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Farm-scale ecological and economic impacts of agricultural change in the uplands

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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. Future trends for upland birds will likely be impacted by changes in agricultural support regimes, such as those currently envisaged in on-going reforms of the Common Agricultural Policy. We developed integrated ecological-economic models, using seven 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 policy and pricing changes on farm incomes, land uses and biodiversity can be misleading. Our results also suggest that a focus on umbrella species or biodiversity indicators (such as total species richness) can miss important compositional effects.

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 (Acs et al., 2010). Recently, upland farm incomes in the UK have fallen dramatically (DEFRA, 2004) 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). Current discussion of the future of the European Union's Common Agricultural Policy (CAP) has included a stress on the need to "protect, maintain and enhance farmland habitats and biodiversity" through the reform of CAP support measures for farming (EC, 2010, p. 3).

The aim of this paper is to provide a farm-scale assessment of the possible impacts of agricultural change in the UK uplands on farm businesses and biodiversity as represented by 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.

Since its origins in the 1960s (Bradfield et al., 2005), scenario analysis has expanded to become widely used in policy analysis. Scenarios attempt to map out what may happen, using "the best evidence from science and other areas to provide visions of the future", and have become popular largely because of the failure of long-term single path predictions (Godet, 1979). When combined with simulation modelling, scenario analysis provides insights into the relative strength and direction of key outcome

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variables and a means of scoping uncertainty when precise predictions are not available or particularly meaningful. The range of such scenario analyses in many diverse areas of research and policy is documented by the European Foresight Monitoring Network (e.g., EFMN, 2008).

In Europe, a variety of projects using scenario analyses have been undertaken to understand how agriculture might evolve in the future under different assumptions (Gomez-Limon et al., 2009). These include: the Ground for Choices project examining how agriculture and forestry might change in the European Union (WRR, 1992); the EURURALIS project examining rural futures in an enlarged EU (Klijn et al., 2005); the FFRAF project aiming to support the development of science and technology policy for agriculture (SCAR, 2007); the SCENAR 2020 project designed to help inform reform under the CAP Health Check (EC, 2007); the Agriculture 2013 project (INRA, 2007); and the FUTURPAC project, which researched the impact of various drivers on agriculture in the Castille Leon region of Spain for 2020 (Gomez-Limon et al., 2009). Most recently, the European Commission has set out a series of three scenarios for the possible future evolution of the Common Agricultural Policy post 2013 (EC, 2010): we return to these scenarios in the "Discussion" section of the paper, since they form an important focus for current policy discussions.

In this paper, we employ "Foresight" scenarios (OST, 2002; Morris et al., 2005b; Sylvester-Bradley and Wisemann, 2005) to define the broad contextual settings within which future drivers and responses affecting the upland livestock sector in the UK could possibly play out. We focus on farm-scale impacts of possible scenarios of future agricultural policies and market conditions measured in terms of long term upland farm incomes, land management practices and avian biodiversity. To do this we use field parameterized farm-scale 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 of different biodiversity indicators. The models were developed using seven alternative indicators of biodiversity based on total avian species richness and individual bird densities. 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).

A number of previous studies have examined possible futures for the UK livestock sector and upland areas (Morris et al., 2005b; Reed et al., 2009, 2010; Acs et al., 2010). For example, ADAS (2008) focused on the possible effect on the UK livestock sector of changes in farm income support under the reform of the Common Agricultural Policy (CAP) and explored scenarios concerned with (i) Business as Usual (BAU), (ii) CAP Pillar 1 Reform, (iii) Trade Liberalisation, and (iv) CAP Pillar 1 Reform + Trade Liberalisation. Declines in livestock numbers relative to BAU were predicted for all scenarios but were particularly severe in Scenario (iv). A number of threats were identified to landscape character such as "loss of boundary features", "increased scrub", and "loss of traditional character". Common themes from this and other scenario studies relevant to the UK uplands are that: (i) the livestock sector has a high level of dependency on farm income support, especially in marginal areas, that if removed could lead to abandonment of land with uncertain social and environmental outcomes, and; (ii) that the more intensive livestock systems can exert considerable pressures on environmental quality unless measures are taken to alleviate them. Particularly relevant to our current study is Reed et al.'s conclusion from their review of eight scenario studies of the UK uplands (Reed et al., 2009) that environmental implications were the least well-developed aspects of these scenario analyses. The farm-scale provides an obvious spatial unit over which such linkages between changing management practices and environmental impacts can be established and modelled.

Methodology

Farm model data

We based the economic component of farmer behaviour on data collected on upland farming in the Peak District National Park. The survey was designed with and carried out by experienced farm business researchers through the winter months of 2006/2007. The survey 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 approximately 3 h 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 the survey results, six types of typical upland farms can be distinguished depending on moorland access: Moorland Sheep and Beef (MSB), Moorland Sheep and Dairy (MSD), Moorland Sheep (MS), Inbye Sheep and Beef (ISB), Inbye Sheep and Dairy (ISD) and Inbye Beef (IB). The distinction between moorland and inbye land was important, since different activities are related to each of these land types and the associated habitats also differ on these sites. These six farm types were used as the basis for six "representative farm" models, which were then used in the scenario simulations reported here. Further details are provided in Acs et al. (2010), where we use linear programming models to explore the effects of changes in support packages on farm incomes and land use. However, no explicit linkages to biodiversity indicators are employed in Acs et al. (2010).

Biodiversity indicator data

We also collected data on birds as indicators of biodiversity on our sample of upland farms. Bird surveys were carried out on the same farms as the farm business surveys, allowing us 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, enabling farmland to be surveyed based on standard methodologies (Newson et al., 2005). On average, 95 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. 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. Detectability 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). Note, however, that this earlier work does not include any linkage to economic modelling of farmer behaviour.

Economic modelling of farm decision-making

Mathematical optimisation models were developed for the six typical farm types. The general structure of these models has the form of a standard Mathematical Programming (MP) model (Hazell and Norton, 1986):

$$\begin{aligned}&\text{Maximise}\{Z = c'x\}\\&\text{Subject to}\quad Ax \le b\\&\text{and}\quad x \ge 0\end{aligned}$$

where Z is the gross margin (net revenue excluding fixed costs) at the farm level, x is a vector of activities, c is a vector of gross margins or costs per unit of activity, A is a matrix of technical coefficients, and b is a vector of resource endowments and technical constraints

Farmers are thus assumed to determine their land use and land management in order to maximise profits, subject to resource constraints and to prices of outputs and inputs over which they have no individual influence. Whilst profit maximisation is only one possible behavioural motivation of farmers (Sheeder and Lynne, 2011), it is consistent with a competitive firm maximising the probability of financial survival over the long run; whilst several studies have found it to be a good predictor of farmer up-take of agri-environment schemes (e.g. Cary and Wilkinson, 1997; Lichtenberg, 2004). 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 (household) 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).

The central element in the MP models is animal production, comprising sheep, beef and dairy. The production and the feeding requirements for each of these types are described in detail in Acs et al. (2010). Land can be used for growing grass for grazing and fodder production purposes. The production of grassland per year depends mainly on the amount of fertiliser (nitrogen) used and cutting frequency. In the model, the most commonly used combination of nitrogen use and cutting frequencies (1–3 cuts for silage and 1 cut for hay) were represented with separate activities ranging from 0 to 375 kg N/ha (Beaton, 2007). The output prices and input costs used for animal and grass production, including labour use, are based on averages from the survey results, on the Farm Management Handbook (SAC, 2006) and the Farm Management Pocketbook (Nix, 2007).

Farmers in the uplands can take part in many different agri-environment schemes. Payments under the CAP are taken into account dependent on the Foresight scenario modelled (see below), 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 were 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 cross-compliance measures. 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 output from the farm model were chosen to link predicted farming activity to the various biodiversity indicators, based on a review of existing ecological evidence for the uplands. The variables are sheep density, beef and dairy cattle density, fertiliser use per hectare and the number of grass cuts per year for silage production. All might be considered alternative indicators of land use intensity.

Ecological modelling linking agricultural land use to biodiversity outcomes

Biodiversity in general (e.g., Billeter et al., 2008), and bird abundance/richness (Donald et al., 2001) in particular, are known to respond to aspects of farm management such as grazing intensity (e.g., Evans et al., 2005) and mix (e.g., Evans et al., 2006). Historically, bird numbers have declined with increased agricultural intensification (characterised by higher livestock numbers, increased fertiliser use and cutting frequency) in the uplands (e.g., Sim et al., 2005). We quantified the effects of farm management variables and farm type on the avian density and richness on our sample farms using statistical regression models, with farm management activities (type, sheep, beef and dairy cattle numbers per hectare, fertilizer inputs and number of grassland cuts per year) as explanatory variables, and the density/richness indicators as response variables.

For avian density indicators, we used linear regression, transforming the response variables as appropriate to meet assumptions of normality (square root transformations were preferred for curlew, lapwing and total density, and no transformation was necessary for the remaining bird density variables). A Poisson error structure, corrected for over-dispersion, was used to model the response of Total Richness. The general format of the model is

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

where B is an avian density/richness indicator, R is the farm type dummies for the IB, ISB, ISD, MSD, MSB and MS (IB 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 between avian biodiversity indicators and farm management variables. This integration of the economic and ecological models is the main way in which the current paper adds to Dallimer et al. (2009, 2010) and Acs et al. (2010).

Tables 2a and 2b show the overall fit for each model, and model parameters. The explanatory power (R^2) of the regression models linking farm management variables to avian density/richness is relatively low (Table 2a). If we were to include micro-habitat variables such as the amount of rush cover, which were also measured as part of the field survey (Dallimer et al., 2009), these R^2 values increase to around 0.5. However, it is unclear how such habitat characteristics would change under the Foresight Scenarios. Therefore, we focus on the farm management variables that can be adequately included within agricultural scenario development (e.g., livestock numbers and fertilizer application rates).

Policy scenarios

Our analysis of the plausible futures for the upland livestock sector uses Foresight scenarios (OST, 2002), which were developed for UK agriculture in the Agricultural Futures projects (Morris et al., 2005b; Sylvester-Bradley and Wisemann, 2005). Whilst in this exercise, inputs and outputs were developed for 2012, 2025, and 2050, a number of considerations prompted our selection of the 2050 indicator values from the Agricultural Futures project for the analysis reported here. Firstly, the Agricultural Futures indicator set was chosen because the development of such indicators is time-consuming, and these provided an existing set of indicators that could be readily used for computer modelling. To our knowledge, there are no other indicator sets for long-term agricultural futures in the UK that we could have used. Secondly, the long-term 2050 scenarios were selected because the inputs and output indicators were broadly assumed to diverge from their starting points over time, so that the consequences of different assumptions for the future combination and direction of current and drivers and trends was illustrated with greater clarity as the "Futures" become more "distant". This therefore provided greater elucidation of the likely consequences of a spectrum of changes in current drivers and trends on farming and biodiversity in the uplands. Thirdly, in a policy context, the long-term 2050 scenarios were selected because facilitating desirable future outcomes, however defined, requires a long-term view, to which shorter term goals and policy choice can contribute.

The Foresight Scenarios have two dimensions; one incorporates social values ranging from individual consumerism to community conservationism, whilst the second incorporates governance conditions ranging from global interdependence to local autonomy. This gives rise to four long term scenarios which are termed "World Markets" (WM), "Global Sustainability" (GS), "National Enterprise" (NE), and "Local Stewardship" (LS), as shown in Fig. 1. We use these scenarios as a means of thinking about broad future agricultural and environmental outcomes and more specifically for evaluating the implications of a range of future world market conditions, trade

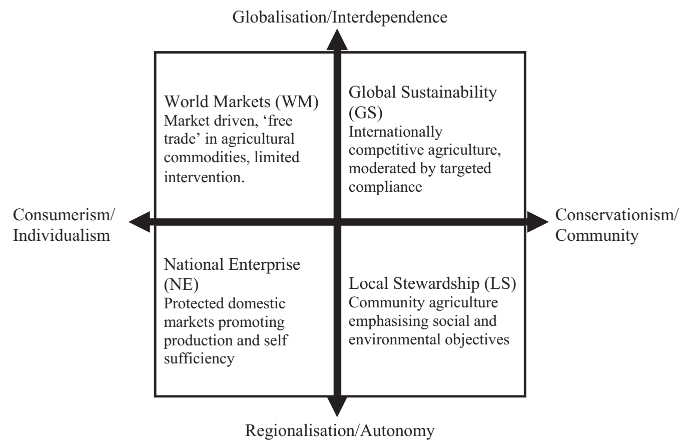

Fig. 1. Future scenarios for agriculture based on Foresight scenarios.
Source: Morris et al. (2005b).

arrangements and Common Agricultural Policy designs on livestock farming and biodiversity in the uplands. As noted earlier, these scenarios should not be viewed as predictions of what will happen in the future but rather as statements of what might happen given certain combinations of circumstances.

A review of historic trends in the Agricultural Futures project (Morris et al., 2005b; Sylvester-Bradley and Wisemann, 2005) 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 included changes in agricultural structure, farming systems and technology, farmer motivation, rural development regulation, and agri-environmental policy. A narrative to represent the main distinguishing features of the scenarios relative to the base case was developed (Rickard et al., 2005). This was combined with expert judgement from a survey of crop and livestock specialists (Morris et al., 2005a), a stakeholder workshop attended by 27 representatives with agricultural and rural interests, and farming systems expertise to produce a set of key indicators for each scenario (e.g., crops and livestock yields, market demand for crop and livestock commodities, level of policy support, and input and output prices).

For the purposes here, a subset of indicators was used to reflect differences in policy, market and technological conditions under each of the future scenarios relative to the "present" situation prevailing in the mid 2000s (Table 1). Varying these indicators allowed the scenarios to represent possible variations in the direction and extent of change of key external drivers, enabling us to investigate the impacts of possible changes in agricultural policies and market conditions in marginal upland areas, relative to the prevailing "present" situation in the mid 2000s. This allowed us to explore the range of likely outcomes for each variable in terms of consequences for land use and biodiversity. It should be noted that we did not analyse transition conditions towards these outcomes, but took instead a comparative static approach, exploring the relative outcomes as they might apply in the long term, namely 2050.

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 by the UK government or via the CAP for either agricultural activities or environmental outcomes from farming, whilst input and output prices are assumed to be lower than the current mid 2000s 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 (compared to the baseline)

Table 1
Relative values for different agricultural scenarios (%).

	Present (baseline)	World Market	Global Sustainability	National Enterprise	Local Stewardship
Policy measures					
CAP headage payment	0	0	0	100	0
CAP single farm payment	100	0	87	0	154
Agri-environment payments	100	0	100	0	120
Input prices					
Fertiliser price	100	80	151	136	147
Wages	100	135	147	100	90
Labour productivity	100	73	87	94	94
Feed prices	100	76	154	96	202
Output prices					
Meat price	100	80	90	111	134
Milk price	100	91	114	87	102

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, and livestock product prices rise.

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.

Commodity prices, especially of cereal and oil seeds, spiked in the 2006/2007 period in response to short-term supply deficits and market volatility. Concerns about global food security suggest that food commodity prices over the next decade may be 20–30% higher than the mid 2000 levels (Foresight, 2011), although rising input prices are also envisaged over this period, implying a downward pressure on farm profits (EC, 2010). In the livestock sector, increased consumption of red meat in transitional economies could more than offset the reductions in per capita consumption of red meat in richer countries (Foresight, 2011). In terms of our analysis, this could imply a strengthening of prices in scenarios that are most affected by global market conditions, namely *World Markets* and, to a lesser extent, *Global Sustainability*. However, here we take a long-term 2050 perspective, by which time it is assumed that under these scenarios, in accordance with long-term observed trends, agricultural commodity prices fall in real terms. Increased agricultural and livestock product prices are assumed under *National Enterprise* and *Local Stewardship* scenarios that place more importance on national/local supply.

Results

Model testing

In order to test the reliability of model output concerning bird densities and species richness we compared predictions in the baseline 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 for individual farms within each farm type. All the models predicted bird densities within the range of the densities observed (Tables 2a and 2b – 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).

Changes to farm management under the scenarios

Gross margins from upland farms 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 (e.g., from £78,961 to £13,669 on Moorland Sheep and Beef farms). In contrast, the Local Stewardship scenario, which envisions strong subsidy support, typically gives 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 act to amplify the effects of these changes, relative to a lowland farm with more options. The variation across farm types relative to the baseline for a given scenario is perhaps most obvious when moorland farms are contrasted with inbye-only farms. For example, the move to

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 (birds/ha)	0.04 (0–0.18)	0.24
Lapwing density (birds/ha)	0.07 (0–0.50)	0.13
Skylark density (birds/ha)	0.08 (0–0.57)	0.20
Song thrush density (birds/ha)	0.02 (0–0.14)	0.18
Linnet density (birds/ha)	0.06 (0–0.40)	0.43
Total density (birds/ha)	2.13 (0.74–3.55)	0.22
Total richness	30.14 (13–45)	0.13

Table 2b
Regression coefficients (±SE) relating each biodiversity indicator to farm management variables.

Biodiversity indicator	Sheep	Cattle	Fertiliser[a]	Cuts
Curlew density	−0.041 (±0.06)	0.028 (±0.06)	−0.134 (±0.38)	−0.036 (±0.03)
Lapwing density	0.085 (±0.12)	0.076 (±0.11)	0.584 (±0.70)	−0.008 (±0.07)
Skylark density	−0.056 (±0.06)	0.077 (±0.06)	−0.442 (±0.36)	−0.048 (±0.04)
Song thrush density	−0.004 (±0.01)	−0.012 (±0.01)	0.097 (±0.01)	0.016 (±0.01)
Linnet density	−0.010 (±0.04)	0.028 (±0.04)	0.554 (±0.27)	0.005 (±0.03)
Total density	−0.199 (±0.13)	0.029 (±0.12)	−0.042 (±0.74)	0.048 (±0.08)
Total richness	0.064 (±0.09)	−0.023 (±0.09)	0.105 (±0.57)	0.021 (±0.06)

[a] Fertiliser coefficient multiplied by 1000.

World Market conditions from the baseline produces an increase in sheep numbers on some 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.

Changes to bird species and the bird community

Table 4 shows how these predicted changes in farm management translate into predicted effects on avian density and richness. For each indicator, Table 4 shows the predicted value (±standard error calculated from the standard errors of the regression coefficients, Table 2b) 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 which correspond to the profit-maximising farm management plan under present policy and market conditions. These predicted densities all fall within the observed ranges on the sample farms (Tables 2a and 2b). 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 these predicted biodiversity changes are summarised graphically in Figs. 2–5.

We look first at 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 density from 0.047 (±0.005) to 0.075 (±0.004) birds/ha, or by 60%, (ii) reduce lapwing density from 0.037 (±0.016) to 0.008 (±0.013) birds/ha or by 77%, (iii) more than doubles skylark density from 0.060 (±0.064) to 0.141 (±0.058) birds/ha, (iv) means the absolute number of song thrushes remains very low, predicting a small possible increase from 0 to 0.002 (±0.014) birds/ha, and (v) increases linnet density from 0.046 (±0.047) to 0.063 (±0.043) birds/ha or by 39%. 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, and their associated errors, 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 (e.g., MSB farm type density falls to 0.028 (± 0.012) birds/ha) across all

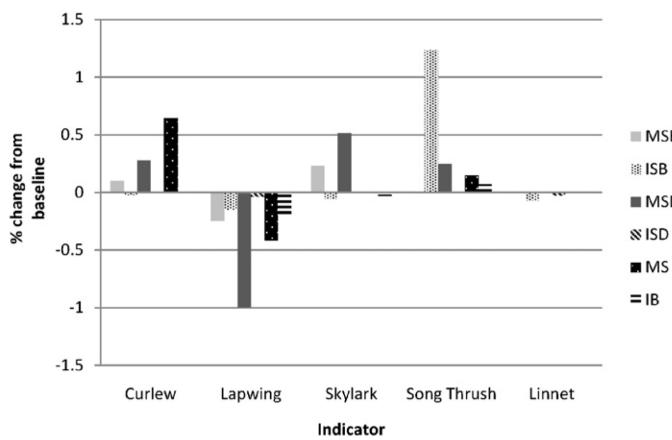

Fig. 3. Effects of a move from the baseline to the Global Sustainability scenario across farm types according to individual species.

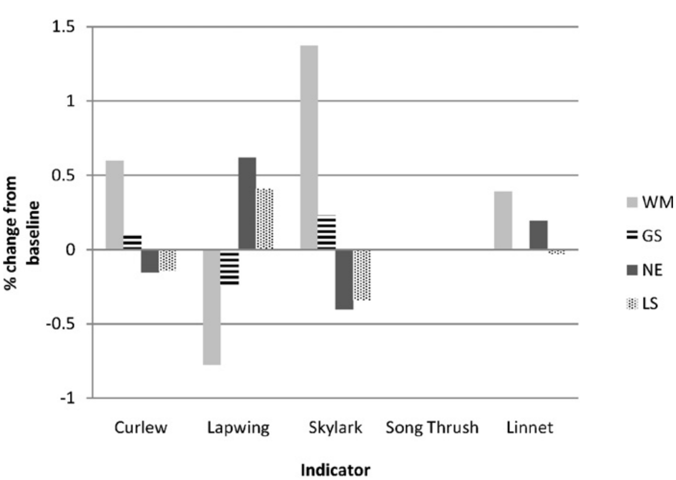

Fig. 2. The effects on different species of a range of future scenarios for the Moorland Sheep and Beef farm type compared with the baseline scenario.

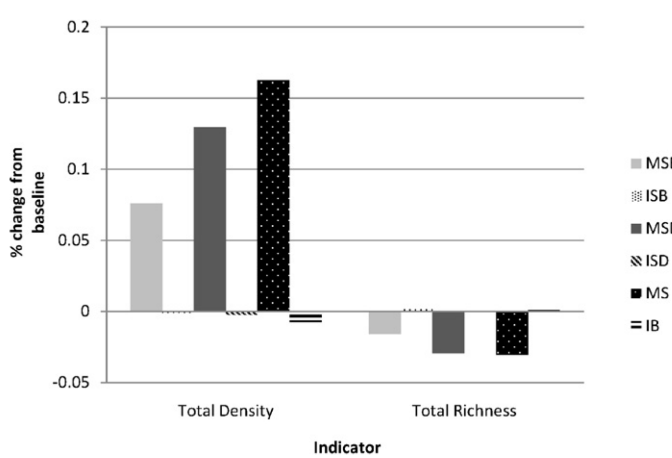

Fig. 4. Effects of a move from the baseline to Global Sustainability across farm types, according to two aggregate measures of biodiversity.

Table 3
Management variables under foresight scenarios.

	Unit	Moorland Sheep and Beef				
		Present	WM	GS	NE	LS
Total gross margin	£	78,691	13,699	59,584	96,993	125,326
Sheep	Number	1383	42	1128	1797	1765
Beef	Number	40	151	0	151	86
Dairy	Number	0	0	0	0	0
Fertiliser	kg	2588	5361	0	20,227	4404
Cuts	Number	82	60	48	124	122
Land used	ha	878	89	692	1018	1018
Land fallow	ha	140	929	326	0	0
	Unit	Inbye Sheep and Beef				
		Present	WM	GS	NE	LS
Total gross margin	£	44,507	9613	36,697	50,412	65,215
Sheep	Number	79	137	77	437	85
Beef	Number	83	83	68	83	83
Dairy	Number	0	0	0	0	0
Fertiliser	kg	2958	2939	2418	2929	2957
Cuts	Number	37	39	36	51	38
Land used	ha	120	61	120	120	120
Land fallow	ha	0	59	0	0	0
	Unit	Moorland Sheep and Dairy				
		Present	WM	GS	NE	LS
Total gross margin	£	101,358	47,777	94,211	78,676	102,770
Sheep	Number	140	0	0	866	298
Beef	Number	0	0	0	0	0
Dairy	Number	94	94	94	94	94
Fertiliser	kg	3364	3337	3365	3312	3355
Cuts	Number	56	48	49	85	59
Land used	ha	238	57	212	304	304
Land fallow	ha	66	247	92	0	0
	Unit	Inbye Sheep and Dairy				
		Present	WM	GS	NE	LS
Total gross margin	£	82,811	48,333	76,496	66,412	75,193
Sheep	Number	0	0	0	264	34
Beef	Number	0	0	0	0	0
Dairy	Number	100	100	96	100	100
Fertiliser	kg	3556	3551	3415	3539	3556
Cuts	Number	52	51	50	62	54
Land used	ha	107	61	107	107	107
Land fallow	ha	0	46	0	0	0
	Unit	Moorland Sheep				
		Present	WM	GS	NE	LS
Total gross margin	£	64,146	8375	50,464	53,505	89,634
Sheep	Number	1146	705	841	1491	1146
Beef	Number	0	0	0	0	0
Dairy	Number	0	0	0	0	0
Fertiliser	kg	0	0	0	2510	0
Cuts	Number	48	29	36	62	48
Land used	ha	639	371	525	639	639
Land fallow	ha	0	268	114	0	0
	Unit	Inbye Beef				
		Present	WM	GS	NE	LS
Total gross margin	£	36,739	6391	30,022	55,056	60,746
Sheep	Number	0	0	0	0	0
Beef	Number	79	74	69	164	164
Dairy	Number	0	0	0	0	0
Fertiliser	kg	2811	2648	2477	5825	5847
Cuts	Number	31	37	28	62	60
Land used	ha	92	37	92	79	92
Land fallow	ha	0	55	0	13	0

Key: WM, World Market; GS, Global Sustainability; NE, National Enterprise; LS, Local Stewardship.

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 optimise gross margins under present day market and policy conditions.

Biodiversity measure	Scenario	Moorland Sheep and Beef		Inbye Sheep and Beef		Moorland Sheep and Dairy	
		Density	Change	Density	Change	Density	Change
Curlew	Present	0.047 ± 0.005		0.037 ± 0.004		0.023 ± 0.006	
	World Market	0.075 ± 0.004	0.597 ± 0.007	0.030 ± 0.006	−0.201 ± 0.008	0.029 ± 0.006	0.278 ± 0.010
	Global Sustainability	0.052 ± 0.003	0.101 ± 0.007	0.036 ± 0.004	−0.023 ± 0.007	0.029 ± 0.006	0.277 ± 0.010
	National Enterprise	0.040 ± 0.007	−0.153 ± 0.010	0.004 ± 0.047	−0.879 ± 0.048	0.003 ± 0.031	−0.888 ± 0.032
	Local Stewardship	0.040 ± 0.007	−0.140 ± 0.010	0.036 ± 0.004	−0.025 ± 0.007	0.017 ± 0.007	−0.265 ± 0.010
Lapwing	Present	0.037 ± 0.016		0.031 ± 0.014		0.002 ± 0.019	
	World Market	0.008 ± 0.013	−0.776 ± 0.026	0.047 ± 0.021	0.523 ± 0.029	0.000 ± 0.021	−1.000 ± 0.035
	Global Sustainability	0.028 ± 0.012	−0.247 ± 0.025	0.026 ± 0.012	−0.148 ± 0.023	0.000 ± 0.021	−0.999 ± 0.035
	National Enterprise	0.060 ± 0.026	0.619 ± 0.034	0.182 ± 0.165	4.903 ± 0.166	0.058 ± 0.107	35.906 ± 0.110
	Local Stewardship	0.052 ± 0.025	0.408 ± 0.034	0.032 ± 0.014	0.049 ± 0.024	0.007 ± 0.024	3.450 ± 0.037
Skylark	Present	0.060 ± 0.064		0.125 ± 0.059		0.052 ± 0.070	
	World Market	0.141 ± 0.058	1.372 ± 0.107	0.097 ± 0.073	−0.224 ± 0.112	0.079 ± 0.074	0.516 ± 0.124
	Global Sustainability	0.073 ± 0.055	0.230 ± 0.103	0.118 ± 0.056	−0.054 ± 0.101	0.079 ± 0.074	0.513 ± 0.124
	National Enterprise	0.036 ± 0.081	−0.402 ± 0.121	0.000	E	0.000	E
	Local Stewardship	0.039 ± 0.081	−0.339 ± 0.121	0.122 ± 0.060	−0.027 ± 0.103	0.023 ± 0.079	−0.564 ± 0.127
Song thrush	Present	0.000		0.001 ± 0.014		0.005 ± 0.017	
	World Market	0.002 ± 0.014	–	0.000	E	0.007 ± 0.018	0.241 ± 0.030
	Global Sustainability	0.000	–	0.002 ± 0.014	1.235 ± 0.024	0.007 ± 0.018	0.248 ± 0.030
	National Enterprise	0.000	–	0.000 ± 0.050	E	0.000	E
	Local Stewardship	0.000	–	0.001 ± 0.015	−0.029 ± 0.025	0.003 ± 0.019	−0.335 ± 0.031
Linnet	Present	0.046 ± 0.047		0.085 ± 0.044		0.000	
	World Market	0.063 ± 0.043	0.389 ± 0.080	0.080 ± 0.055	−0.058 ± 0.083	0.000	–
	Global Sustainability	0.045 ± 0.041	−0.003 ± 0.079	0.079 ± 0.042	−0.069 ± 0.075	0.000	–
	National Enterprise	0.054 ± 0.061	0.192 ± 0.090	0.056 ± 0.153	−0.348 ± 0.166	0.000	–
	Local Stewardship	0.044 ± 0.060	−0.029 ± 0.090	0.085 ± 0.045	−0.005 ± 0.077	0.000	–
Total density	Present	1.615 ± 0.017		1.740 ± 0.015		2.068 ± 0.021	
	World Market	2.357 ± 0.014	0.459 ± 0.029	1.495 ± 0.023	−0.141 ± 0.032	2.336 ± 0.024	0.130 ± 0.038
	Global Sustainability	1.738 ± 0.013	0.076 ± 0.028	1.738 ± 0.014	−0.001 ± 0.025	2.336 ± 0.024	0.130 ± 0.038
	National Enterprise	1.427 ± 0.028	−0.117 ± 0.038	0.534 ± 0.182	−0.693 ± 0.183	0.935 ± 0.118	−0.548 ± 0.122
	Local Stewardship	1.438 ± 0.028	−0.110 ± 0.037	1.715 ± 0.016	−0.015 ± 0.027	1.782 ± 0.027	−0.138 ± 0.040
Total richness	Present	34.461 ± 1.100		31.129 ± 1.097		31.089 ± 1.116	
	World Market	31.591 ± 1.093	−0.083 ± 1.902	32.129 ± 1.120	0.032 ± 1.914	30.170 ± 1.123	−0.030 ± 1.937
	Global Sustainability	33.909 ± 1.087	−0.016 ± 1.898	31.171 ± 1.092	0.001 ± 1.897	30.171 ± 1.123	−0.030 ± 1.937
	National Enterprise	35.378 ± 1.129	0.027 ± 1.922	37.771 ± 1.364	0.213 ± 2.066	36.293 ± 1.284	0.167 ± 2.035
	Local Stewardship	35.299 ± 1.128	0.024 ± 1.922	31.237 ± 1.098	0.003 ± 1.901	32.150 ± 1.130	0.034 ± 1.941

Biodiversity measure	Scenario	Inbye Sheep and Dairy		Moorland Sheep		Inbye Beef	
		Density	Change	Density	Change	Density	Change
Curlew	Present	0.021 ± 0.004		0.005 ± 0.010		0.014 ± 0.003	
	World Market	0.021 ± 0.004	0.006 ± 0.007	0.010 ± 0.005	0.985 ± 0.015	0.013 ± 0.003	−0.055 ± 0.006
	Global Sustainability	0.021 ± 0.004	−0.003 ± 0.007	0.008 ± 0.006	0.645 ± 0.016	0.014 ± 0.003	−0.015 ± 0.006
	National Enterprise	0.002 ± 0.024	−0.921 ± 0.024	0.002 ± 0.017	−0.547 ± 0.022	0.016 ± 0.005	0.173 ± 0.007
	Local Stewardship	0.017 ± 0.004	−0.180 ± 0.007	0.005 ± 0.010	0.000 ± 0.018	0.017 ± 0.005	0.185 ± 0.007
Lapwing	Present	0.032 ± 0.014		0.029 ± 0.036		0.008 ± 0.011	
	World Market	0.032 ± 0.015	0.001 ± 0.025	0.013 ± 0.016	−0.566 ± 0.053	0.008 ± 0.011	−0.107 ± 0.020
	Global Sustainability	0.031 ± 0.015	−0.038 ± 0.025	0.017 ± 0.021	−0.416 ± 0.054	0.007 ± 0.011	−0.197 ± 0.020
	National Enterprise	0.149 ± 0.082	3.666 ± 0.085	0.048 ± 0.060	0.641 ± 0.079	0.032 ± 0.018	2.800 ± 0.024
	Local Stewardship	0.042 ± 0.013	0.324 ± 0.024	0.029 ± 0.036	0.000 ± 0.062	0.032 ± 0.019	2.812 ± 0.025
Skylark	Present	0.170 ± 0.061		0.000		0.143 ± 0.106	
	World Market	0.170 ± 0.061	0.003 ± 0.106	0.027 ± 0.065	–	0.138 ± 0.105	−0.039 ± 0.093
	Global Sustainability	0.168 ± 0.061	−0.008 ± 0.106	0.014 ± 0.073	–	0.139 ± 0.106	−0.030 ± 0.064
	National Enterprise	0.027 ± 0.145	−0.839 ± 0.169	0.000 ± 0.124	–	0.184 ± 0.135	0.286 ± 0.103
	Local Stewardship	0.151 ± 0.058	−0.110 ± 0.104	0.000 ± 0.096	–	0.185 ± 0.136	0.291 ± 0.103
Song thrush	Present	0.012 ± 0.015		0.010 ± 0.023		0.004 ± 0.013	
	World Market	0.012 ± 0.015	−0.015 ± 0.025	0.012 ± 0.016	0.213 ± 0.036	0.005 ± 0.013	0.369 ± 0.022
	Global Sustainability	0.012 ± 0.015	0.003 ± 0.025	0.011 ± 0.018	0.148 ± 0.037	0.004 ± 0.013	0.070 ± 0.023
	National Enterprise	0.004 ± 0.035	−0.635 ± 0.041	0.008 ± 0.030	−0.130 ± 0.044	0.001 ± 0.017	−0.809 ± 0.025
	Local Stewardship	0.011 ± 0.014	−0.079 ± 0.025	0.010 ± 0.023	0.000 ± 0.040	0.000 ± 0.017	−0.884 ± 0.025

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 (e.g., MSB density rises to 0.052 (±0.003) birds/ha). However, on inbye-only farms, curlew density remains broadly similar (e.g., ISB density alters from 0.037 (±0.004) to 0.036 (±0.004) birds/ha) 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 (Fig. 2). The idiosyncratic nature of single species responses to changes in farm management practices is shown by the facts that (i) there are winners and losers, in terms of some species experiencing increases and some experiencing declines; and (ii) that the relative change varies so much across species.

We can also observe patterns across species' responses to alternative scenarios relative to the baseline as 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 numbers and positively related to cattle numbers. Skylark density also falls where fertiliser input and cutting frequency are high. Both the World Market and Global Sustainability scenarios lead to a decrease 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 (Figs. 2 and 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, rising cattle numbers on IB farms lead to increased skylark density.

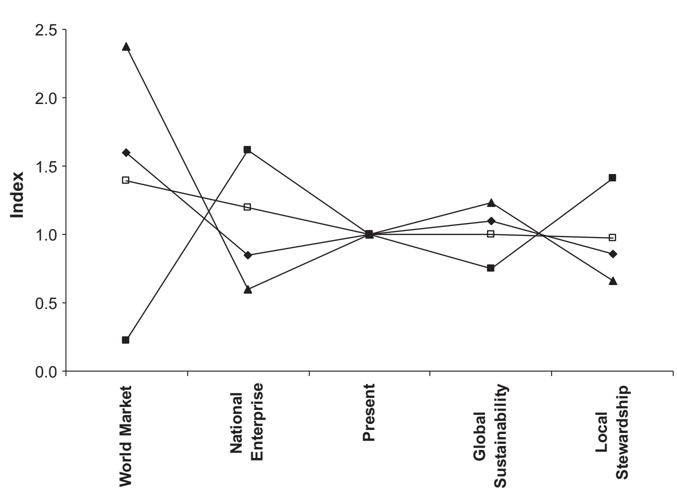

Fig. 5. Relative change in density of four bird species on Moorland Sheep and beef farms under foresight scenarios (filled triangle, skylark; filled diamond, Eurasian curlew; filled square, northern lapwing; open square, linnet).

Fig. 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, Fig. 5 shows the relative effects on four bird species of all four scenarios relative to baseline (labelled as "Present"). Again, this illustrates the mix of gains and losses across species and across scenarios.

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. (2005b) to do this. Our analyses are not intended to portray any actual future outcome, but rather to allow an investigation of the farm-scale ecological and economic consequences of a range of changes in agricultural prices and subsidy regimes which correspond to different visions of the future. The scenarios 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 to management variables through regression coefficients and their associated errors.

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 makes sense, 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 plausible, since each type encapsulates differences in production opportunities (for example, whether access to moorland grazing exists).

Despite the variability and the error associated with our predictions, certain headline commonalities emerge for 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 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 present schemes 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 between farm types, or changes in the number or average size of farms. 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 (Pykälä, 2003; Pykälä et al., 2005). In contrast, such management is rarely beneficial for many birds (e.g., Söderström 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 changes in the intensity of agricultural land use 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 advise 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.

Finally, it is possible to consider the implications of the results described here for current debates over reform of the Common Agricultural Policy (CAP) of the European Union. As noted earlier, current debate is structured around three scenarios for future policy change, namely the Adjustment, Integration and Re-Focus scenarios (EC, 2010). The scenarios vary in the distribution of spending between pillars 1 and 2, the degree of cross-compliance, the extent of local variation in measures and the degree of market support applied in the future. Whilst none of these EU scenarios are identical to the Foresight scenarios we employ, some parallels can be drawn. For instance, the “Adjustment” scenario retains single farm payments since its focus is on income maintenance, along with a limited increase in agri-environment and rural development spending. This is similar to the *Local Stewardship* scenario employed here. The “Re-Focus” scenario moves support away from pillar 1 to pillar 2 and sees a phasing out of the single farm payment by 2020, and so is similar to the *Global Sustainability* scenario. A lesson which emerges is that the choice of either produces quite different impacts on different indicators of biodiversity. A second lesson is that reducing pillar 1 supports (whether as single farm payments or market supports) does not have to result in a deterioration in biodiversity, if accompanied by targeted increases in agri-environmental spending. However, it is likely to lead to further falls in upland farm incomes.

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