as unenclosed semi-natural rough grazing, situated at higher altitude, providing the poorest grazing: it is characterised by heather and other dwarf shrub cover and rough grassland. The "inbye" land is agriculturally improved, more productive pasture land situated at lower altitudes. Based on these survey results, six types of typical upland farms can be distinguished depending on whether a part of the farm has moorland access or not: Moorland Sheep & Beef (MSB), Moorland Sheep & Dairy (MSD), Moorland Sheep (MS), Inbye Sheep & Beef (ISB), Inbye Sheep & Dairy (ISD) and Inbye Beef (IB). These six farm types were used as the basis for six "representative farm" models, which were then used in the scenario simulations reported here.

2.2 Biodiversity Indicator data

We also collected data on birds as indicators of biodiversity on upland farms. Bird surveys were carried out on the same farms as the farm business surveys described above in order to have full overlap in the data. We are therefore able to make a direct connection between farm management practices and bird diversity and abundance for each farm type. Bird surveys covered individual properties using equidistant parallel transects, thus enabling farmland to be surveyed based on standard methodologies (Newson et al 2005). On average, 95.0 ha of farmland was surveyed per property, with an average 1651 m of transect walked. Only birds resident in, or making use of, the surveyed property were included. During surveys, on encountering a bird, the distance and angle from the observer were measured using a laser rangefinder (Leica LRF1200) and compass. This enabled the perpendicular distance of the bird from the transect to be calculated and distance sampling methodology to be employed

(Thomas et al. 2010). Bird surveys were carried out between one and three hours after sunrise, on two separate visits at least six weeks apart between 28th March and 5th July 2007.

When bird numbers are converted to density estimates, detectability must be taken into account. This can be influenced by the cue that was used to locate the bird (i.e. whether the individual was seen or heard). This was taken into account by including cue type as a covariate when calculating the detection functions. Species-specific density functions were estimated for 33 species with 60 or more registrations. For the remaining less common species, a detection function was estimated using registrations for a group of similar species. Subsequently, candidate models of the detection function were chosen and tested against the data. Model selection was based on minimum Akaike Information Criteria (AIC) and χ^2 goodness of fit tests. The detection function model was then applied to the number of encounters on each transect to give a species-specific estimate of the density of individuals. Distance data were analysed using Distance 5.0 release 2 (Thomas et al. 2006). The density of all birds (*Total Density*) and of five individual species of particular conservation interest (Eurasian curlew *Numenius arquata*, northern lapwing *Vanellus vanellus*, skylark *Alauda arvensis*, song thrush *Turdus philomelos*, linnet *Carduelis cannabina*) were calculated. In addition, a list of all bird species (*Total Species Richness*) encountered on a farm during both field visits was compiled. For further detail on the ecological modelling of these biodiversity indicators, see Dallimer *et al*. (2009, 2010).

2.3 Economic modelling of farm decision-making

Mathematical optimisation models were developed for the six typical farm types (more details are given in Acs et al, 2010). The general structure of these models has the form of a standard mathematical programming (MP) model (Hazell & Norton, 1986), where some equations contain non-linear expressions:

Maximise $\{Z = c'x\}$

Subject to $Ax \leq b$

and $x \geq 0$

where:

Z =gross margin (net revenue excluding fixed costs) at the farm level

x = a vector of activities

c = a vector of gross margins or costs per unit of activity

A = a matrix of technical coefficients

b = a vector of resource endowments and technical constraints

The six farm models consist of different activities and constraints. The activities, based on typical upland farming practices, are production activities representing several fodder crops and animal production systems, supply of seasonal labour, purchase of fertilizer and feed, activities for sold animal products and receipt of subsidy payments, including agri-environment scheme payments. Several constraints were included in each model: land availability, supply and demand of fixed and seasonal labour, feeding and housing requirements for livestock, fertilizing requirements per land type, constraints on organic manure use in Nitrate Vulnerable Zone, constraints on subsidies for Single Payment based on production and land type, and restrictions on payments from Hill Farm Allowance and different agri-environment schemes. The objective function of the farm models is to maximise farm gross margin, i.e. total returns from animal production and subsidy payments minus variable costs, including variable operations, fertilizer and seasonal labour. The output of the models include the corresponding production plan with optimal land use, labour use and fertilizer application. To obtain the optimal solution for the farm models, the CONOPT solver was used in GAMS (General Algebraic Modelling System).

Farmers in the uplands can take part in many different agri-environment schemes. Payments under the CAP are taken into account dependent on the policy scenario modelled, along with UK agri-environment schemes. The Single Payment scheme replaced most crop and livestock payments from 2005. To comply with this scheme, farmers need to keep their land in good agricultural and environmental condition and comply with specified legal requirements relating to the environment, animal health and welfare ("cross-compliance"). The payment is connected to eligible land types and quantity on the farm. The payment also incurs costs of compliance, which was estimated based on the costs per hectare required to maintain grassland in "good agricultural condition". Agri-environment payments are intended to compensate or provide an incentive for farmers to undertake environmental measures which go beyond Good Farming Practice. The most frequently used options of the agri-environmental schemes in the upland area were selected and added to the model. These options can be taken up, with restrictions on fertiliser use and livestock density, as part of the maximisation of gross margin. Finally, most of the farms in the uplands in this region are situated within a Nitrate Vulnerable Zone, which imposes a limit on organic manure applications. This limit is also included in the model as a constraint.

Five management variables which are outputs from the farm model were chosen to link predicted farming activity to the various biodiversity indicators. These variables were selected on the basis of a review of existing ecological evidence for the uplands. These variables are: sheep density, beef cattle density, dairy cattle density, fertiliser use per hectare and the number of grass cuts per year for silage production. All five might be considered alternative indicators of land use intensity. These variables make a link between economic activity and biodiversity indicators, this linkage being achieved using regression results relating these five management variables to species richness and abundance, as detailed below.

Ecological modelling linking agricultural land use to biodiversity outcomes

We quantified the effects that farm management variables had on the avian biodiversity indicators on our sample farms by using regression models, with farm management activities (sheep and cattle numbers per hectare, fertilizer inputs and number of grassland cuts per year) as explanatory variables, and the biodiversity indicators as response variables. For density-based indicators, we used linear regression, transforming the response variables as appropriate to meet assumptions of normality (square root transforms were preferred for curlew, lapwing and total density). A Poisson error structure, corrected for over-dispersion, was used to model the response of Total Richness. The regional location of any farm site (Dark Peak, Eastern Moors, South-West Peak) was also included to account for regional gradients in habitat quality in both farmland and moorland. The general format of the model is shown below.

$$B = b_1*R + b_2*S + b_3*C + b_4*F + b_5*Cut + \varepsilon$$

where B is an avian biodiversity indicator, R are regional dummies for the Dark Peak and South-West Peak (Eastern Moors being the reference category), S and C refer to sheep and cattle numbers per hectare, F is the fertiliser use per hectare, and Cut is the number of grass cuts per hectare for silage production. These ecological regression models were integrated into economic models by back-transforming where appropriate and adding them as separate equations that provide the relationships betweens avian biodiversity indicators and farm management variables. Tables 2a and 2b show the overall fit for each model, and model parameters.

Policy scenarios

In order to investigate the impacts of possible agricultural policies and changes in market conditions in marginal upland areas, the four policy scenarios described above based on the Foresight exercise (“World Markets” (WM), “Global Sustainability”(GS), "National Enterprise" (NE) and “Local Stewardship” (LS)) were analysed. The scenarios allow us to explore the range of likely outcomes for each variable in terms of consequences for land use and biodiversity. However, we do not analyse transition conditions towards these outcomes, but take instead a comparative static approach. As noted previously, we used indices for these Foresight scenarios as developed for UK agriculture by Morris et al. (2005) and Table 1 shows these as relative values for 2050 against a 2002 baseline.

In the World Market (WM) scenario it is assumed that policy emphasis is on private consumption in a highly developed and integrated world market. No support is given from the UK government or CAP for either agricultural activities or environmental outcomes from farming, whilst input and output prices are assumed to be lower than in the present situation.

In the Global Sustainability (GS) scenario there is collective action to address social and environmental issues. Growth is slower but more equitably distributed compared with the WM scenario. In this scenario income support is given from the state to farmers in the form of a reduced Single Farm Payment, and as agri-environment payments. However, input prices tend to be higher, in general, especially for fertiliser and feed, which rise by around 50% relative to the baseline.

In the National Enterprise (NE) scenario farm support reverts to the pre-2003 mode of support coupled to production through headage payments. There is no public spending on agri-environment schemes. Input costs are again higher than the baseline.

In the Local Stewardship (LS) scenario the government puts emphasis on social values in rural areas and on conservation of the environment. This means also higher support is given to the farmers in the framework of the CAP (both pillar 1 and pillar 2), with generally higher input and output prices. Wages fall due to an increase in rural labour supply. Higher fertiliser prices reflect carbon pricing.

3. Results

3.1. Model testing

In order to test the reliability of model output concerning bird densities and species richness we compared predictions in the base case for the six different farm types to actual field data. For this we used "Survey adjusted" farm models, which means that the livestock numbers are adjusted to the average of individual farms within each farm type. All the models predicted bird densities within the range of the densities observed (Table 2 – summary of biodiversity indicators). Calibration results for the farm models, in terms of predicted land use and intensities in the base case, are reported in Acs et al (2010).

3.2. Changes to farm management under the scenarios

Gross margins from these upland farms would decrease under the scenarios that envision more globalized markets (WM and GS, Table 3), with the greatest reduction in gross margins under the World Markets scenario (for example from £78,961 to £13,669 on Moorland Sheep and Beef farms). In contrast the Local Stewardship scenario, which envisions strong subsidy support, would give the greatest gains in gross margins.

The different scenarios also have important implications for farm management choices. Effects on stocking rates are complex. National Enterprise involves re-coupling subsidy payments to output production as might be expected under policies designed to advance domestic food security. This scenario predicts the highest stocking rate in all cases. The scenarios that envision more international integration of agricultural markets (WM and GS) involve lower stocking rates than those scenarios (NE and LS) that focus more on the UK as an independent food producer. These same patterns are also reflected in predictions about land abandonment and agricultural labour use. Under a more globalized market system (WM and GS) more land is predicted to be abandoned and there is less demand for labour on farms. Focusing on aggregate stocking rates alone (livestock units per hectare) can hide shifts in enterprise mix. For example, Moorland Sheep and Beef farms in World Markets are predicted to move away from sheep production but to increase their beef cattle herds. The predicted changes of fertiliser use on inbye land are particularly sensitive to the different scenarios, with very large increases predicted for some farms especially under the National Enterprise scenario.

In general the impacts of changes in prices and government support policies on agricultural land use vary considerably across the four scenarios relative to the baseline. This is not surprising since some of the relative changes in input prices, output prices and government subsidy we model are large. Moreover, hill farms are rather constrained in their production options, which acts to amplify the effects of these changes, relative to a lowland farm with more options. The impacts relative to the baseline vary considerably across farm types, for a given scenario. This is perhaps most obvious when moorland farms are contrasted with inbye-only farms. For example, the move to World Market conditions from the baseline produces an increase in sheep numbers on inbye-only farms, but a reduction in sheep numbers on moorland sheep and beef farms; whilst the change to a National Enterprise scenario produces a much bigger proportionate change in the intensity of grassland management on MSB farms compared to ISB farms.

3.2 Changes to bird species and the bird community

Table 4 shows how these predicted changes in farm management translate into predicted effects on avian biodiversity. For each indicator, Table 4 shows the predicted value of the indicator for each scenario/farm type combination, and what percentage change this represents compared with the baseline value ("change from present"). The Table shows values for individual species densities first, and then for total (cross-species) density and total species richness. Baseline values in the Table are the predicted bird densities from the regression equations corresponding to the profit maximizing farm management plan under present policy and market conditions, which all fall within the observed ranges on the sample farms (Table 2). Where baseline values are small in absolute terms (e.g. lapwing in the baseline for Moorland Sheep and Dairy farms), percentage changes can be large. Some of the predicted biodiversity changes are summarised in Figures 2 to 5.

Let us first consider variability in the impacts of a given scenario across indicators for a given farm type. Comparing the baseline with World Market conditions, and looking first at just one farm type (Moorland Sheep and Beef), we see that this change in market conditions and support payments leads to changes in farm management which: (i) increase curlew numbers by 59%, (ii) reduce lapwing numbers by 77%, (iii) produce a greater than 100% rise in skylarks, (iv) means the absolute number of song thrushes remains very low, and (v) increases linnet by 38%. These changes come about due to the predicted changes in sheep and cattle numbers, fertiliser use and number of grassland cuts from the farm model as shown in Table 3, translated into changes in biodiversity using the regression coefficients from the ecological model shown in Table 2b. For example, lapwing density responds positively to both sheep and cattle numbers (Table 2b), so under the Global Stewardship scenario their numbers decline across all farm types due to the loss of beef cattle and the extensification of sheep and dairy farming operations. For the same scenario, curlews exhibit a different pattern. Their density is negatively related to sheep density, and therefore curlew show an increase in numbers across the moorland farm types as sheep numbers fall. However, on inbye-only farms, curlew density declines due to the combined effect of lower cattle numbers, higher fertiliser inputs and an increased frequency of cutting.

Two points to note here, which carry through to other scenarios and farm types, are that some species gain whilst others lose; and that very low initial absolute numbers of some species in the baseline mean large percentage changes when they increase. This is illustrated graphically in Figure 2. That there are gainers and losers, and that the relative change varies so much across species, illustrates the idiosyncratic nature of single species responses to changes in farm management practices.

We can also observe patterns across species' responses to alternative scenarios relative to the baseline, as also shown in Table 4. These species responses again come about due to the links between price incentives and land management, and between land management and bird response. For example, skylark density is negatively related to sheep and positively related to cattle numbers. Skylark density also falls where fertiliser input is high and a high frequency of cutting is undertaken. Both the World Market and Global Sustainability scenarios lead to a fall in sheep numbers for farms with a moorland holding. For MSB farms this is severe under the WM scenario, with sheep numbers declining from 1383 to 42. Sheep disappear entirely from MSD farms. Cattle numbers increase on MSB farms, which otherwise remain unchanged. Cutting frequency declines across all moorland farm types. Under such conditions, skylark density increases on all moorland farm types for both scenarios (Figure 2 and Figure 3). For inbye farms, the changes to the farm businesses under the same scenario lead to skylark declines in two farm types (ISB and IB), with little change on ISD farms. National Enterprise and Local Stewardship scenarios generally lead to a decline in skylark density as sheep numbers, fertiliser use and cutting frequency all increase. Indeed, skylarks are predicted no longer to be found on ISB and MSD farm types under the National Enterprise scenario. However, the rising cattle numbers on IB farms does lead to increased skylark density.

Figure 4 shows changes in Total Density and Total Richness for a move from the baseline to the Global Sustainability scenario. If we consider these assemblage-level changes, total density increases for many farm types, whilst the number of species (Total Richness) falls slightly. This makes sense if a change in abundance of common species outweighs the loss of other, less common, species. Finally, Figure 6 shows the relative effects on four bird species of all four scenarios relative to the baseline (labelled as "Present"). Again, this illustrates the mix of gains and losses across species and across scenarios.

4. Discussion and Conclusions

In this paper, we have used ecological-economic modelling to investigate likely responses of biodiversity to changes in future agricultural land use brought about by changes in market prices for inputs and outputs, and changes in government support regimes. We use Foresight scenarios and related indices as developed for UK agriculture by Morris et al., (2005) to do this. These scenarios are not intended to portray any actual future outcome, but rather to allow an investigation of a range of changes in prices and subsidies which correspond to different visions of the future. The scenario span axes of globalization versus national self-sufficiency, greater or lesser recognition of environmental goods through agri-environment schemes, changes in core farm income support and changes in prices for principal inputs and outputs.. Our economic models then capture behavioural changes by farmers in terms of land use and land management decisions, based on the maximisation of profits. Our ecological models are estimated from a data set drawn from the same farms from which the economic models are constructed, and are linked through regression coefficients for management variables which were found to influence different biodiversity indicators. Whilst the explanatory power of the ecological models is modest (R^2 values range from 0.13 to 0.43), they enable case study-specific links to be established with four aspects of land management which are in turn key response variables to changes in agricultural policies, input and output prices, and agri-environment expenditures.

The main conclusions which emerge from the analysis are that winners and losers emerge in terms of biodiversity. That is, one's conclusion as to whether a given future scenario would be beneficial or harmful to birds depends on which indicator one chooses, whether this is in terms of individual species, or different aggregate measures (density or richness). Impacts of a particular scenario relative to the baseline differ qualitatively and quantitatively across different indicators. This is unsurprising, in that we chose species for inclusion in the ecological models for their expected contrasting responses to changes in land management. We also find differences in response across farm types. This is also unsurprising, since each type encapsulates differences in production opportunities (for example, whether access to moorland grazing exists).

Despite the variability, certain headline commonalities emerge of how biodiversity indicators and specific farm types respond to the different scenarios. For example, we noted that access to moorland grazing is one important factor underlying the nature of farm-level response in terms of proportional changes in input use and outputs per hectare; these changes then feed into changes in alternative biodiversity indicators according to the sensitivity of different species with respect to our measures of management intensity. Re-introducing production-related support (as under the NE scenario) produces the biggest change in livestock numbers, and thus has the biggest proportionate effect on birds most sensitive to this management variable. However, scenarios with greater public spending on agri-environment schemes (GS and LS) do not always produce increases in bird numbers or species richness relative to the baseline, compared to scenarios with the lowest level of spending on these schemes. This results from the complex interactions between agri-environment scheme prescriptions and rewards and their incentive effects on land use; and from the fact that such schemes at present do not pay for environmental outputs, but for changes in management.

It is interesting to speculate on the extent to which these results could be transferred to other farm systems. We would expect similar variability in the sign and size of response across alternative biodiversity indicators. However, the absolute size of response may be greater in upland than in lowland systems since the former are more constrained in their production possibilities: this has the effect of exaggerating land management response in terms of stocking rates and fertiliser use to changes in output and input prices, relative to systems which have more options to change what is being produced.

Dynamics are not captured in the integrated model employed here. This includes dynamic responses from birds (how long the predicted responses shown in Table 4 take to occur), or amongst farmers (responses in Table 3). We are also unable to represent switches in farm types, or changes in the number or average size of farm. Numbers and average size of farm will respond to changes in farm incomes, measured here using Total Gross Margin, relative to returns on alternative land uses such as forestry. Farm incomes turn out to be highest under the Local Stewardship scenario for almost all farm types. In this scenario, the Single Farm Payment rises above the baseline by 54%, whilst agri-environmental scheme spending is maintained.

Numerous studies demonstrate that biodiversity declines with increased land use intensity (Donald et al 2001; Benton et al 2002; Green et al 2005), and across many taxonomic groups in Europe, species richness is lower where agricultural intensity is high (Billeter et al 2008). However, assuming a simple relationship between intensification and biodiversity may not always be appropriate. For instance, vascular plant species richness is often encouraged by a relatively intensive mowing and grazing regime (Pykala 2003; Pykala et al 2005). In contrast such management is rarely beneficial for many birds (e.g. Soderstrom et al 2001; Henderson et al 2004). Even within taxa, different species do not respond in a uniform fashion to the same measures of land use (e.g. for European bees; Le Feon et al 2010). Therefore, perhaps the most important and most generalisable finding that emerges from this modelling is the lack of a simple relationship between increasing intensity of land use (measured by livestock density, fertiliser use or grassland management) and biodiversity. Species vary in their responses to changes in intensity, and to alternative measures of intensity. General measures of intensity of land use are therefore an unsatisfactory gradient for predicting changes in biodiversity. Moreover, changes in intensity in response to changes in prices of inputs and outputs are mediated by considerations of farm structure, and show considerable variation across farm types. Again, this advises against a reliance on general predictions of how rising world food prices, rising fertiliser costs or changes in the nature of farm subsidies will translate into increasing pressure on biodiversity on farmland.

Acknowledgements

We thank the farmers and landowners of the Peak District, the National Farmers Union, Peak District National Park Authority, Moors for the Future Partnership, National Trust, RSPB, P. Robertson and P. Wilson. The research was funded as part of the UK Research Councils' Rural Economy and Land-use Programme (RELU). RELU is a collaboration between ESRC, NERC and BBSRC with additional funding from Defra and the Scottish Government.

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Table 1. Relative values of factors for different policy scenarios (%).

Characteristics	Future scenarios				
	Present	World Market	Global Sustainability	National Enterprise	Local Stewardship
Regulations					
Common Agricultural Policy: Headage Payment	0	0	0	100	0
Common Agricultural Policy: Single Farm Payment	100	0	87	0	154
Agri-environment schemes	100	0	100	0	100
Input prices					
fertiliser price	100	80	151	136	147
labour wage	100	135	147	100	90
labour reduction (technology development)	100	73	87	94	94
feed prices	100	76	154	96	202
Output prices					
meat prices	100	80	90	111	134
dairy milk pirce	100	91	114	87	102

Table 2a. Mean (range) of biodiversity indicators and the R^2 of regression models exploring the relationship between the indicators and farmland management variables.

Biodiversity indicator	Mean	R^2
Curlew density	0.04 (0 – 0.18)	0.24
Lapwing density	0.07 (0 – 0.50)	0.13
Skylark density	0.08 (0 – 0.57)	0.20
Song thrush density	0.02 (0 – 0.14)	0.18
Linnet density	0.06 (0 – 0.40)	0.43
Total Density	2.13 (0.74 – 3.55)	0.22
Total Richness	30.14 (13 – 45)	0.13

Table 2b. Regression coefficients relating each biodiversity indicator to farm management variables.

Biodiversity Indicator	Sheep	Cattle	Fertiliser*	Cuts
Curlew density	-0.041	0.028	-0.134	-0.036
Lapwing density	0.085	0.076	0.584	-0.008
Skylark density	-0.056	0.077	-0.442	-0.048
Song thrush density	-0.004	-0.012	0.097	0.016
Linnet density	-0.010	0.028	0.554	0.005
Total density	-0.199	0.029	-0.042	0.048
Total richness	0.064	-0.023	0.105	0.021

* Fertiliser coefficient multiplied by 1000

Table 3 Management variables under foresight scenarios

		Moorland Sheep & Beef				
Management variables	Unit	Present	World Market	Global Sustainability	National Enterprice	Local Stewardship
Total Gross Margin	£	78961	13669	59584	96993	125326
Sheep	nos	1383	42	1128	1797	1765
Beef	nos	40	151	0	151	86
Dairy	nos	-	-	-	-	-
Fertiliser	kg	2588	5361	0	20227	4404
Cuts	nos	82	60	48	124	122
Livestock Unit	nos	237	120	169	383	329
Own labour	hours	4388	4059	3703	4389	4389
Hired labour	hours	2883	120	1384	7591	5964
Total labour	hours	7271	4179	5087	11980	10354
Land used	ha	878	89	692	1018	1018
Land fallow	ha	140	929	326	0	0

		Inbye Sheep & Beef				
Management variables	Unit	Present	World Market	Global Sustainability	National Enterprice	Local Stewardship
Total Gross Margin	£	44507	9613	36697	50412	65215
Sheep	nos	79	137	77	437	85
Beef	nos	83	83	68	83	83
Dairy	nos	-	-	-	-	-
Fertiliser	kg	2958	2939	2418	2929	2957
Cuts	nos	37	39	36	51	38
Livestock Unit	nos	74	83	62	128	75
Own labour	hours	2699	2779	2362	3302	2724
Hired labour	hours	100	81	0	1254	98
Total labour	hours	2799	2860	2362	4555	2823
Land used	ha	120	61	120	120	120
Land fallow	ha	0	59	0	0	0

		Moorland Sheep & Dairy				
Management variables	Unit	Present	World Market	Global Sustainability	National Enterprice	Local Stewardship
Total Gross Margin	£	101358	47777	94211	78676	102770
Sheep	nos	140	0	0	866	298
Beef	nos	-	-	-	-	-
Dairy	nos	94	94	94	94	94
Fertiliser	kg	3364	3337	3365	3312	3355
Cuts	nos	56	48	49	85	59
Livestock Unit	nos	115	94	94	224	139
Own labour	hours	4131	4127	4131	4131	4131
Hired labour	hours	2411	1532	1711	5956	3084
Total labour	hours	6543	5659	5842	10087	7215
Land used	ha	238	57	212	304	304
Land fallow	ha	66	247	92	0	0

Table 3 (continued)

		Inbye Sheep & Dairy				
Management variables	Unit	Present	World Market	Global Sustainability	National Enterprice	Local Stewardship
Total Gross Margin	£	82811	48333	76496	66412	75193
Sheep	nos	0	0	0	264	34
Beef	nos	-	-	-	-	-
Dairy	nos	100	100	96	100	100
Fertiliser	kg	3556	3551	3415	3539	3556
Cuts	nos	52	51	50	62	54
Livestock Unit	nos	100	100	96	140	105
Own labour	hours	4131	4131	4131	4131	4131
Hired labour	hours	2072	1889	1757	3399	2237
Total labour	hours	6203	6020	5889	7530	6368
Land used	ha	107	61	107	107	107
Land fallow	ha	0	46	0	0	0

		Moorland Sheep				
Management variables	Unit	Present	World Market	Global Sustainability	National Enterprice	Local Stewardship
Total Gross Margin	£	64146	8375	50464	53505	89634
Sheep	nos	1146	705	841	1491	1146
Beef	nos	-	-	-	-	-
Dairy	nos	-	-	-	-	-
Fertiliser	kg	0	0	0	2510	0
Cuts	nos	48	29	36	62	48
Livestock Unit	nos	172	106	126	224	172
Own labour	hours	3509	2661	2944	3838	3505
Hired labour	hours	1791	441	834	3108	1763
Total labour	hours	5300	3102	3778	6946	5268
Land used	ha	639	371	525	639	639
Land fallow	ha	0	268	114	0	0

		Inbye Beef				
Management variables	Unit	Present	World Market	Global Sustainability	National Enterprice	Local Stewardship
Total Gross Margin	£	36739	6391	30022	55056	60746
Sheep	nos	-	-	-	-	-
Beef	nos	79	74	69	164	164
Dairy	nos	-	-	-	-	-
Fertiliser	kg	2811	2648	2477	5825	5847
Cuts	nos	31	37	28	62	60
Livestock Unit	nos	59	56	52	123	123
Own labour	hours	1990	1911	1842	2066	2066
Hired labour	hours	271	47	119	2422	2502
Total labour	hours	2261	1957	1961	4487	4568
Land used	ha	92	37	92	79	92
Land fallow	ha	0	55	0	13	0

Table 4. Biodiversity outcomes for each Foresight scenario. E indicates that a species is no longer found on that farm type under the given scenario. No proportional changes are calculated (indicated '–') when densities are predicted to be zero with the farm management plan that would optimize gross margins under Present day market and policy conditions.

		Moorland sheep & beef		Inbye sheep & beef		Moorland sheep & dairy		Inbye sheep & dairy		Moorland sheep		Inbye beef	
Biodiversity Measure	Scenario	Density	Change	Density	Change	Density	Change	Density	Change	Density	Change	Density	Change
Curlew	Present	0.047		0.037		0.023		0.021		0.005		0.014	
	World Market	0.075	0.597	0.030	-0.201	0.029	0.278	0.021	0.006	0.010	0.985	0.013	-0.055
	Global Sustainability	0.052	0.101	0.036	-0.023	0.029	0.277	0.021	-0.003	0.008	0.645	0.014	-0.015
	National Enterprise	0.040	-0.153	0.004	-0.879	0.003	-0.888	0.002	-0.921	0.002	-0.547	0.016	0.173
	Local Stewardship	0.040	-0.140	0.036	-0.025	0.017	-0.265	0.017	-0.180	0.005	0.000	0.017	0.185
Lapwing	Present	0.037		0.031		0.002		0.032		0.029		0.008	
	World Market	0.008	-0.776	0.047	0.523	0.000	-1.000	0.032	0.001	0.013	-0.566	0.008	-0.107
	Global Sustainability	0.028	-0.247	0.026	-0.148	0.000	-0.999	0.031	-0.038	0.017	-0.416	0.007	-0.197
	National Enterprise	0.060	0.619	0.182	4.903	0.058	35.906	0.149	3.666	0.048	0.641	0.032	2.800
	Local Stewardship	0.052	0.408	0.032	0.049	0.007	3.450	0.042	0.324	0.029	0.000	0.032	2.812
Skylark	Present	0.060		0.125		0.052		0.170		0.000		0.143	
	World Market	0.141	1.372	0.097	-0.224	0.079	0.516	0.170	0.003	0.027	–	0.138	-0.039
	Global Sustainability	0.073	0.230	0.118	-0.054	0.079	0.513	0.168	-0.008	0.014	–	0.139	-0.030
	National Enterprise	0.036	-0.402	0.000	E	0.000		0.027	-0.839	0.000	–	0.184	0.286
	Local Stewardship	0.039	-0.339	0.122	-0.027	0.023	-0.564	0.151	-0.110	0.000	–	0.185	0.291
Song thrush	Present	0.000		0.001		0.005		0.012		0.010		0.004	
	World Market	0.002	–	0.000	E	0.007	0.241	0.012	-0.015	0.012	0.213	0.005	0.369
	Global Sustainability	0.000	–	0.002	1.235	0.007	0.248	0.012	0.003	0.011	0.148	0.004	0.070
	National Enterprise	0.000	–	0.000	E	0.000	E	0.004	-0.635	0.008	-0.130	0.001	-0.809
	Local Stewardship	0.000	–	0.001	-0.029	0.003	-0.335	0.011	-0.079	0.010	0.000	0.000	-0.884
Linnet	Present	0.046		0.085		0.000		0.069		0.000		0.000	
	World Market	0.063	0.389	0.080	-0.058	0.000	–	0.069	-0.001	0.000	–	0.000	–
	Global Sustainability	0.045	-0.003	0.079	-0.069	0.000	–	0.068	-0.027	0.000	–	0.000	–
	National Enterprise	0.054	0.192	0.056	-0.348	0.000	–	0.045	-0.352	0.000	–	0.018	–
	Local Stewardship	0.044	-0.029	0.085	-0.005	0.000	–	0.066	-0.045	0.000	–	0.018	–
Total density	Present	1.615		1.740		2.068		2.352		1.447		1.569	
	World Market	2.357	0.459	1.495	-0.141	2.336	0.130	2.351	-0.001	1.793	0.239	1.573	0.003
	Global Sustainability	1.738	0.076	1.738	-0.001	2.336	0.130	2.346	-0.003	1.682	0.162	1.557	-0.008

	National Enterprise	1.427	-0.117	0.534	-0.693	0.935	-0.548	1.098	-0.533	1.202	-0.170	1.675	0.067
	Local Stewardship	1.438	-0.110	1.715	-0.015	1.782	-0.138	2.163	-0.081	1.447	0.000	1.672	0.066
Total richness	Present	34.461		31.129		31.089		27.313		32.603		25.192	
	World Market	31.591	-0.083	32.129	0.032	30.170	-0.030	27.307	0.000	31.174	-0.044	25.246	0.002
	Global Sustainability	33.909	-0.016	31.171	0.001	30.171	-0.030	27.322	0.000	31.608	-0.030	25.219	0.001
	National Enterprise	35.378	0.027	37.771	0.213	36.293	0.167	32.044	0.173	33.780	0.036	24.927	-0.011
	Local Stewardship	35.299	0.024	31.237	0.003	32.150	0.034	27.888	0.021	32.603	0.000	24.918	-0.011

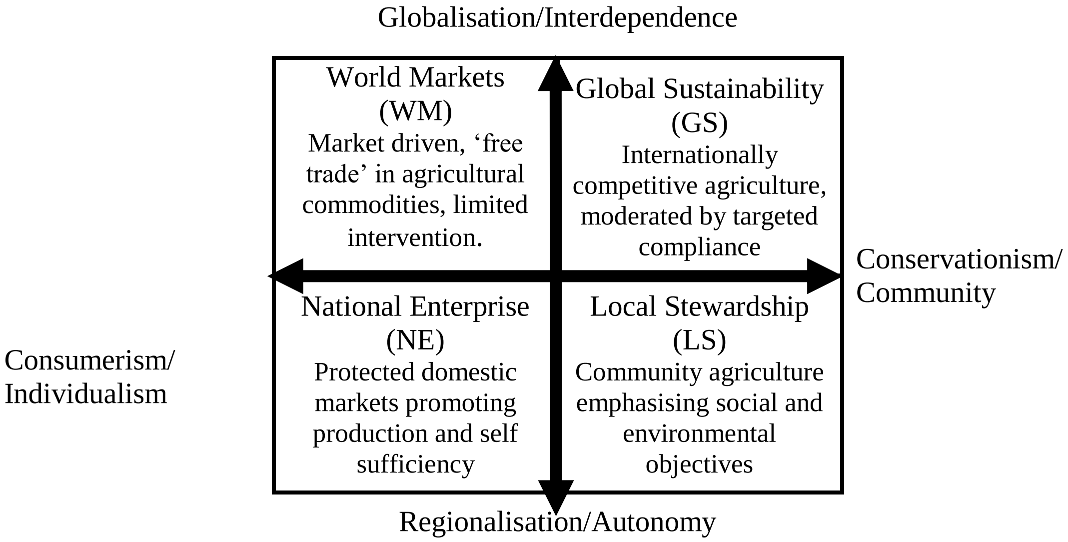

Figure 1: Future scenarios for agriculture based on Foresight scenarios (source: Morris et al. 2005)

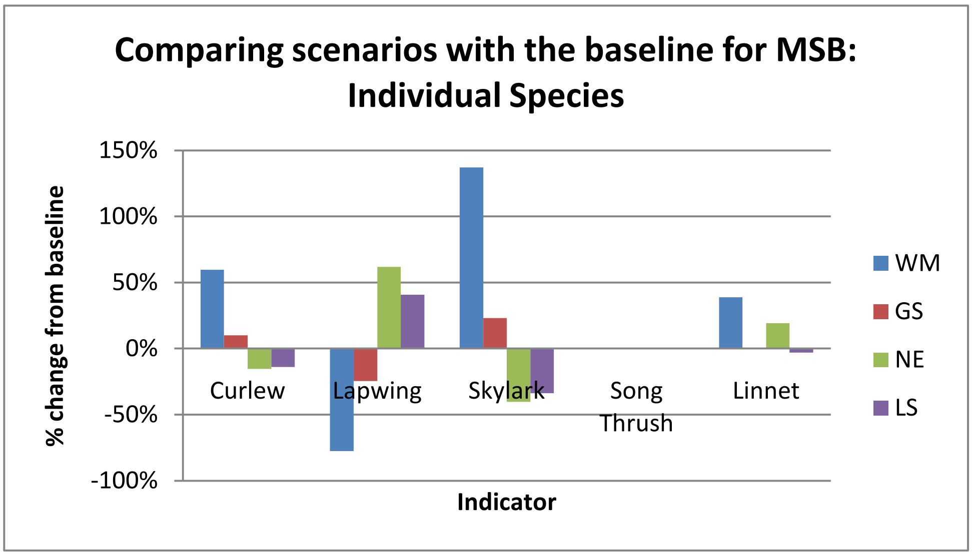

Figure 2. The effects on different species of a range of future scenarios for the Moorland Sheep and Beef farm type.

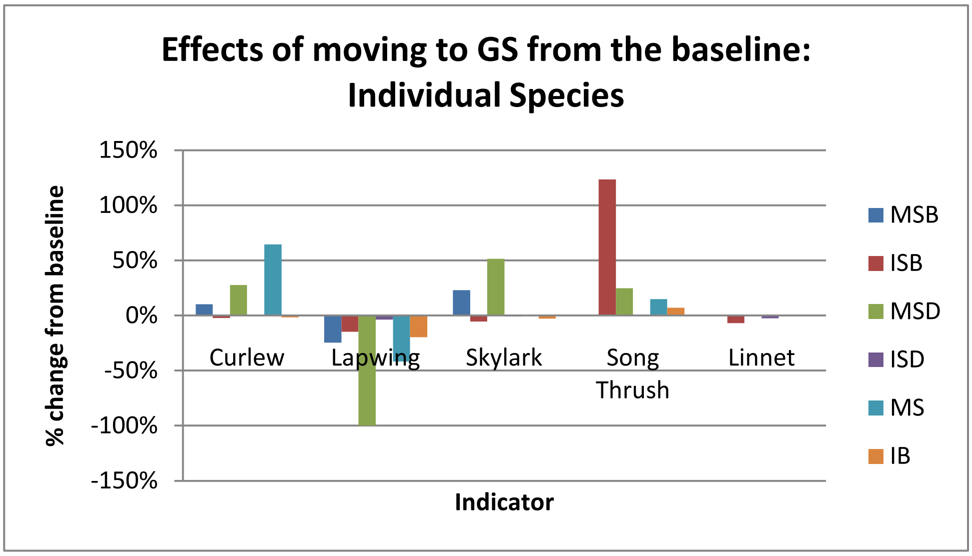

Figure 3: effects of a move from the baseline to the Global Sustainability scenario across farm types according to individual species.

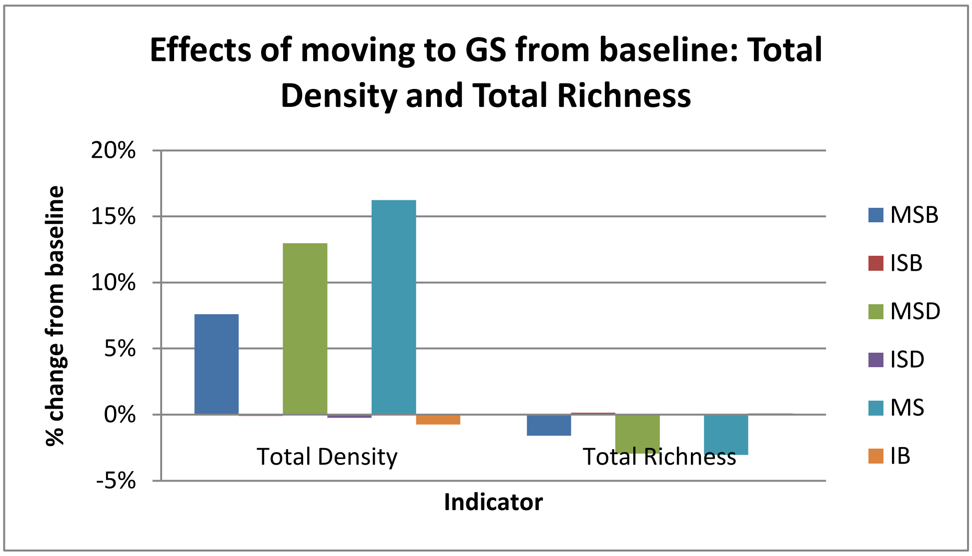

Figure 4: effects of a move from the baseline to Global Sustainability across farm types, according to two aggregate measures of biodiversity.

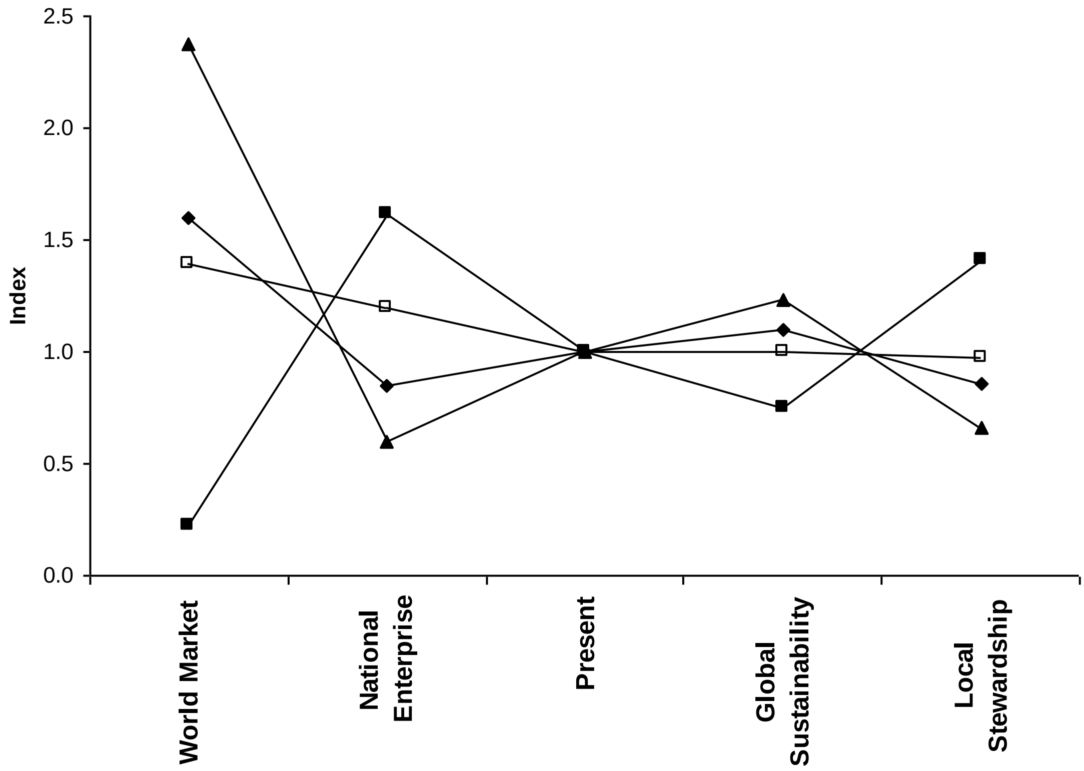

Figure 5. Relative change in density of four bird species on Moorland Sheep and Beef farms under Foresight scenarios. (filled triangle – skylark, filled diamond – Eurasian curlew, filled square – northern lapwing, open square – linnet).