Sustainability of Hill Farming, 2007-2008

Ecological Data

USER GUIDE

Bird data guide - data descriptions

Worksheet	Description
Farmland species list	A list of all species observed on 44 individual properties in the Peak district
Moorland Species	A list of all species observed on 37 moorland sites in the Peak district
Species Status	A list of all species, together with their conservation status and their status as a UK upland breeding species
Avian Summary Data	Richness and Density (in birds per hectare) according to Region (Dark Peak, Eastern Moors, South West Peak) in the Peak District
Regression Summary	Parameter estimates for the relationships between measures of avian diversity and abundance and farm management variables. Explanatory variables are those taken from socio-economic questionnaires (summary data provided elsewhere)

Region	Farms With Moorland	Farms Without Moorland	Total
Dark Peak	16	8	24
Eastern Moors	3	5	8
Southwest Peak	5	7	12
Total	24	20	44

Bird data guide - species status

Species	Common Name	UK Conservation Status	BAP Species	South Pennines Moors SPA Qualifying Feature	Conservation Concern	Upland Species
Phalacrocorax carbo	Cormorant	Amber			✓	
Ardea cinerea	Grey Heron	Green				
Anser anser	Greylag Goose	Amber			✓	
Brent canadensis	Canada Goose	Green				
Anas platyrhynchos	Mallard	Green				
Aythya fuligula	Tufted Duck	Green				
Accipiter nisus	Sparrowhawk	Green				
Buteo buteo	Buzzard	Green				✓
Pandion haliaetus	Osprey	Amber			✓	
Falco tinnunculus	Kestrel	Amber			✓	
Lagopus lagopus	Red Grouse	Amber	✓		✓	✓
Alectoris rufa	Red-legged Partridge	Green				
Perdix perdix	Grey Partridge	Red	✓		✓	
Phasianus colchicus	Pheasant	Green				
Gallinula chloropus	Moorhen	Green				
Fulica atra	Coot	Green				
Haematopus ostralegus	Oystercatcher	Amber			✓	
Pluvialis apricaria	Golden Plover	Green		✓	✓	✓
Vanellus vanellus	Lapwing	Amber	✓		✓	
Gallinago gallinago	Snipe	Amber			✓	✓
Numenius arquata	Curlew	Amber	✓		✓	✓
Actitus hypoleucos	Common Sandpiper	Green				✓
Larus ridibundus	Black-headed Gull	Amber			✓	
Larus canus	Common Gull	Amber			✓	
Larus fuscus	Lesser Black-backed Gull	Amber			✓	
Larus argentatus	Herring Gull	Amber	✓		✓	
Columba livia	Feral Pigeon	Green				
Columba oenas	Stock Dove	Amber			✓	
Columba palumbus	Woodpigeon	Green				
Streptopelia decaocto	Collared Dove	Green				
Cuculus canorus	Cuckoo	Amber	✓		✓	
Athene noctua	Little Owl	Green				
Strix aluco	Tawny Owl	Green				
Apus apus	Swift	Green				
Picus viridis	Green Woodpecker	Amber			✓	
Dendrocopus major	Great Spotted Woodpecker	Green				
Dendrocopos minor	Lesser Spotted Woodpecker	Red	✓		✓	
Alauda arvensis	Skylark	Red	✓		✓	
Hirundo rustica	Swallow	Amber			✓	
Delichon urbica	House Martin	Amber			✓	
Anthus trivialis	Tree Pipit	Amber	✓		✓	✓
Anthus pratensis	Meadow Pipit	Amber			✓	✓

Motacilla cinerea	Grey Wagtail	Amber		✓	✓
Motacilla alba	Pied Wagtail	Green			
Cinclus cinclus	Dipper	Green			✓
Troglodytes troglodytes	Wren	Green			
Prunella modularis	Dunnock	Amber	✓	✓	
Erithacus rubecula	Robin	Green			
Phoenicurus phoenicurus	Redstart	Amber		✓	✓
Saxicola torquata	Stonechat	Amber		✓	✓
Oenanthe oenanthe	Wheatear	Green			✓
Turdus torquatus	Ring Ouzel	Red	✓	✓	✓
Turdus merula	Blackbird	Green			
Turdus pilaris	Fieldfare	Amber		✓	
Turdus philomelos	Song Thrush	Red	✓	✓	
Turdus viscivorus	Mistle Thrush	Amber		✓	
Acrocephalus schoenobaenus	Sedge Warbler	Green			
Sylvia curruca	Lesser Whitethroat	Green			
Sylvia communis	Whitethroat	Green			
Sylvia borin	Garden Warbler	Green			
Sylvia atricapilla	Blackcap	Green			
Phylloscopus sibilatrix	Wood Warbler	Amber	✓	✓	✓
Phylloscopus collybita	Chiffchaff	Green			
Phylloscopus trochilus	Willow Warbler	Amber		✓	
Regulus regulus	Goldcrest	Amber		✓	
Muscicapa striata	Spotted Flycatcher	Red	✓	✓	
Ficedula hypoleuca	Pied Flycatcher	Green			✓
Aegithalos caudatus	Long-tailed Tit	Green			
Parus ater	Coal Tit	Green			
Parus caeruleus	Blue Tit	Green			
Parus major	Great Tit	Green			
Sitta europaea	Nuthatch	Green			
Certhia familiaris	Treecreeper	Green			
Garrulus glandarius	Jay	Green			
Pica pica	Magpie	Green			
Corvus monedula	Jackdaw	Green			
Corvus frugilegus	Rook	Green			
Corvus corone	Carrion Crow	Green			
Corvus corax	Raven	Green			✓
Sturnus vulgaris	Starling	Red	✓	✓	
Passer domesticus	House Sparrrow	Red	✓	✓	
Fringila coelebs	Chaffinch	Green			
Carduelis chloris	Greenfinch	Green			
Carduelis carduelis	Goldfinch	Green			
Carduelis spinus	Siskin	Green			✓
Carduelis cannabina	Linnet	Red	✓	✓	
Carduelis flavirostris	Twite	Red	✓	✓	✓
Carduelis flammea	Lesser Redpoll	Amber	✓	✓	✓
Pyrrhula pyrrhula	Bullfinch	Red	✓	✓	
Emberiza citrinella	Yellowhammer	Red	✓	✓	
Emberiza schoeniclus	Reed Bunting	Red	✓	✓	

Journal of Applied Ecology

British Ecological Society

Journal of Applied Ecology 2009, **46**, 647–656 doi: 10.1111/j.1365-2664.2009.01616.x

What explains property-level variation in avian diversity? An inter-disciplinary approach

Martin Dallimer[1]*, Szvetlana Acs[2], Nick Hanley[2], Paul Wilson[3], Kevin J. Gaston[1] and Paul R. Armsworth[1]

[1]*Biodiversity and Macroecology Group, Department of Animal and Plant Sciences, University of Sheffield, Sheffield S10 2TN, UK;* [2]*Department of Economics, University of Stirling, Stirling FK9 4LA, UK; and* [3]*Rural Business Research Unit, University of Nottingham, Sutton Bonington Campus, Loughborough LE12 5RD, UK.*

Summary

1. Modern farmed landscapes have witnessed substantial losses in biodiversity principally driven by the ecological changes associated with agricultural intensification. The causes of declines are often well described, but current management practices seem unlikely to deliver the EU-wide policy objective of halting biodiversity losses.

2. Available evidence suggests that property-scale factors can be influential in shaping patterns of biodiversity; however, they are rarely included in studies. Using 44 upland farms in the Peak District, northern England, we investigate the roles of ecological, agricultural and socio-economic factors in determining avian species richness, for the first time incorporating information from all three influences.

3. Although we might expect that habitat quality would be the main factor affecting species richness, these variables had little influence. The landscape context of each property was unimportant in explaining any of the three measures of species richness (*Total*, *Upland* and *Conservation Concern*) used here. Within-property habitat quality did explain 42% of the variation in richness of upland specialist species, but had no influence on Total or Conservation Concern Richness.

4. Socio-economic circumstances of farms alone accounted for 24% of the variation in Total Richness, with land tenure and labour inputs important predictors of avian diversity. However, net income, rental value and the level of Agri-Environment Scheme (AES) payments did not play a role in predicting species richness.

5. Farm management variables, including many of the main prescriptions outlined in AES, accounted for 23% of the variation in the richness of species of Conservation Concern, but less than 10% for Total Richness. However, no farm management variable alone was shown to offer better predictive power of avian species richness than random.

6. *Synthesis and applications.* The agricultural landscape is managed by a mosaic of landowners, all of whom can influence biodiversity conservation. We demonstrate that variation at the property-scale in habitat, management and socio-economics can feed into determining patterns of biodiversity. Currently, farmland conservation policy largely assumes that socio-economic barriers and financial costs of implementing conservation measures are constant. Incorporating a consideration of the varying circumstances of individual properties into policy design is likely to result in substantial biodiversity gains.

Key-words: AES, Agri-Environment Scheme, habitat quality, hill farm, in-bye, moorland, Peak District, species richness, upland, UK

Introduction

Modern farmed landscapes account for nearly half of the land cover in the European Union (FAO 2003) and yet are severely depleted in both habitat heterogeneity and biodiversity (Kareiva *et al.* 2007). Indeed, recent decades have witnessed substantial losses in biodiversity in the wider countryside of this region, principally driven by the ecological changes associated with intensification of agricultural production (Benton *et al.* 2002; Robinson & Sutherland 2002; Donald *et al.* 2006).

*Correspondence: M.Dallimer@sheffield.ac.uk

Patterns of biodiversity across the landscape have been well studied (e.g. Marini *et al.* 2008; Rundlöf, Bengtsson & Smith 2008). The causes of declines are often well described (e.g. Chamberlain *et al.* 2000; Preston *et al.* 2002; Robinson & Sutherland 2002), and some of the mechanisms understood (e.g. Baines 1988; Wickramasinghe *et al.* 2003; Smith *et al.* 2004; Pocock & Jennings 2008). Management prescriptions are available, in the form of Agri-Environment Schemes (AES), which aim to halt those declines (Defra 2005a,b). Nonetheless, the results of AES in terms of biodiversity gain are equivocal (Kleijn & Sutherland 2003; Kleijn *et al.* 2006), calling into question whether current designs of AES will deliver the EU-wide policy objective of halting biodiversity loss (Whittingham 2007).

Although rarely included in biodiversity studies (but see Hudson 1992; Tharme *et al.* 2001), property-scale factors are likely to be highly influential in driving patterns of biodiversity, not least because management actions are undertaken at this scale. Indeed, a range of ecological and non-ecological factors will almost certainly influence between-property variation in biodiversity. Here we investigate the importance of habitat, management and socio-economic variables as predictors of biodiversity at the property scale.

This question is particularly pertinent for avian diversity in the UK uplands at this time, as these areas continue to experience widespread habitat change (Haines-Young *et al.* 2003). Agricultural land management resulted in a 7% increase in the area of improved grassland, indicating a continuation of agricultural intensification in the uplands that is less apparent in lowland areas. The ecological consequences of such a dramatic shift in land-use are marked, and substantial declines in upland breeding bird populations continue (Sim *et al.* 2005).

Differences in habitat type and quality are well known to shape the occurrence of avian species in the upland landscape (e.g. Stillman & Brown 1994; Tharme *et al.* 2001). We would therefore expect that the most proximal factors influencing variation in species richness at a property level would be delimited by habitat availability and quality, both on the property concerned and in the surrounding landscape. In addition, altering farm management practices (such as stocking rates or chemical use) can have a profound influence on the extent and quality of habitat and food resources available to the avian community (e.g. Peach *et al.* 2001; Whittingham *et al.* 2007). We would therefore also predict that variation in farming practice at the property level should explain variation in species richness as well. Empirical evidence also exists for coarse-scale patterns of correlation between biodiversity and socio-economic factors (e.g. Huby *et al.* 2006), and studies show that land ownership can influence conservation decision-making (e.g. Ando & Getzner 2006). Moreover, the willingness of land managers to engage in environmentally sensitive management practices depends on a range of socio-economic conditions (e.g. Willock *et al.* 1999; Vanslembouck, Van Huylenbroeck & Verbeke 2002), some of which are determined by agricultural, environmental and rural development policy. Hence, it is possible that variation in the socio-economic conditions on a farm will influence decisions that are made about farming system and management practices, which in turn can be expected to affect species richness.

In common with Europe as a whole (Donald *et al.* 2006), farming remains the dominant land-use in the UK uplands, although it operates on the margins of agricultural productivity. Recently, hill farm incomes in the UK have fallen dramatically in response to lower lamb and beef prices (Defra 2005c) and the viability of upland farms often depends on core subsidy support (such as the Single Farm Payment) and on AES payments (Peak District Rural Deprivation Forum 2004; Acs *et al.* 2008). Further, as with other rural areas, changing farming practice in the uplands has gone hand in hand with marked shifts in the socio-economic make up of rural areas, with a reduction in the number of full time agricultural workers, an increase in the age of the population, farm amalgamations and continued social deprivation with income growth lagging behind that in much of the rest of society (Defra 2004).

Upland areas represent a dynamically changing ecological and socio-economic environment where current management and knowledge has so far proven inadequate to address biodiversity losses. In this study, using the Peak District National Park of northern England as a case study, we investigate the roles of ecological, agricultural and socio-economic factors in patterning avian species richness in the uplands, incorporating information from all three influences at the property-scale for the first time. We argue that a property-scale focus is particularly valuable for understanding ecological outcomes, since this is the scale at which current agri-environmental policy operates.

Materials and methods

STUDY SYSTEM

This study focussed on the uplands of the Peak District National Park in northern England (Fig. 1). The Peak District is a region of hills characterized by heather *Calluna vulgaris* dominated moorland managed principally for pastoral farming and grouse *Lagopus lagopus* shooting, with almost all of the moorland receiving additional protected area designation such as the Southern Pennines Moors Special Protection Area (SPA) designated to protect the region's breeding bird interests. Farming in the Peak District operates on the margins of profitability and is reliant on agricultural subsidies (Acs *et al.* 2008) and the long-term economic sustainability of upland farming in its current form remains in doubt.

Although agriculture is the dominant land-use, other drivers of changes in biodiversity in the Peak District include moorland management using controlled burning, which has altered the region dramatically in recent years (Yallop *et al.* 2006), aerial pollution and climate change. Historically, the Peak District has been subject to high amounts of airborne pollution (NEGTAP 2001). The impacts of these pollutants on the vegetation community have resulted in the almost complete loss of sphagnum and moss communities on moorland and bogs (Lee 1998). Climate warming is viewed as a major driver of change in all global ecosystems (Millennium Ecosystem

Fig. 1. A map of the Peak District National Park in northern England. The stippled area indicates the extent of moorland; the shaded area represents a buffer 2 km wide around the major moorland blocks. All study farms had their main land-holding in this moorland fringe zone. Inset shows location of the Peak District in Britain.

Assessment 2005). The Peak District lies at the southern and eastern margins of climatic suitability for upland bog formation and is therefore likely to be severely impacted.

DATA COLLECTION

In order to characterize property-scale avian species richness, 44 farms were selected whose main landholding fell within 2 km of moorland (Fig. 1). Three properties did not fall within the National Park, and a further 11 farms were outside the boundaries of the North Peak or South West Peak Environmentally Sensitive Areas (ESA). Only five farms included farmland (as opposed to moorland) that was covered by additional protected area designations. Property maps were obtained from the farmer, and transect routes planned prior to any bird surveys being conducted, based on the size and shape of the landholding and suitable access points. To minimize the potential for recording birds outside the survey farm, transects were placed 200 m from a property boundary. Birds were only included as present if they were seen or heard within the property, irrespective of the distance from the transect. Where needed, parallel transects were placed 400 m apart to avoid double-sampling the same parts of the farm. In this situation, birds were only recorded within 200 m of the transect line. Bird surveys were carried out on two separate visits between 28 March and 5 July 2007, with the second visit at least 6 weeks after the first. To ensure that the maximum number of species was encountered, visits began between 1 and 3 h after sunrise.

A list of all bird species encountered on each farm during both visits was compiled. The number of species observed was used directly as the measure of species richness. Species were classified into two further groups with greater conservation relevance: Upland Species and Species of Conservation Concern (Supporting Information, Appendix S1). The habitat specialist Upland Species group consisted of species that have a predominantly upland breeding distribution, based on the UK Breeding Bird Atlas (Gibbons, Reid & Chapman 1993). The Conservation Concern species group comprised species that are either Amber or Red listed (Gregory *et al.* 2002), appear on the UK BAP list (Biodiversity Reporting and Information Group 2007) or are qualifying features for the South Pennine Moors SPA (Stroud *et al.* 2001).

Habitat variables were collected from surveyed fields within each farm (Table 1). These variables were those that have been shown to influence avian species richness and population size for a variety of species in the UK uplands (e.g. Baines 1988; Robson & Percival 2002; Pearce-Higgins & Yalden 2003) and for farmland birds in general (e.g. Atkinson *et al.* 2005; Whittingham *et al.* 2005). The landscape context within which each property was found was characterized by calculating the proportion of six different habitat types (moorland, woodland, arable, inland water, urban/rural developed land and grassland) based on the Land Cover Map 2000 (Haines-Young *et al.* 2000) in a 500-m buffer around each property.

Farm management and socio-economic characteristics of the same 44 farms were gathered using a questionnaire-based survey delivered in person during farm visits by experienced professional farm business researchers (Table 1). The purpose of the socio-economic survey was to investigate how land is managed on hill farms, what resources were available to farmers, and how land-use and resources related to farm incomes (Acs *et al.* 2008). The survey included a mix of closed and open-ended questions that covered the landholding, production activities (e.g. livestock numbers, labour and fertilizer use), other management activities (e.g. activities complying with different AES), and financial data such as input costs, output prices and subsidy payments received.

Initial contact with suitable farms was established through the Rural Business Research Unit at the University of Nottingham, local farming and conservation organizations, and by word of mouth. Sixty-seven farmers were contacted directly by telephone and asked whether they wished to participate in the research programme, 55 of whom indicated their interest. Of these, 47 farmers were visited and 44 were included in the economic analyses and ecological surveys. The remaining three did not actively farm themselves, with all land either rented out or used for non-agricultural activities. In total, 10 person-months were spent making contact with the farming community, establishing direct relationships with farmers and delivering the questionnaires in a face-to-face interview.

Variables recorded in the questionnaire were categorized as covering farm management practices, or describing the socio-economic status of the farm. Farm management variables pertained to the farming system, nutrient input, livestock units, areas of key land types, information relating to AES prescriptions, as well as whether predator control (known to be important for some bird species; Holt *et al.* 2008) was carried out. Socio-economic variables included data on patterns of land ownership, known changes in the socio-economic make-up of rural areas and information on the economic performance and subsidy uptake of each property. These

Table 1. Definitions of variables used in the analysis of the patterns of avian species richness across hill farms in the Peak District, northern England

Variable	Median	Lower–upper quartile	Description
(a) Habitat			
Intensive grass	0·88	0·72–0·97	Proportion of surveyed fields that were improved
Mowed land	0·25	0·03–0·53	Proportion of surveyed fields that were cut for silage or hay
Vegetated boundaries	0·08	0·03–0·15	Proportion of field boundaries that were vegetated (hedges, woods)
Trees	142	62–270	Total number of trees within surveyed fields
Sheep	88	21–175	Total number of adult sheep within surveyed fields
Cows	13	0–36	Total number of adult cows within surveyed fields
Rush cover	0·02	0·00–0·05	Proportion of surveyed fields with rush (mainly *Juncus effusus*) cover
Wet features	0·13	0·00–0·30	Proportion of surveyed fields with wet features (ditches, ponds, streams)
(b) Landscape context			
Arable	0·01	0·00–0·06	Proportion of arable within 500 m of the farm.
Moorland	0·06	0·01–0·17	Proportion of moorland within 500 m of the farm.
Grassland	0·64	0·57–0·77	Proportion of grassland within 500 m of the farm.
Urban/rural developed	0·02	0·00–0·05	Proportion of urban/rural developed land within 500 m of the farm.
Inland water	0·00	0·00–0·01	Proportion of inland water within 500 m of the farm.
Woodland	0·09	0·03–0·15	Proportion of woodland within 500 m of the farm.
(c) Farm management			
Farm type	Not applicable	Not applicable	Whether the farm was a sheep (7 farms), cattle (6 farms) or mixed (31 farms) enterprise
Rough grazing	12·60	3·00–29·95	Area (ha) of the farm that the farmer stated was managed as rough grazing
LU/Ha	0·98	0·70–1·46	Density of livestock units (ha^{-1}) on the farm
Predator control	10	4·50–33	Number of days of predator control a year carried out on the property by the farmer, gamekeeper (whether employed on that property or not) or other professional person.
Cutting dates	Not applicable	Not applicable	Whether the land was cut before (18 farms) or after (21 farms) mid-July
Number of cuts	Not applicable	Not applicable	Number of cuts (between zero and three) taken. No cuts taken on 5 farms, one cut on 25 farms, two cuts on 12 farms and three cuts taken on two farms.
Fertilizer input	43·00	18·00–119·50	Nitrogen input (kg ha^{-1}) from fertilizer and manure
(d) Socio-economic			
Ownership	0·30	0·03–0·72	Proportion of the farm that was owned
Farm workers	1·70	1·06–2·29	Number of workers on the farm, calculated from the questionnaire
On farm income	0·82	0·55–1·00	Proportion of farm income from farming
Net farm income	6067	–6758·50 to 33189·50	Net farm income (£), calculated from the questionnaire
AES payment	7500	1353·50–16285·00	Total AES payment (£), taken from the questionnaire
Rental value	44·10	23·25–84·00	Rental value of the farm (£ ha^{-1}), calculated from overall questionnaire returns

factors were considered potentially to play a role in influencing property-scale management decisions, and hence, avian species richness.

Many of the farm management and socio-economic data were usable directly from the questionnaire. However, several variables required further calculation; these included density of livestock units, fertilizer input, number of farm workers, rental value of the farm and net farm income. The density of grazing livestock units was based on total livestock numbers reported by the farmer weighted by the type of livestock and proportional to the farm area. Fertilizer input represents the total nitrogen (N) use per hectare, which was based on the N content of fertilizer and manure applied. The number of farm workers was calculated according to the labour input from the farmer, family labour and hired labour working either full- or part-time. Net farm income was derived from total returns from agricultural production and subsidy payments minus variable costs, such as those for fertilizer, sprays and feed.

DATA ANALYSIS

All analyses were carried out at the level of the property holding, excluding any unenclosed extensively grazed moorland. Explanatory variables consisted of four broad classes: (i) Habitat, (ii) Landscape context, (iii) Farm management, and (iv) Socio-economic. Each of the response variables (Total Species Richness, Upland Species Richness and Conservation Concern Species Richness) were modelled with the four sets of variables separately in order to avoid over-specifying any one model.

The Information Theoretic approach (Burnham & Anderson 2002; Johnson & Ohmland 2004) was used to model these data based on Akaike Information Criteria (AIC). All possible subsets of the variables were modelled using a Generalized Linear Model with Poisson errors; species richness at each site was the dependant variable and explanatory variables were transformed appropriately. For the complete set of models, AIC, the difference in AIC for that model relative to the best-fitting model with the minimum AIC (termed ΔAIC), the Akaike weight (termed w_i) and R^2 were all calculated. The best-fitting model was defined as that with the lowest AIC. Models that differ by less than 2 AIC units have substantial support in terms of explaining the data (Burnham & Anderson 2002).

The probability of each individual explanatory variable appearing in the best-fitting model was also calculated (termed k). However, poor explanatory variables can still have high selection probabilities. A single randomly generated variable was therefore added to the existing data set (Whittingham *et al*. 2005). One hundred model sets were generated, and k for the random variable was calculated. Explanatory variables that do not offer predictive power significantly different from random have a probability (k) falling within the 95% confidence intervals of this random variable. All analyses were performed in R version 2·6·2 (R Development Core Team 2008).

To investigate each of the four classes of explanatory variables together, the two variables from each with the highest k were included in a further model, termed the Joint Model. In total, therefore, five best-fitting models (one for each variable type and the Joint Model) were generated for each measure of species richness. From these, the model that best predicted the pattern of avian species richness was chosen based on minimum AIC.

Results

There were between 13 and 45 bird species observed on each farm and a total of 97 species across all 44 study farms. Twenty-one upland specialist species were observed (range: one to eight) and 43 Conservation Concern Species (range: two to 10). On average, 95·0 ha (SD 66·7 ha) of farmland was surveyed per property, with an average 1651 m (SD 561 m) of transect walked. Surveyed farm area and transect length were positively correlated ($\rho = 0{\cdot}697$, $P < 0{\cdot}001$). There was no bivariate relationship between species richness and the area of farmland surveyed (e.g. for Total Species Richness, $R^2 = 0{\cdot}01$, $P > 0{\cdot}05$), nor length of transect walked (e.g. for Upland Species Richness, $R^2 = 0{\cdot}03$, $P > 0{\cdot}05$). Neither transect length nor farm area was therefore included in any of the models reported, to reduce model complexity. Indeed, when farm area was included in the models there were no substantive changes to the model outcomes. Colinearity between explanatory variables was investigated using correlation matrices. Although associations were apparent, they were not sufficient to preclude their inclusion into the modelling process. Within each model, Variance Inflation Factors (VIFs) were within accepted norms, indicating that problematic levels of multi-colinearity were not present (Myers 1990). One farm was excluded from data analyses, as it was an extreme outlier in terms of farm size, structure and management.

Habitat variables explained 42% of the variation in upland species richness (Table 2). For these upland specialists, the quality of the habitat was important, with fewer species where more fields were mowed for silage or hay, and more species with increasing numbers of cows and proportion of field with rush cover (Table 3; Supporting Information, Appendix S2). All three variables offered explanatory power that was better than random. Habitat characteristics did not offer any explanatory power for Conservation Concern or Total Species Richness ($R^2 = 0$), and k for these variables did not differ from random, further indicating the relative unimportance of habitat variables in predicting Total and Conservation Concern Species Richness.

Landscape context variables offered little explanatory power for all three measures of species richness. Indeed, the null model was the best-fitting model for both Total and

Table 2. Information theoretic results for the relationship between species richness of three different avian species groups (Total, Upland and Conservation Concern) in the Peak District in relation to each set of explanatory variables. The proportion of the variation explained (R^2), number of models appearing in the 95% set (95% set) and number of models appearing in the ΔAIC < 2 set. The overall Best Model (based on lowest AIC) for each species group is highlighted in bold.

Explanatory variable set	Species richness	R^2	AIC	95% set	ΔAIC < 2
(a) Habitat	Total	0·00	300·61	164	12*
	Upland	**0·42**	**170·47**	**111**	**5**
	Conservation Concern	0·00	223·62	137	6*
(b) Landscape context	Total	0·00	301·10	41	5*
	Upland	0·13	179·03	50	14*
	Conservation Concern	0·00	223·62	46	7*
(c) Farm management	Total	0·09	300·01	82	5*
	Upland	0·07	179·33	86	10*
	Conservation Concern	**0·23**	**223·07**	**87**	**12***
(d) Socio-economic	Total	0·24	291·34	27	4
	Upland	0·10	177·79	46	7*
	Conservation Concern	0·18	222·37	43	6*
(e) Joint models	**Total**	**0·27**	**289·94**	**33**	**2**
	Upland	0·37	171·93	37	5
	Conservation Concern	0·18	222·31	52	29*

* – indicates that the null model appeared in the ΔAIC < 2 model set, suggesting that this represents a plausible alternative to the best model. The null model was also the Best Model for Conservation Concern Species Richness for the Habitat variable set and for Total and Conservation Concern Species Richness for the landscape context variable set.

Table 3. Akaike weights (*k*) for each explanatory variable included in species richness models for Total Species Richness (Total), Upland Species Richness (Upland) and Conservation Concern Species Richness (Conservation Concern) on hill farms in the Peak District. The Akaike weights indicate the probability that each variable is included in the best-fitting model. Figures in bold indicate variables that appear in the best model. For each species group, the two explanatory variables with the highest *k* from each variable set (excluding landscape context) were included in the Joint Model. Relationship indicates the direction of any relationship between species richness and variables featuring in the best model. For parameter estimates, see Supporting Information, Appendix S2. The *random variable* shows the 95% confidence intervals for the probability *k* that a random unrelated variable appears in the best model.

	Total		Upland		Conservation concern	
Variable set	*k*	Relationship	*k*	Relationship	*k*	Relationship
(a) Habitat						
Intensive grass	0·22		0·21		0·23	
Mowed land	0·40		**0·75**	–	0·30	
Vegetated boundaries	**0·49**	+	0·21		0·22	
Trees	**0·49**	+	0·22		0·22	
Sheep	0·23		0·26		0·41	
Cows	0·28		**0·89**	+	0·27	
Rush cover	0·27		**0·60**	+	0·23	
Wet features	0·34		0·43		0·33	
Random Variable	*0·21–0·90*		*0·20–0·48*		*0·22–0·69*	
(b) Landscape context						
Arable	0·24		0·31		0·43	
Moorland	0·41		**0·53**	+	0·40	
Grassland	0·30		0·38		0·38	
Urban/rural developed	0·23		0·45		0·30	
Inland water	0·23		**0·49**	–	0·28	
Woodland	0·31		0·27		0·25	
Random variable	*0·22–0·93*		*0·22–0·81*		*0·22–0·69*	
(c) Farm management						
Farm type	0·34		0·31		**0·45**	**Fewest species on sheep-only farms**
Rough grazing	0·29		0·33		0·22	
LU ha^{-1}	0·23		0·28		0·27	
Predator control	**0·50**	+	**0·52**	+	**0·43**	+
Cutting dates	0·23		0·24		0·25	
Number of cuts	0·23		0·28		0·30	
Fertilizer input	**0·56**	+	0·33		**0·51**	+
Random variable	*0·21–0·71*		*0·22–0·65*		*0·21–0·56*	
(d) Socio-economic						
Ownership	**0·83**	–	**0·61**	–	**0·47**	–
Farm workers	**0·96**	+	0·33		**0·63**	+
On farm income	**0·55**	–	0·32		0·31	
Net farm income	0·22		0·24		0·23	
AES payment	0·30		0·35		0·23	
Rental value	0·23		0·28		0·26	
Random variable	*0·21–0·78*		*0·22–0·67*		*0·22–0·67*	
(e) Joint model						
Mowed land	–		**0·84**	–	–	
Trees	0·38		–		–	
Vegetated boundaries	**0·69**	+	–		–	
Sheep	–		–		0·36	
Cows	–		**0·90**	+		
Wet features	–		–		0·38	
Farm type	–		–		0·39	
Predator control	0·22		0·33		–	
Fertilizer input	0·33		0·23		**0·48**	+
Ownership	**0·90**	–	0·42		**0·58**	–
Farm workers	**0·80**	+	–		0·48	
AES payment	–		**0·43**	+	–	
Random variable	*0·21–0·73*		*0·21–0·52*		*0·21–0·58*	

Conservation Concern Species Richness. For Upland Species Richness, landscape context explained 13% of variation. However, no variables had a *k* that differed from random. As landscape context variables were poor predictors across the range of species richness measures, they were not included in the final Joint Model.

Farm management explained 23% of the variation in Conservation Concern Species Richness, this figure falling to 9% and 7% for Total and Upland Species Richness, respectively. For all three richness measures, no variable offered explanatory power that was better than random and the null model appeared in the ΔAIC < 2 model set in each case. Both results indicate the lack of confidence that should be placed in the described relationships.

Socio-economic variables explained 24% of the variation in Total Species Richness across the study farms. Variables included in the best model were the number of workers on a farm, the proportion of the farm that is owned and the proportion of farm income generated from farming. Fewer species were present where more of the farm income was generated on-farm and where more of the land area of the farm was owned. Conservation Concern Species Richness mirrored Total Species Richness with regards to the socio-economic variables, with 18% of the variation explained by ownership levels and farm workers, although no relationship was found with on-farm income. Socio-economic variables only offered limited explanatory power (10%) for Upland Species Richness. Net farm income, rental value and AES payments did not appear in any best-fitting model.

Two variables from each explanatory variable set with the highest Akaike weight for each species group were included in a Joint Model in order to investigate the relative importance of the variable sets (Table 3). The best-fitting model for the Joint Model for both Upland and Conservation Concern Species Richness had lower R^2 and higher AIC than models containing only one explanatory variable type. Conversely for Total Species Richness, R^2 increased and AIC decreased, indicating that explanatory power improved with the addition of the habitat variable measuring the proportion of field boundaries that were vegetated. Although additional explanatory power was gained for Total Species Richness, the increase was modest and the added variable did not offer explanatory power that was different from random.

Discussion

Ecological variation across wider agricultural landscapes has been well studied (e.g. Marini *et al.* 2008; Rundlöf *et al.* 2008). However, this landscape is owned and managed by a complex mosaic of different public and private landowners, which can influence conservation management decisions (Ando & Getzner 2006). Here we demonstrate that variation at the property level in habitat, management and the socio-economic circumstances of the landowners can all feed into determining patterns of biodiversity at the property-scale.

Variation in habitat quantity and quality are the key proximal factors that influence the presence and abundance of avian species. Many of the habitat requirements of farmland birds, both in the uplands and more generally, are well known. Hence, we might anticipate that describing the composition of habitat should be sufficient to understand variation in avian species richness at the property level. Indeed, habitat is important for the suite of species that are UK upland specialists, and many of these patterns are those that would be expected based on previous studies. More upland habitat specialists were present where farms had more rush cover and fewer fields managed by cutting for hay or silage (Baines 1988; Robson & Percival 2002; Pearce-Higgins & Yalden 2003). However, for Total Species Richness and Conservation Concern Species Richness, habitat offered no explanatory power, although the variables measured included features pertaining to the extent and quality of the field boundaries, tree and woodland cover, which have been argued to be beneficial to many farmland birds (Hinsley & Bellamy 2000).

Often birds will make use of habitat over a wide area and are not restricted to a single property or habitat (e.g. Whittingham *et al.* 2000). We might therefore expect that the quantity of habitat types surrounding the study farms would influence species richness on each property. However, the landscape context of a farm did not account for any variation in Total or Conservation Concern Species Richness, and only had limited influence on Upland Species Richness.

Although farm management variables explained 23% of the variation in Conservation Concern Species Richness, the null model represented a plausible alternative and no individual variable was more likely than random to appear in the best-fitting model. Many of these variables are prescribed options for AES (e.g. mixed farming system to include cattle, cutting dates, number of cuts, stocking density, fertilizer input; Defra 2005a,b). Nonetheless, only one variable enhanced avian species richness. Although the extent of the influence should not be overstated, more species of conservation concern were present where a farming system included cattle. In addition, for the upland specialists, the actual numbers of cows present on a farm was positively related to species richness, although overall livestock density on farms was not found to be important. The counter-intuitive positive relationship between biodiversity and fertilizer input (see Billeter *et al.* 2008) may simply be a reflection of the relatively low artificial nutrient input levels used in an upland pastoral farming system. Our results are broadly in line with large-scale studies across Europe that have been unable to find consistent agricultural land-use variables that explained species richness across taxa (Billeter *et al.* 2008).

In the complex farming systems of the Peak District, we may expect interactions between the characteristics of individual farms, some of which may influence biodiversity. One such interaction is between levels of sheep and cattle grazing, which has been shown to affect the breeding success of an upland passerine (Evans *et al.* 2006). Although not included in the main modelling process, the addition of the interaction term between sheep and cattle numbers led to an increase in AIC for all three measures of species richness, indicating a lack of evidence that this particular interaction influences species richness as a whole.

In the Peak District, we were able to demonstrate a strong relationship between socio-economic circumstances and avian species richness. Species richness declined with increased ownership levels and reliance on farming for the household income. This pattern perhaps indicates that farms that are more important sources of income for their owners are managed in more intensive ways that are less beneficial to biodiversity, where this intensity is not reflected in management variables such as stocking rates and fertilizer use.

The number of farm workers can be taken as a surrogate for the amount of management effort that an individual farm receives. The positive relationship with Total Species Richness could therefore be interpreted as an effect of increased management effort where there is potentially more time available for carrying out activities that are not solely related to agricultural production and which benefit avian diversity. One result of recent policy changes to agricultural subsidy support is a predicted reduction in farm labour (Acs *et al.* 2008). In the heavily managed landscape of the Peak District, this decline will therefore not only result in social changes, but also impact on levels of biodiversity.

There remains little consensus as to whether or not AES in their current form will deliver substantial conservation gain (Whittingham 2007), although in five European countries, species from across a range of taxa benefited from AES (Kleijn *et al.* 2006). Here we found that the overall level of AES payment did not determine species richness. In part, this could be because voluntary enrolment may not lead to agreements on the highest-value properties for biodiversity (a problem of adverse selection; Hanley, Shogren & White 2007). It may also be due to the need for neighbouring farms to take joint actions, which is currently not encouraged by policy design (Parkhurst & Shogren 2007).

Although species richness is one of the simplest and most commonly discussed measurements of biodiversity, the question remains as to which species would be most relevant to conservation policy in a given region. Here we tested the richness of three different sets of species (Total, Upland specialists, Conservation Concern). Importantly, the conclusions drawn from the analyses depend very much on the measure of species richness that is used.

The farmland conservation literature has within it an implicit assumption that the socio-economic barriers and financial costs of implementing landscape-scale conservation measures are constant. However, the opportunity costs of land vary spatially (Naidoo & Iwamura 2007), and dimensions of conservation costs, such as management can also vary geographically (Balmford *et al.* 2000, 2003). The key policy instruments for delivering biodiversity gain in the EU are AES (EEA 2004; CEC 2006), which currently do not take account of property-level heterogeneity in farm socio-economics, factors that can influence the willingness of farmers to enter into an AES as well as the effectiveness of their management actions once in the scheme (Willock *et al.* 1999; Vanslembouck *et al.* 2002). Hence, the outcomes of any broad-brush policy at the farm level will not be the same. AES development would therefore benefit from following a similar trajectory to the conservation planning literature by incorporating tools that take into account variations in economic costs (Naidoo *et al.* 2006) and socio-economic and management barriers to biodiversity conservation across the farmed landscape. Such an approach is likely to lead to substantial conservation gains if future land management practices can be designed and implemented to account for the situations of individual properties.

Acknowledgements

We thank the farmers of the Peak District, without whom this study would not have been possible. Help identifying suitable farms was provided the National Farmers Union, the Peak District National Park Authority, the Moors for the Future Partnership, the National Trust and the RSPB. Socio-economic surveys were performed by Richard Darling, John Farrar, Nick Harpur, Helen McCoul, Phil Robertson and Robert Yates. Andrew Skinner and Richard Fuller carried out additional fieldwork. We thank Zoe Davies, Steve Redpath and an anonymous referee for comments that much improved an earlier version of the manuscript. The research was funded as part of the UK Research Councils' Rural Economy and Land Use Programme (RELU). RELU is a collaboration between the Economic and Social Research Council, the Natural Environment Research Council and the Biotechnology and Biological Sciences Research Council, with additional funding from Defra and the Scottish Government. K.J.G. holds a Royal Society Wolfson Research Merit Award.

References

Acs, S., Hanley, N., Dallimer, M., Gaston, K.J., Robertson, P., Wilson, R. & Armsworth, P.R. (2008) The effect of decoupling on marginal agricultural systems: implications for farm incomes, land use and upland ecology. *Stirling Economics Discussion Paper* 2008-18. http://www.econ.stir.ac.uk/DPs/SEDP-2008-18-Acs-Hanley-et-al.pdf.

Ando, A.W. & Getzner, M. (2006) The roles of ownership, ecology, and economics in public wetland-conservation decisions. *Ecological Economics*, **58**, 287–303.

Atkinson, P.W., Fuller, R.J., Vickery, J.A., Conway, G.J., Tallowin, J.R.B., Smith, R.E.N., Haysom, K.A., Ings, T.C., Asteraki, E.J. & Brown, V.K. (2005) Influence of agricultural management, sward structure and food resources on grassland field use by birds in lowland England. *Journal of Applied Ecology*, **42**, 932–942.

Baines, D. (1988) The effects of improvement of upland, marginal grasslands on the distribution and density of breeding wading birds (Charadriiformes) in Northern England. *Biological Conservation*, **45**, 221–236.

Balmford, A., Gaston, K.J., Rodrigues, A.S.L. & James, A. (2000) Integrating costs of conservation into international priority setting. *Conservation Biology*, **14**, 597–605.

Balmford, A., Gaston, K.J., Blyth, S., James, A. & Kapos, V. (2003) Global variation in terrestrial conservation costs, conservation benefits, and unmet conservation needs. *Proceedings of the National Academy of Sciences of the United States of America*, **100**, 1046–1050.

Benton, T.G., Bryant, D.M., Cole, L. & Crick, H.Q.P. (2002) Linking agricultural practice to insect and bird populations: a historical study over three decades. *Journal of Applied Ecology*, **39**, 673–687.

Billeter, R., Liira, J., Bailey, D., Bugter, R., Arens, P., Augenstein, I., Aviron, S., Baudry, J., Bukacek, R., Burel, F., Cerny, M., De Blust, G., De Cock, R., Diekoetter, T., Dietz, H., Dirksen, J., Dormann, C., Durka, W., Frenzel, M., Hamersky, R., Hendrickx, F., Herzog, F., Klotz, S., Koolstra, B., Lausch, A., Le Coeur, D., Maelfait, J.P., Opdam, P., Roubalova, M., Schermann, A., Schermann, N., Schmidt, T., Schweiger, O., Smulders, M.J.M., Speelmans, M., Simova, P., Verboom, J., van Wingerden, W.K.R.E., Zobel, M. & Edwards, P.J. (2008) Indicators for biodiversity in agricultural landscapes: a pan-European study. *Journal of Applied Ecology*, **45**, 141–150.

Biodiversity Reporting and Information Group. (2007) *Report on the Species and Habitat Review*. Report to the UK Biodiversity Partnership, JNCC, Peterborough, UK.

Burnham, K.P. & Anderson, D.R. (2002) *Model Selection and Multimodal Inference*. Springer, New York.

CEC. (2006) *Communication from the Commission. Halting the Loss of Biodiversity by 2010 and Beyond: Sustaining Ecosystem Services for Human Well-Being*. Commission of the European Communities, Brussels, Belgium.

Chamberlain, D.E., Fuller, R.J., Bunce, R.G.H., Duckworth, J.C. & Shrubb, M. (2000) Changes in the abundance of farmland birds in relation to the timing of agricultural intensification in England and Wales. *Journal of Applied Ecology*, **37**, 771–788.

Defra (2004). *An Assessment of the Impacts of Hill Farming in England on the Economic, Environmental and Social Sustainability of the Uplands and More Widely*. Defra, London.

Defra (2005a). *Entry Level Stewardship Handbook*. Department of Environment, Food and Rural Affairs, London.

Defra (2005b). *Higher Level Stewardship Handbook*. Department of Environment, Food and Rural Affairs, London.

Defra (2005c). *Farm Incomes in the United Kingdom*. Department of Environment, Food and Rural Affairs, London.

Donald, P.F., Sanderson, F.J., Burfield, I.J. & van Bommel, F.P.J. (2006) Further evidence of continent-wide impacts of agricultural intensification on European farmland birds, 1990–2000. *Agriculture, Ecosystems and Environment*, **116**, 189–196.

EEA. (2004) *High Nature Value Farmland – Characteristics, Trends and Policy Challenges*. European Environment Agency, Copenhagen, Denmark.

Evans, D.M., Redpath, S.M., Evans, S.A., Elston, D.A., Gardner, C.J., Dennis, P. & Pakeman, R.J. (2006) Low intensity, mixed livestock grazing improves the breeding abundance of a common insectivorous passerine. *Biology Letters*, **2**, 636–638.

FAO. (2003) *FAOSTAT Land Use Data Archives*. http://faostat.fao.org/site/418/DesktopDefault.aspx?PageID=418. Accessed April 2008.

Gibbons, D.W., Reid, J.B. & Chapman, R.A. (1993) *The New Atlas of Breeding Birds in Britain and Ireland: 1988–1991*. BTO/SWC/IWC. T. & A.D. Poyser, London.

Gregory, R.D., Wilkinson, N.I., Noble, D.G., Robinson, J.A., Brown, A.F., Hughes, J., Procter, D.A., Gibbons, D.W. & Galbraith, C.A. (2002) The population status of birds in the United Kingdom, Channel Islands and Isle of Man: an analysis of conservation concern 2002–2007. *British Birds*, **95**, 410–450.

Haines-Young, R., Barr, C.J., Firbank, L.G., Furse, M., Howard, D.C., McGowan, G., Petit, S., Smart, S.M. & Watkins, J.W. (2003). Changing landscapes, habitats and vegetation diversity across Great Britain. *Journal of Environmental Management*, **67**, 267–281.

Haines-Young, R., Barr, C.J., Black, H.I.J., Briggs, D.J., Bunce, R.G.H., Clarke, R.T., Cooper, A., Dawson, F.H., Firbank, L.G., Fuller, R.M., Furse, M.T., Gillespie, M.K., Hill, R., Hornung, M., Howard, D.C., McCann, T., Morecroft, M.D., Petit, S., Sier, A.R.J., Smart, S.M., Smith, G.M., Stott, A.P., Stuart, R.C. & Watkins, J.W. (2000) *Accounting for Nature: Assessing Habitats in the UK Countryside*, Department of Environment, Transport and the Regions, London.

Hanley, N., Shogren, J. & White, B. (2007) *Environmental Economics in Theory and Practice*, 2nd edn. Palgrave Macmillan, London.

Hinsley, S.A. & Bellamy, P.E. (2000) The influence of hedge structure, management and landscape context on the value of hedgerows to birds: a review. *Journal of Environmental Management*, **60**, 33–49.

Holt, A.R., Davies, Z.G., Tyler, C. & Staddon, S. (2008). Meta-analysis of the effects of predation on animal prey abundance: evidence from UK vertebrates. *PLoS One*, **3**, 32400.

Huby, M., Cinderby, S. Crowe, A.M., Gillings, S., McClean, C.J., Moran, D., Owen, A. & White, P.C.L. (2006) The association of natural, social and economic factors with bird species richness in rural England. *Journal of Agricultural Economics*, **57**, 295–312.

Hudson, P.J. (1992) *Grouse in Space and Time*. Game Conservancy Trust, Fordingbridge, UK.

Johnson, J.B. & Ohmland, K.S. (2004) Model selection in ecology and evolution. *Trends in Ecology & Evolution*, **19**, 101–108.

Kareiva, P., Watts, S., McDonald, R. & Boucher, T. (2007) Domesticated nature: shaping landscapes and ecosystems for human welfare. *Science*, **316**, 1866–1869.

Kleijn, D. & Sutherland, W.J. (2003) How effective are European agri-environment schemes in conserving and promoting biodiversity? *Journal of Applied Ecology*, **40**, 947–969.

Kleijn, D., Baquero, R.A., Clough, Y., Diaz, M., De Esteban, J., Fernandez, F., Gabriel, D., Herzog, F., Holzschuh, A., Johl, R., Knop, E., Kruess, A., Marshall, E.J.P., Steffan-Dewenter, I., Tscharntke, T., Verhulst, J., West, T.M. & Yela, J.L. (2006). Mixed biodiversity benefits of agri-environment schemes in five European countries. *Ecology Letters*, **9**, 243–254.

Lee, J.A. (1998) Unintentional experiments with terrestrial ecosystems: ecological effects of sulphur and nitrogen pollutants. *Journal of Ecology*, **86**, 1–12.

Marini, L., Fontana, P., Scotton, M. & Klimek, S. (2008) Vascular plant and Orthoptera diversity in relation to grassland management and landscape composition in the European Alps. *Journal of Applied Ecology*, **45**, 361–370.

Millennium Ecosystem Assessment. (2005) *Ecosystems and Human Well-being: Biodiversity Synthesis*. World Resources Institute, Washington, D.C.

Myers, R. (1990) *Classical and Modern Regression with Applications*, 2nd edn. Duxbury, Boston MA, USA.

Naidoo, R. & Iwamura, T. (2007) Global-scale mapping of economic benefits from agricultural lands: implications for conservation priorities. *Biological Conservation*, **140**, 40–49.

Naidoo, R., Balmford, A., Ferraro, P.J., Polasky, S., Ricketts, T.H. & Rouget, M. (2006). Integrating economic costs into conservation planning. *Trends in Ecology & Evolution*, **21**, 681–687.

NEGTAP. (2001) *Transboundary Air Pollution: Acidification, Eutrophication and Ground-Level Ozone in the UK*. Department of Environment, Food and Rural Affairs, London.

Parkhurst, G. & Shogren, J. (2007) Spatial incentives to coordinate contiguous habitat. *Ecological Economics*, **64**, 344–355.

Peach, W.J., Lovett, L.J., Wotton, S.R. & Jeffs, C. (2001) Countryside stewardship delivers cirl buntings (*Emberiza cirlus*) in Devon, UK. *Biological Conservation*, **101**, 361–373.

Peak District Rural Deprivation Forum. 2004. *Hard Times: A Research Report into Hill Farming and Farm Families in the Peak District*. Peak District Rural Deprivation Forum, Hope, Derbyshire, UK.

Pearce-Higgins, J.W. & Yalden, D.W. (2003) Variation in the use of pasture by breeding European golden plovers *Pluvialis apricaria* in relation to prey availability. *Ibis*, **145**, 365–381.

Pocock, M.J.O. & Jennings, N. (2008) Testing biotic indicator taxa: the sensitivity of insectivorous mammals and their prey to the intensification of lowland agriculture. *Journal of Applied Ecology*, **45**, 151–160.

Preston, C.D., Telfer, M.G., Arnold, H.R., Carey, P.D., Cooper, J.M., Dines, T.D., Hill, M.O., Pearman, D.A., Roy, D.B. & Smart, S.M. (2002) *The Changing Flora of the UK*. Department of Environment, Food and Rural Affairs, London, UK.

R Development Core Team. (2008). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Robinson, R. & Sutherland, W.J. (2002) Post-war changes in arable farming and biodiversity in Great Britain. *Journal of Applied Ecology*, **39**, 157–176.

Robson, G., & Percival, S.M. (2002) The use of marginal farmland by curlew *Numenius arquata* breeding on upland moors. *Aspects of Applied Biology*, **67**, 75–84.

Rundlöf, M., Bengtsson, J. & Smith, H.G. (2008) Local and landscape effects of organic farming on butterfly species richness and abundance. *Journal of Applied Ecology*, **45**, 813–820.

Sim, I.M.W., Gregory, R.D., Hancock, M.H. & Brown, A.F. (2005) Recent changes in the abundance of British upland breeding birds. *Bird Study*, **52**, 261–275.

Smith, R.K., Jennings, N.V., Robinson, A. & Harris, S. (2004) Conservation of European hares *Lepus europeaus* in Britain: is increasing habitat heterogeneity in farmland the answer? *Journal of Applied Ecology*, **41**, 1092–1102.

Stillman, R.A. & Brown, A.F. (1994) Population sizes and habitat associations of upland breeding birds in the south Pennines, England. *Biological Conservation*, **69**, 307–314.

Stroud, D.A., Chambers, D., Cook, S., Buxton, N., Fraser, B., Clement, P., Lewis, P., McLean, I., Baker, H. & Whitehead, S. (2001) *The UK SPA Network: Its Scope and Content*. JNCC, Peterborough, UK.

Tharme, A.P., Green, R.E., Baines, D., Bainbridge, I.P. & O'Brien, M. (2001) The effects of management for red grouse shooting on the population density of breeding birds on heather-dominated moorland. *Journal of Applied Ecology*, **38**, 439–457.

Vanslembouck, I., Van Huylenbroeck, G. & Verbeke, W. (2002) Determinants of willingness of Belgian farmers to participate in agri-environmental measures. *Journal of Agricultural Economics*, **53**, 489–511.

Whittingham, M.J. (2007) Will agri-environment schemes deliver substantial biodiversity gain, and if not why not? *Journal of Applied Ecology*, **44**, 1–5.

Whittingham, M.J., Percival, S.M. & Brown, A.F. (2000) Time budgets and foraging of breeding golden plover *Pluvialis apricaria*. *Journal of Applied Ecology*, **37**, 632–646.

Whittingham, M.J., Swetnam, R.D., Wilson, J.D., Chamberlain, D.E. & Freckleton, R.P. (2005) Habitat selection by yellowhammers *Emberiza citrinella* on lowland farmland at two spatial scales: implications for conservation management. *Journal of Applied Ecology*, **42**, 270–280.

Whittingham, M.J., Krebs, J.R., Swetnam, R.D., Vickery, J.A., Wilson, J.D. & Freckleton, R.P. (2007) Should conservation strategies consider spatial generality? Farmland birds show regional not national patterns of habitat association. *Ecology Letters*, **10**, 25–35.
Wickramasinghe, L.P., Harris, S., Jones, G. & Jennings, N.V. (2003) Bat activity and species richness on organic and conventional farms: impact of agricultural intensification. *Journal of Applied Ecology*, **40**, 984–993.
Willock, J, Deary, I.J., Edwards-Jones, G., Gibson, G.J., McGregor, M.J., Sutherland, A., Dent, J.B., Morgan, O., Grieve, R. (1999) The role of attitudes and objectives in farmer decision making: business and environmentally-oriented behaviour in Scotland. *Journal of Agricultural Economics*, **50**, 286–303.
Yallop, A.R., Thacker, J.I., Thomas, G., Stephens, M., Clutterbuck, B., Brewer, T. & Sannier, C.A.D. (2006) The extent and intensity of management burning in the English uplands. *Journal of Applied Ecology*, **43**, 1138–1148.

Received 13 November 2008; accepted 7 January 2009
Handling Editor: Davy McCracken

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Species list and conservation status for all birds recorded on 44 upland farms in the Peak District, Northern England

Appendix S2. Parameter estimates for generalized linear model with Poisson errors and a log link function relating the three measures of species richness to transformed explanatory variables

Please note: Wiley-Blackwell are not responsible for the content or functionality of any supporting materials supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.

ACTIVITIES AND ACHIEVEMENTS QUESTIONNAIRE

1. Non-Technical Summary

A 1000 word (maximum) summary of the main research results, in non-technical language, should be provided below. The summary might be used by the Research Councils to publicise the research. It should cover the aims and objectives of the project, main research results and significant academic achievements, dissemination activities and potential or actual impacts on policy and practice.

SEE ALSO RELU POLICY AND PRACTICE NOTE IF LOOKING FOR TEXT TO PUBLICISE THE RESEARCH TO THESE CONSITITUENCIES.

Upland ecosystems support traditional rural industries like hill farming, are home to emblematic species and habitats of conservation concern, and provide a wealth of ecosystems goods and services. Upland ecosystems that we see today have been shaped by land management practices by farmers and others. However, policies affecting hill farming are in a state of flux. Policy-makers need to understand how ongoing policy changes are likely to affect hill farming communities and ecosystems and whether they can deliver what the public want from the hills. This project examined hill farming in the Peak District National Park as a case study into what is happening in the uplands.

Objectives (from original proposal) **and Relevant Results**
Primary Priority

1. To develop coupled ecological-economic models that predict how representative hill farms will respond to changing framework conditions.

A range of coupled farm-scale ecological and economic models have been constructed that are parameterised with socioeconomic and ecological survey data on a panel of Peak District hill farms. These models have been used to examine the effects of particular policy shifts on hill farms.

For example, one set of analyses, which is published in *Land Use Policy*[1], examines the economic incentives provided to hill farmers by decoupling, finding that the economic incentives this policy provides to farmers encourages:

- a reduction in stocking densities with a shift away from beef cattle.
- a concomitant reduction in the amount of additional labour employed on the farm.
- further specialisation by farms in what they produce.
- but little abandonment of land, with farming likely to continue in a way that keeps the land in “good agricultural condition”.
- little change to farm incomes on average with some farms seeing slight increases in income and others slight losses.

In a second example, we published a discussion of the differences in statistical modelling approaches in ecology and economics and how these might be overcome in *Journal of Applied Ecology*[2] in April.

2. To design modelling techniques that account for economic and ecological interactions among farms:

Measuring spatial ecological and economic interactions among farms and designing policies that encourage farmers to internalise these interactions is a very significant empirical and theoretical challenge that we have begun to address through multiple different elements of the work programme. For example, we have developed a collaboration with RELU Exchange Fellow Professor Jim Shortle in Penn State University and his student, Simanti Bannerjee, which has shown how agrienvironment policy designs (the agglomeration bonus) intended to encourage farmers to cooperate to provide spatial ecological benefits (see below for how these are measured) can be adjusted to overcome technological externalities (sheep trespass) that act in direct opposition to the positive externality. Bannerjee and Shortle are currently testing these policies in a lab setting. The collaboration has also aided the development of additional grant proposals to answer new questions raised by the work.

3. To estimate public understanding of and preferences for contrasting moorland futures…

We have used choice experiments and valuation workshop methodologies to assess what people wanted from the hills and whether they would be willing to pay to achieve that vision. Key findings include:

- Visitors to the Peak District National Park would be willing to pay an additional parking fee to support conservation of key habitats, especially for moorlands, where people would be willing to pay an average of £4 per visit.
- However, residents of towns surrounding the National Park would not be willing for local taxes to increase in order to support further conservation efforts.
- That estimates of people's willingness to pay for environmental goods are affected when respondents are taken to visit exemplar sites, given time to reflect on their choices, or provided with expert witness testimony.

A first manuscript presenting the valuation results is in preparation for publication as a book chapter in International Handbook on Non-Market Environmental Valuation. Future manuscripts examining other elements of these results are also planned.

4. To assess whether alternative policy interventions can deliver a sustainable hill farming economy compatible with moorland conservation

The ecological economic models let us examine how agricultural subsidy schemes can be designed more effectively to provide environmental benefits. In this work, we have been able to derive an estimate of the "true" private costs of providing environmental benefits and from it of the most cost effective policy design for delivering particular conservation benefits. These results are currently in the process of being written up.

Secondary Priority

- To demonstrate whether and how moorland bird species respond to land management practices and landscape features,…

Ecological survey results for moorland fringe habitats were published in *Journal of*

Applied Ecology[3] in June 2009 and demonstrate an important role for socioeconomic characteristics of farms in influencing species richness patterns for birds across properties.

- To describe long-term spatio-temporal patterns in farm production decisions and evaluate how well historical changes in production explain changes in habitat condition and cover.

An analysis of historical data sources for the Peak District was published in *Journal of Applied Ecology*[4] in April 2009 and relates the history of intensification and specialisation of agriculture in the region to very dynamic patterns of habitat change and to stakeholder perceptions of historical changes (a more detailed analysis of the latter and its implications for valuation and policy setting was published as a book chapter[5] in March 2009).

- To quantify the extent to which environmental factors constrain present-day farm production decisions and profitability …

The farm models, ecological and economic data all demonstrate strong subregional environmental signals. We have shown that, as a consequence, policy impacts will be different in different areas and are analysing how policies can be designed to reflect heterogeneous conditions experienced by farms.

Peer Reviewed Publications:

1. Acs, S., Hanley, N., Dallimer, M., Gaston, K.J., Robertson, P., Wilson, P., Armsworth, P.R. 2009. The effect of decoupling on marginal agricultural systems: Implications for farm incomes, land use and upland ecology. Land Use Policy, in press. Published online August 2009 doi:10.1016/j.landusepol.2009.07.009
2. Armsworth, P.R., Gaston, K.J., Hanley, N.D. & Ruffell, R.J. 2009. Contrasting approaches to regression in ecology and economics. Journal of Applied Ecology, 46, 265-268.
3. Dallimer, M., Acs, S., Hanley, N., Wilson, P., Gaston, K.J. & Armsworth, P.R. 2009. What explains property-level variation in biodiversity? Taking an inter-disciplinary approach. Journal of Applied Ecology, 46, 647-656.
4. Dallimer, M., Acs, S., Tinch, D., Hanley, N., Gaston, K.J. & Armsworth, P.R. 2009. 100 years of change: examining agriculture, habitat change and stakeholder perceptions through the 20th century. Journal of Applied Ecology, 46, 334-343.
5. Tinch, D., Hanley, N., Dallimer, M., Posen, P., Acs, S., Gaston, K.J. & Armsworth, P.R. 2009. Historical perspectives on the development of multifunctional landscapes: a case study from the UK uplands. In: Multifunctional Rural Land Management: Economics and Policies. Brouwer, F. & van der Heide, M. (eds.). Earthscan, London, UK, pp. 277-294.

Examples of other Dissemination activities

- More publications in preparation.
- Over 30 conference presentations,
- Project website.

1.6 RELU Research Report

A full report on the research should accompany the completed report form. The report should not exceed 7,000 words in length and should be a succinct, self-contained document, giving a straightforward and critical appraisal of the research in, as far as possible, non-technical language.

Peer reviewed publications

Journal Articles

1. Armsworth, P.R., Gaston, K.J., Hanley, N.D. & Ruffell, R.J. 2009. Contrasting approaches to regression in ecology and economics. *Journal of Applied Ecology*, 46, 265-268.
2. Dallimer, M., Acs, S., Hanley, N., Wilson, P., Gaston, K.J. & Armsworth, P.R. 2009. What explains property-level variation in biodiversity? Taking an inter-disciplinary approach. *Journal of Applied Ecology*, 46, 647-656.
3. Dallimer, M., Acs, S., Tinch, D., Hanley, N., Gaston, K.J. & Armsworth, P.R. 2009. 100 years of change: examining agriculture, habitat change and stakeholder perceptions through the 20th century. *Journal of Applied Ecology*, 46, 334-343.
4. Acs, S., Hanley, N., Dallimer, M., Gaston, K.J., Robertson, P., Wilson, P. & Armsworth, P.R. 2009. The effect of decoupling on a marginal agricultural system. *Land Use Policy*, in press. Published online: August 2009

Book Chapter

5. Tinch, D., Hanley, N., Dallimer, M., Posen, P., Acs, S., Gaston, K.J. & Armsworth, P.R. 2009. Historical perspectives on the development of multifunctional landscapes: a case study from the UK uplands. In: *Multifunctional Rural Land Management: Economics and Policies*. Brouwer, F. & van der Heide, M. (eds.). Earthscan, London, UK, pp. 277-294.

Manuscripts currently in preparation

Currently in manuscript form or being written up

i) Dallimer, M., et al. 2009. Multiple habitat associations: the role of off-site habitat in determining on-site avian species density. Submitted.

ii) Dallimer, M. et al. 2009. The ecological effectiveness of agrienvironment schemes at field and landscape-scales. In development.

iii) Acs, S. et al. 2009. Linking biodiversity, land-use and incomes at the farm level: an interdisciplinary modelling approach. In development.

iv) Armsworth, P.R. et al. 2009 Failure to account for farmers' behavioural responses undermines incentive payments for biodiversity conservation. In development.

v) Banerjee, S. et al. 2009. Effectiveness of the Agglomeration Bonus in the presence of technological interdependencies: A case study of the Peak District (UK). In development.

vi) Tinch, D., Hanley, N. 2009. Decision versus experienced utility: an investigation using the choice experiment method. Invited book chapter contribution for International Handbook on Non-Market Environmental Valuation. In development.

Additional analyses are still under way and planned and will be developed into publications in due course.

Presentations and Seminars

1. Project Team 18/01/06. Poster presentation. A Landscape-scale Analysis of the Sustainability of the Hill Farming Economy and Impact of Farm Production Decisions on Upland Landscapes and Biodiversity. Rural Economy and Land Use: Enabling Knowledge Exchange. Manchester.
2. Armsworth 19/01/06. Discussant. Constructing Evidence for Public Policy. Rural Economy and Land Use: Enabling Knowledge Exchange. Manchester.
3. Project Team 20/01/06. A Landscape-scale Analysis of the Sustainability of the Hill Farming Economy and Impact of Farm Production Decisions on Upland Landscapes and Biodiversity. Rural Economy and Land Use: Enabling Knowledge Exchange. Manchester.
4. Hanley 16/03/06. Debate. Farming's no place for wildlife. Rural Economy and Land Use Debates. London.
5. Armsworth and Dallimer 09/10/06. Hill Farm Economics, Landscapes and Biodiversity in the Peak District. Breeding Birds of the Peak District Moorlands. Edale.
6. Hanley and Colombo 09/11/06. Valuing the Uplands. Moors for the Future: Upland Ecosystem Services. Castleton.
7. Project Team 10/11/06. Hill Farm Economics, Upland Landscapes and Biodiversity. Moors for the Future: Upland Ecosystem Services. Castleton.
8. Acs S, 16th May 2007. "Impacts of Policy Reform on Sustainability of Hill Farming", RELU Conference - Research on Rural Resource Management and the Rural Economy: Addressing the Local Dimension, Edinburgh.
9. Dallimer M, 10th September 2007 "The Impact of Hill Farming on Upland Bird Communities in the Peak District", BES Annual Conference in Glasgow.
10. Acs S, 1st October 2007 "Sustainability of Hill Farming in the Uplands" RELU Workshop - Farm Production Modelling, Sheffield.
11. Acs S, Dallimer M, 20th Nov 2007 "The Economics of Hill Farming and its Contribution to Supporting Biodiversity", Moors for the Future Annual Conference - Climate Change and Upland Management, Castleton.
12. Hanley N, November 2007. Seminar, CEMAGREF, Montpellier.
13. Hanley N, December 2008. Seminar, Resource and Agricultural Economics Department, UWA, Perth.
14. Acs S, 3-6th December 2007 "Impacts of Policy Reform on Sustainability of Hill Farming in UK", Tradition and Innovation International Conference, Gödöllö, Hungary
15. Presentation: Acs S, 16th May 2007. "Impacts of Policy Reform on Sustainability of Hill Farming", RELU Conference - Research on Rural Resource Management and the Rural Economy: Addressing the Local Dimension, Edinburgh.
16. Poster: Tinch D, 16th May 2007. "Historical Drivers of Change in the Peak District National Park" ", RELU Conference - Research on Rural Resource

Management and the Rural Economy: Addressing the Local Dimension, Edinburgh.

17. Presentation: Acs S, Dallimer M, 20th Nov 2007 "The economics of hill farming and its contribution to supporting biodiversity", Moors for the Future Annual Conference - Climate Change and Upland Management, Castleton.
18. Workshop participation: Armsworth, P 11th Dec 2007 RELU Land Use Commission, London
19. 01/08. Impacts of policy reform on sustainability of hill farming in UK by means of bio-economic modelling. 107th Seminar of the EAAE, Modelling Agricultural and Rural Development Policies, Sevilla, Spain.Presenter: Acs.
20. 01/08. Valuing an upland ecosystem using choice experiments. Scottish Graduate Programme in Economics, Edinburgh. Presenter: Tinch.
21. 06/08. Effectiveness of the Agglomeration Bonus in the presence of technological interdependencies: A case study of the Peak District (UK). Presented at the Annual NAREA/ CAES meetings.Presenter: Bannerjee.
22. Moors for the Future's 5th Research Day, 20 June 2008, Bakewell. Title: Effects of subsidy changes on hill farm production decisions, income and biodiversity. Authors: Acs et al.
23. Moors for the Future's 5th Research Day, 20 June 2008, Bakewell. Title: Valuation of upland landscapes and biodiversity. Authors: Tinch et al.
24. NE Board Workshop on Ecosystem Services, 24/06/08, Sheffield. Title: Ecosystem Services. Authors Armsworth et al.
25. RELU / CCF The Future of Farming, 03/07/08, Cambridge. Title: The Future of the Uplands. Authors: Armwsorth et al.
26. 09/08 Incentive mechanisms for landscape management: the Agglomeration Bonus with technological externalities in different neighborhoods. Presented at 10th Annual Bioecon Conference, Cambridge. Presenter Bannerjee.
27. 09/08. Incentive mechanisms for landscape management and habitat conservation: the Agglomeration Bonus and the Agglomeration Reverse Auction. Department of Economics, University of Stirling. Presenter: Bannerjee. (Authors: Bannerjee, Shortle, Kwasnica, Armsworth, and Hanley).
28. 09/08. Incentive mechanisms for landscape management and habitat conservation: the Agglomeration Bonus and the Agglomeration Reverse Auction. Department of Animal and Plant Sciences, University of Sheffield. Presenter: Bannerjee.
29. 10/08. Future impacts of agriculture on biodiversity and socio-economics in the UK uplands. Seminar, TEAGASC, Athenry, Ireland. Presenter: Hanley.
30. Moors for the Future, Upland Research Forum, 25/11/08, Castleton. Title: Hill Farm Economics and Biodiversity in the Peak District. Authors: Armsworth et al.
31. 03/09. Hill-Farming and Biodiversity: an analysis for the Peaks. Presented at RELU conference on Rural Land Use in the North: Future Challenges, York. Presenter: Nick Hanley.
32. 04/09. Linking biodiversity, land-use and incomes at the farm level: an interdisciplinary modelling approach. Presented at Agricultural Economics Society Conference, Dublin, Ireland. Presenter: Hanley.

33. Evidence to Commission on Rural Communities, 20/03/09, Alnwick. Presented by Philip Lowe on behalf of the project
34. Relu: The Future of Rural Land Use, 04/06/09, London. Title: The Future for the Uplands. Authors: Armsworth et al.
35. Moors for the Future's 6th Research Day, 07/07/09, Bakewell. Title: Sustainable hill farming. Authors: Armsworth et al.
36. European Congress of Conservation Biology, 03/09/09, Prague. Title: The implications of agricultural change on avian diversity and the economics of upland farming. Authors: Dallimer et al.

BACKGROUND

Uplands ecosystems contain many unique ecological community types and support many species of conservation interest (Thompson et al. 1995). For example, eight upland bird species are red-listed and thirty-one are amber-listed (BTO 2005). Despite their ecological value, large areas of upland habitat deteriorated throughout the last century, due in part to the steady intensification of hill farming (Anderson & Yalden 1981, Tudor & Mackey 1995) and these areas continue to experience widespread habitat change (Haines-Young et al. 2003). The ecological consequences of such a dramatic shift in land-use are marked, and substantial declines in upland breeding bird populations continue (Sim *et al*. 2005).

Many upland ecosystems are semi-natural and have been shaped by centuries of human exploitation. As such, the current condition and future of these ecosystems and the species that inhabit them depends in part on the land management actions of hill farmers and others. Production possibilities for farmers in the uplands are tightly constrained by climate, topography and soil productivity. Livestocking is the main farm enterprise Recently, hill farm incomes in the UK have fallen dramatically in response to lower lamb and beef prices (Defra 2005) and the viability of upland farms often depends on subsidy support (Peak District Rural Deprivation Forum 2004). The form of government subsidies has been changing. In 2005, the Single Farm Payment replaced previous headage payments and decoupled core support from production decisions. Hill farmers also depend on other subsidy schemes, notably agrienvironment schemes and the Hill Farm Allowance (HFA), which themselves are in flux. Over the longer term the future of agricultural subsidies depends on maintaining public support for these policies, which in turn will depend on the ability of the subsidy schemes to deliver what people want to see from upland areas.

We used the Peak District National Park as a case study to examine the impact of hill farming practices on upland biodiversity (using birds as an indicator group); how hill farms were responding to ongoing and future changes to policies and prices; what this would in turn imply for upland biodiversity; what the public wanted from upland ecosystems and how policies could be designed better to deliver public goods from hill farms.

To answer these questions, we conducted ecological and economic surveys on hill farms; used survey results to parameterise ecological and economic models of this farming system; developed new ways to integrate these into coupled ecological and economic models and paid particular attention to interactions across farm and habitat boundaries; used the models to evaluate the performance of existing policies and to test designs that could lead to more effective policies; and conducted a range of choice experiments with different cross-sections of the general public to evaluate their preferences for upland landscapes.

METHODS: DATA COLLECTION

Primary Data

Sample Farms:

Ecological and economic surveys were conducted on a panel of 44 farms, where the main landholding fell within 2 km of the Moorland boundary within the Peak District National Park. We know of no comparable published datasets that present a detailed micreconomic description of the state of farm businesses and the biodiversity on the same properties at the same time.

Economic Surveys

A questionnaire based survey was designed and carried out with the help of experienced farm business researchers through the winter months of 2006/2007. The survey included questions on land area, land types and use, production activities and subsidy payments received during the reference period of 2006.

Ecological Surveys

Walking transects and distance sampling were used to survey all bird species on farms and on 37 paired moorland areas nearby. On average, 95.0ha (SD = 66.7ha) of farmland was surveyed per property, with an average 1651m (SD = 561m) of transect walked. Moorland bird surveys were carried out by walking two parallel transects (total length 2km) on a 1x1km square (100ha) near to each farm. Birds were only included as present if they were seen or heard within the property, irrespective of the distance from the transect. Bird surveys were carried out on two separate visits in Spring-Summer 2007. Distance sampling allows estimates of bird densities to be obtained while controlling for differences in detectability of the different species.

We conducted habitat surveys within the farmland and moorland areas. In farmland, each surveyed field was characterised according to whether it was improved grassland, cut for silage or hay in the year of the survey, the proportion of the field boundaries that were vegetated with hedges or woodlands, the number of trees present in the surveyed fields, the proportion of rush cover and the proportion of fields with wet features. To assess moorland habitat, quadrats (50 x 50 cm) were placed every 100m along four parallel transects 200m apart (44 per survey square). In each quadrat, vegetation height, vegetation cover, and whether or not managed burning had been conducted, were recorded.

We also conducted intensive behavioural observations of a species of particular interest to upland conservation, the Eurasian curlew (*Numenius arquata*), during its 2008 breeding season. Vantage-point watches of focal individuals were carried out at five sites covering the eastern edge of the Peak District, noting movements and behaviour. Individual behaviour was recorded every minute for as long as the bird remained in view, for a minimum of ten minutes. For each movement (any flight or directional walk that did not involve foraging), the habitat type at the start and end points was recorded along with the six-figure grid references of each start and end point by reference to physical features using laser rangefinder and compass.

Valuation Workshops

We administered choice experiments through a workshop approach (Alvarez-Farizo and Hanley, 2006). In total 385 participants completed the choice experiment drawn from three different stakeholder groups (local residents, visitors and farmers). All policies under consideration were changes to agri-environmental schemes to reduce or increase management intensity, but not to abandon farmland. The choice experiment included five choice attributes: intensity of management in three habitat areas - moorland, moorland fringe and valley bottom farmland; footpath network quality; and a payment vehicle, (e.g., annual household tax increases for local residents). In relation to biodiversity impacts it was posited to participants that less intensive management would lead to a greater variety of habitats and species. Six levels were selected for the payment vehicle; other attributes had three levels (e.g., more intensive management, no change, less intensive).

Secondary Sources

Historical records on agricultural change and land cover change were collated to help put the results of our own data collection efforts and model predictions in context. Changes in agricultural practice were derived from the June Agricultural Census (JAC). Data were collected every 10 years from 1900 to 2000 and for the years 1914, 1932, 1966 (broadly relating to when habitat and land-use maps were available; see below) and 1988 (to ensure that the full time span of parish data were used). Data from 32 parishes (for 1900 to 1988, and 22 wards for 2000) were collated. The area of agricultural land ascribed to each parish changed between years, as JAC data include all agricultural activity registered to properties within a particular parish. Parish boundaries themselves also altered. To overcome the effect of shifting agricultural area, all variables were converted to a per-hectare basis, or as a proportion of the overall land area.

At the time this project component was undertaken, habitat maps were available from 1913 (Moss 1913), 1940 (Ordnance Survey 1952), 1978/1979 (Anderson & Yalden 1981; Anderson 1983), 1990 (Barr *et al.* 1993), and 2000 (Haines-Young *et al.* 2000). The complete area featured in all maps was 891 km^2 and covered the northern portion of the Peak District National Park. Each habitat map used a different set of vegetation types and definitions. However, these were assigned to new common categories that were consistent across the set of surveys (Dwarf Shrub Moor, Acid Grassland, Scrub, Urban, Inland Water and Woodland). All other land types, whether they were primarily agricultural or semi-natural, were not compatible across the habitat maps and were hence included in a single category 'All Other Land'. Although cotton grass represents a major semi-natural habitat type, it was not consistently mapped through the study period, and therefore, we were not able to consider it in detail. To assess habitat change, a 50 × 50 m grid was placed over the survey area. A random sample of 1% of these grid squares (3452 in total) was selected and examined for every map. Each grid square was ascribed a habitat category, based on the predominant habitat type for that cell. For every available year, the number and proportion of squares that belong to each habitat type were recorded.

OBJECTIVE 1

To develop coupled ecological-economic models that predict how representative hill farms will respond to changing framework conditions.

Methods: Economic models
The economic survey results were used to develop and to parameterise a set of linear programming models that estimates the economic incentives presented to farmers by different policy changes. Versions have been created that are tailored to different types of farm as measured by enterprise mix, different types of farm by region, and whole-region models.

Results: Economic models
One set of analyses of these economic models examines the economic incentives provided to hill farmers by decoupling and the switch to the Single Farm Payment. These analyses demonstrate that decoupling results in little change to farm incomes on average with some farms seeing slight increases in income and others slight losses, and that the economic incentives provided by the new policy encourages farmers to:

- reduce stocking densities
- shift away from beef cattle
- reduce the amount of additional labour employed on the farm
- further specialise in what they produce.
- but not abandon land, but rather to keep farming in a way that keeps the land in "good agricultural condition".

Moreover the analyses suggest that agrienvironment schemes and the Hill Farm Allowance played an important role in moderating the influence of decoupling, by lessening the impact on farm incomes and encouraging greater reductions in stocking raqtes of beef cattle than would otherwise have occurred. These core economic predictions are in press in *Land Use Policy* (**Acs et al. 2009**). The sensitivity of these results to price variation was also considered.

Methods: Ecological models
The ecological survey data were used to construct statistical regression based models relating land management changes (stocking rates, fertiliser application, etc.) to responses of the bird community and of individual bird species (**Dallimer et al. 2009a**). Throughout information theoretic approaches to model simplification and multi model inference were followed. Different study questions required differing degrees and types of non-linearity to be considered in these models.

Results: Ecological models
Summarised in response to Objective 5 below.

Methods: Coupled ecological and economic models
The two sets of models were combined to arrive at coupled ecological and economic models for exploring the implications of policy and price changes for hill farm businesses and upland biodiversity. Two different approaches were taken, each answering different questions. The first approach considers discrete policy or pricing scenarios changes. The second modelling approach focuses on decision-making at the margin and is better suited for studying incremental changes to policies or prices.

The first (discrete policy change) approach simply enters the changes in land management variables predicted under different policy and pricing scenarios into the statistical regressions predicting likely responses of the bird community.

The second marginalist, approach involved generalising the models using nonlinear programming techniques that allowed the biodiversity response function to be entered directly into the farm production decisions just like conventional agricultural inputs and outputs. In effect, it modelled farmers as producers of biodiversity just as they are producers of livestock and milk. With the relevant input data, the techniques developed in this part of the grant could readily be generalised to consider the production of other goods and services (improvements in water quality, changes to soil carbon storage, etc.) from farms.

Results

Analyses of both sets of coupled models is ongoing and two papers (one presenting each modelling approach) are currently in preparation. Analyses of discrete policy and pricing changes (like the switch from headage payments to the Single Farm Payment) make very apparent that simple generalities about the implications for biodiversity are unlikely to be obtainable. Rather a given policy change will likely benefit some species and community indices, but will negatively impact others, reflecting the differing ecological requirements that different species have. Moreover, the impacts also vary across farm types and regions adding further complexity to the results.

With the nonlinear programming models, we have been able to build trade-off curves that allow us to identify locations where biodiversity gains can be made in particular biodiversity measures at relatively little cost in terms of farm profitability, after accounting for adaptation on the part of farmers to any requirements to provide particular biodiversity benefits. One early lesson from the development of these trade-off curves however, is that trying to pursue multiple biodiversity targets simultaneously with a single policy, limits the prospects for finding such win-win scenarios. A second early lesson suggested by comparing the trade-off curves obtained when trying to buy improved conservation of individual species versus improvements to whole community measures is that low cost biodiversity gains are easier to come by when targeting individual species, whereas biodiversity gains are more costly when trying to improve whole community measures of biodiversity (such as species richness or the total density of birds).

As an interdisciplinary team, we have learned a great deal about different modelling approaches by bringing ecologists and economists together, an experience we have tried to share with other teams in the RELU program by organising cross-team meetings (see below). We have also published a perspective piece (**Armsworth et al. 2009**) in *Journal of Applied Ecology* that aims to open up a discussion of some of these difference in modelling philosophies and practices across the disciplines to the wider community.

OBJECTIVE 2

To design modelling techniques that account for economic and ecological interactions among farms.

Ecological interactions across the landscape

When examining ecological interactions across the landscape, we first focused on ecologically or geographically meaningful spatial units (e.g., habitat boundaries, circular buffers). The measurements we obtained from these spatial units can then be used to derive estimates of the importance of movements that cross property boundaries and the potential ecological pay-offs that can be obtained through spatially coordinated conservation actions among farmers.

Spatial Covariation in Bird Densities Across Habitats

Across both habitat types, 90 species were observed. Of these, 83 occurred on farmland, 50 on moorland and 43 species were shared between the two habitat types. We examined spatial covariation of bird abundance between habitats for three whole community measures (the density of all bird species, all upland specialist species and all species of conservation concern that were found in both habitats) and for nine individual species: three upland specialists (snipe *Gallinago gallinag*; Eurasian curlew *Numenius arquata* and meadow pipit *Anthus pratensis*), four species of conservation concern (willow warbler *Phylloscopus trochilus*, common linnet *Carduelis cannabina*, reed bunting *Emberiza schoeniclus* and skylark *Alauda arvensis*) and two widespread and common species (carrion crow *Corvus corone* and winter wren *Troglodytes troglodytes*).

For the individual species, a correlation between bird density on moorland and farmland sites ranged from -0.08 (ns) for skylark to 0.42 ($p<0.05$) for the carrion crow. Community-level (Total, Upland or Conservation Concern) densities were all negatively correlated between paired sites, although none of the relationships were significant.

We then tested how well on-site habitat variables explained variation in bird abundance (e.g., how well moorland habitat variables explained spatial variation in the density of linnet across moorland sites) relative to offsite habitat variables (e.g., how well farmland habitat variables explained spatial variation in linnet density on nearby moorland). We used information theoretic approaches to seek parsimonious explanations for variations in bird abundance.

When considering partial r^2 (a measure of the amount of variation in density that is explained) for farmland densities, between 0 (for the reed bunting) and 0.15 (Eurasian Curlew) of the total variation was explained by off-site moorland habitat characteristics. For a single species (common linnet) a greater proportion of their variation on farmland was explained by off-site than by on-site habitat characteristics. For birds on moorlands, between 0.03 (skylark) and 0.23 (linnet) of the total variation in moorland species densities was explained by off-site habitat characteristics. In five cases, more of the variation in density was explained by off-site variables than on-site variables.

Proportion of the surrounding landscape in agrienvironment schemes

Additionally in analyses that are currently in review, we examine how field-scale measurements of bird abundance (of individual species and of groups of species) are affected by the proportion of the surrounding landscape within a 500m buffer that is in a semi-natural state and is included in agrienvironment schemes. Results of these analyses indicate that the abundance of upland specialist species in fields increases with the proportion of the surrounding landscape that is covered by AES and that is semi-natural, effects are more marked for fields that are semi-improved. Early results also indicate that half of the species we have analysed to date are more abundant where the landscape has a high proportion of AES coverage, and all but two species are more abundant as the landscape was increasingly semi-natural.

Direct observations of curlew movements and behaviour

Twenty-five curlew pairs were identified across the study sites. Behavioural observations covered over 110 hours on 216 separate occasions. In total, 652 movements were recorded; a quarter of these were between inbye (improved and semi-improved fields) and moorland habitats. Movement length ranged from 4m to 1400m, and were significantly longer between habitat types than within. The proportion of time spent carrying out the four major activities varied between moorland and inbye habitats. A greater proportion of time was spent foraging on farmland than moorland (63% compared to 33%). While on moorland, curlew spent a greater proportion of time loafing (29%), being vigilant (19%) and carrying out reproductive behaviour (5%).

Modelling ecological and economic interactions among farms

To address economic interactions among farms, we have developed models in collaboration with RELU Exchange Fellow Professor Jim Shortle in Penn State University and his student, Simanti Bannerjee. The models are designed to be parameterised on the cost side from the results of the whole farm LP models described under objective 1 and the evidence for ecological benefits from landscape coordination across farms described above. In the models, the continuous control choices examined in the LP model are ‘packaged’ into discrete choices (e.g., enter AES on moorland or not), from which the relevant Nash pay-off matrices can be constructed. We have developed a stylized geometry of hill farms, which captures essential dynamics of a number of regions within the Peak District, while allowing sufficient simplification to enable computation of the many Nash equilibria involved in the spatial game.

The work we have undertaken with Shortle and Bannerjee to date examines how agrienvironment policy designs intended to encourage farmers to cooperate to provide spatial ecological benefits (the agglomeration bonus) must be adjusted to overcome technological externalities (sheep trespass) that act in direct opposition to the positive externality to be effective. The results of these models are written up in manuscript form and was presented at the BioEcon and NAREA conferences last year. Further analyses and model development are still ongoing

Bannerjee and Shortle are currently testing these policies in an experimental lab setting. The collaboration has also aided the development of an additional grant proposal. If funded, this follow up proposal would enable us to replicate these experimental economics in the field with our survey farmers and would also answer new questions raised by the work about the trade-off encouraging cooperation among farmers to capture spatial externalities and requiring competition among farmers to overcome adverse selection problems in scheme design.

Objective 3

To estimate public understanding of and preferences for contrasting moorland futures…

Methods: contrasting valuation estimates across stakeholder groups

We used the Choice Experiment technique to assess what people wanted from the hills and whether they would be willing to pay to achieve that vision. Similar experiments were conducted with 50 residents from villages surrounding the park, 305 visitors to the park and 30 farmers in order to determine if different user groups valued the park's environmental resources in divergent ways. Data were analysed using Error Component Logit Models from which implicit prices were estimated. It was necessary to adopt different payment vehicles for different groups, so comparison relied upon the relative weight placed on different choice features.

Results: contrasting valuation estimates across stakeholder groups

Key findings include:

- Different user groups have divergent preferences for management in the park
- Visitors to the Peak District National Park would be willing to pay an additional parking fee to support conservation of key habitats, especially for moorlands, where visitors would be willing to pay an average of £4 per visit.
- However, residents of towns surrounding the National Park would not be willing for local taxes to increase in order to support further conservation efforts.
- No user group (Local Residents, Visitor or Farmers) would like to see increased management intensity within the National Park boundaries with all groups stating a Willingness to Pay to avoid such management.

Methods: the role of experience and reflection in determining valuation estimates

We also tested methodological questions regarding the reliability and interpretation of valuation estimates derived through these approaches. Specifically, we tested the role of experienced versus anticipated utility and time for reflection on valuation estimates obtained using several experimental treatments with the same participants (**Tinch & Hanley, in prep.**).

<u>Treatment 1</u> (baseline) was run in a local hall prior to the visit to the National Park and represents the value derived in most choice experiments (and other stated preference techniques), since it is based on information given to participants through description, visual images and aurally.

<u>Treatment 2</u> (experienced utility) aims to identify the impact of the moment of experience of landscape on values, and was conducted on site where a representative series of landscapes could be seen. Participants were driven to the Park and shown the landscape characteristics which they were valuing in the choice experiment. Individuals could identify the impacts of management changes without needing to rely on their own anticipation of changes and (to some extent) anticipation of adaptation to landscape changes. Participants were shown landscape features characteristic of each proposed level for each attribute, and were asked to identify those features relevant to the combinations presented in the choice before them.

<u>Treatment 3</u> (Remembered 1) was conducted upon return to the village hall on the same day as the site visit.

<u>Treatment 4</u> (Remembered 2) was administered during a second workshop held four months after the first.

Results of the choice experiments were analysed using both the nested logit model and error component model. Complete Combinatorial Convolutions Methodologies and the Johnson and Duke Test for Transfer Errors were adopted to analyse differences in preference between treatments.

Results: the role of experience and reflection in determining valuation estimates
We found differences between treatments showing that preferences are impacted by both experience and memory. We found consistency in the results between an initial WTP (first treatment) and the final (fourth treatment) WTP which to all intents and purposes remained the same. However, upon visitation and experience of management in the National Park mean WTP values fell by almost half for current levels of management intensity over a general shift to more OR less intensively managed landscapes. This result suggests that experience has an impact on the preference for environmental goods. While memory led to a shift in mean willingness to pay to an intermediary level between the 2^{nd} and 3^{rd} treatments in the short term and between the 3^{rd} and 4^{th} treatments in the longer term. In our case, this seems to mitigate the impact of experience all together.

Objective 4

To assess whether alternative policy interventions can deliver a sustainable hill farming economy compatible with moorland conservation

The coupled ecological economic models described under Objective 1 that take a marginal approach to understanding policy changes are specifically designed to allow us to examine the effectiveness of alternative policy designs. From the trade-off curves between farm profit and particular biodiversity benefits that we construct, we can derive the theoretically optimal (i.e., most cost effective) incentive payment that one would need if trying to purchase a given level of improvement in biodiversity from a farmer. This optimal policy accounts for adjustment in the farm enterprise when setting incentive payment levels, which, if unaccounted for, allows farms to claw-back substantial revenue and leaves them over-compensated for actions that they undertake. The optimal policy varies by region, with the amount of a given biodiversity target provided on the farm, and with different choices of biodiversity target(s).

This most cost effective scheme design would be very hard to implement. However, with it, we are able to evaluate the cost incurred (either in terms of the overall economic cost of the scheme or the amount of biodiversity provided for a given budget) when employing simpler but more manageable scheme designs, such as spatially uniform payments, or fixed payments per unit biodiversity target produced on a given farm. These analyses are still under way, but early results suggest that some simplifications to scheme design can greatly reduce effectiveness (by up to 70 or 80%) and those that are most costly are those that preclude an agrienvironment scheme design from exploiting a low-cost biodiversity gain identified in the trade-off curves.

Secondary Priority: Objective 5

To demonstrate whether and how moorland bird species respond to land management practices…

Results that describe individual species and cross-habitat movements are summarised under Objective 2. Here we focus on the response of species richness based measures of bird diversity to land management practices within a given habitat type. Early this year, we published a first paper presenting ecological survey results that focused on what explained patterns of species richness (all species, upland specialist species, and species of conservation concern) across farms (**Dallimer et al. 2009b**)

Farm management variables, including many of the main prescriptions outlined in AES, accounted for 23% of the variation in the richness of species of Conservation Concern, but less than 10% for Total Richness. However, no farm management variable alone was shown to offer better predictive power of avian species richness than random. Importantly, Agri-Environment Scheme payments also did not play a significant role in predicting species richness.

Also Landscape context variables (proportion of different habitat types in a 500-m buffer around each property) offered little explanatory power for all three measures of species richness.

Instead within-property habitat quality explained 42% of the variation in richness of upland specialist species with fewer species where more fields were mowed for silage or hay, and more species with increasing numbers of cows and proportion of field with rush cover. But within-property habitat quality had no influence on Total or Conservation Concern Richness. Interestingly socio-economic circumstances of farms alone accounted for 24% of the variation in Total Richness, with land tenure and labour inputs important predictors of this measure of avian diversity.

Objective 6

To describe long-term spatio-temporal patterns in farm production decisions and … habitat condition and cover.

We published a study examining long-term changes in agricultural production and habitat change in the Peak District in the *Journal of Applied Ecology* in April 2009 (**Dallimer et al. 2009b**). In the paper, we also include a summary of discussion with stakeholder about their perspectives on historical changes in the region that are written up in more detail in a recent book chapter (**Tinch et al. 2009**).

Headline messages from these analyses include that since 1900:
- sheep numbers maintained by farms in the hill parishes increased five-fold.
- medium sized farms decreased in numbers as large farm businesses and hobby farmers emerged.
- farming simplified as traditional mixed enterprises disappeared (as evidenced by a loss of small oat fields, losses of horses kept on farm, etc,), resulting in increased specialisation in livestocking.
- the amount of labor employed on farms remained relatively constant, because the steady intensification of agriculture offset the labour reductions per unit output made possible by technological improvement.
- upland ecosystems are dynamic with high turnover rates among habitat types. E.g., despite a stable percentage of squares being occupied by dwarf shrub moor between

1913 and 2000, only 55% of the squares classified as dwarf shrub moor in 1913, retained this classification in 2000.

When comparing these trends in historical records with stakeholder perceptions revealed through workshop activities, we found that some stakeholder perceptions accorded well with the available historical evidence, such as the major intensification of sheep farming. However, other stakeholder perceptions' were at odds with the historical records, for example those concerning the dynamic nature of vegetation changes and the patterns in agricultural labour. In discussing the relevance of this disconnect between stakeholder perceptions and available historical evidence, we noted that if policies do not address those drivers that stakeholders see as important for underpinning trends in land-use, land cover or rural jobs and incomes, then it will be harder to achieve a high level of acceptability for particular policies. This can lead to low levels of uptake and higher implementation costs (e.g. legal fees and monitoring).

Objective 7

To quantify the extent to which environmental factors constrain present-day farm production decisions and profitability and determine the relationship between current production, profitability and habitat quality.

We have not prepared manuscripts specifically addressing the role of environmental constraints on production choices, but rather have woven this regional, environmental perspective throughout the analyses detailed above.

For example, among the different types of farm production model that we have developed , we have specifically developed a family of models that examines regional variation in farm profitability across different regions within the National Park. These regions were identified a priori based on their ecological and physical characteristics (particularly wetness and elevation gradients) and the different models are then developed by grouping the economic survey results to these regions when deriving parameter estimates. There are clear shifts in profitability and enterprise mix across the different regions. This methodology is particularly important when seeking to integrate the farm production model with the ecological models (Objective 1), because the ecological models themselves are strongly influenced by the response of birds to these broad-scale environmental patterns. We have shown in our policy evaluations (discrete policy change scenarios) using these models how predictions about policy impact on land management choices, farm incomes, or biodiversity demonstrate heterogeneity across these regional gradients. In our examinations of cost effective agrienvironment scheme design, we have quantified the cost incurred if policies fail to account for this regional, environmental variation.

While this objective explicitly focuses on present day environmental variation, the data collated for the historical analyses of agricultural and habitat change allow consideration of spatio-temporal environmental variation (e.g., Fig. 1 in **Dallimer et al. 2009b**), something we have begun to explore but that could be developed further.

INTERDISCIPLINARITY

A description of how the interdisciplinary aspect of the project was designed and managed, and the contributions made to interdisciplinary research.

As is apparent from the project design, activities and results, this is a fundamentally interdisciplinary project, which has had a particular emphasis on the integration of ecology and economics. The design, collection and analysis of all datasets involved active input from both ecological and economic staff as did the design and analysis of the modelling that was undertaken. Research products (including publications and research presentations) have been coauthored by staff coming from ecological and economic backgrounds and have been published in interdisciplinary outlets.

Management of interdisciplinarity was made easier by the relatively compact nature of the project team and the prior experience of all PIs and Co-Is in past interdisciplinary work. The new interdisciplinary collaborations forged in this project are continuing now it has been completed and various combinations of the investigator team have submitted three joint grant applications within the past year (at least one of which has been funded – see below.)

Contract research staff participated in interdisciplinary training days early in the project and have gone on to secure positions in interdisciplinary science on completion of their contracts (e.g., M. Dallimer is now employed as part of an interdisciplinary EPSRC SUE 2 consortium where he is examining well-being benefits provided by biodiversity in urban river corridors).

Despite the past experience of project staff in interdisciplinary working, new lessons had to be learned by all staff about interdisciplinarity. We recognise the intellectual value in that learning process itself and have endeavoured to share those lessons with the wider research community. For example, in April 2009, we published a commentary in the *Journal of Applied Ecology* that discusses different emphases given by ecologists and economists to the assumptions that underpin statistical regression techniques (**Armsworth et al. 2009**). In a second example, we organised two technical workshops examining farm production modelling techniques to which we invited staff involved in modelling from other RELU projects.

- Farm Production Modelling workshop, 1st October 2007, Sheffield. Project staff organised, ran and participated in a meeting of RELU researchers on Farm Production Modelling in Sheffield on the 1st of October. Eighteen researchers met to discuss approaches being taken to farm production modelling in six different RELU projects (The Sustainability of Hill Farming, Modelling the Impacts of the Water Framework Directive, Sustainable Uplands: Frameworks for Adaptive Management, Integrated Management of Floodplains, Management Options for Biodiverse Farming, Implications of a Nutrition Driven Food Policy for the Countryside). Funding for the meeting was provided through the Programme Directorate. The meeting also gave new RELU International Exchange Fellow Professor Shortle an opportunity to meet with each project. During his stay, Professor Shortle also visited field sites in the Peak District and explored more focused opportunities for collaboration with our project staff.

- Farm Production Modelling Workshop 2, 30/06/08, Technical workshop on how farm production modelling techniques can be integrated with other activities within the programme including Exchange Fellow Jim Shortle plus representatives from two other RELU teams (Sutherland and Hubacek)

KNOWLEDGE TRANSFER, USER ENGAGEMENT AND IMPACTS

We have undertaken 6-8 outreach activities per year for / with different stakeholder audiences and organisations through the life of the project. These include formal presentations, running workshops face-to-face meetings / visits by the project team, production of bespoke reports and written materials, etc. We highlight some examples only below.

1. Rural Economy and Land Use Programme Project Launch. 27/02/06. Castleton. Joint project launch run in collaboration with the Hubacek-led RELU project and Moors for the Future. As well as featuring a presentation from both project teams, the event also featured presentations from the Chief Executive of the Peak District National Park Authority, the RELU Programme Director and the head of Moors for the Future and a discussion panel. 80 delegates registered for the meeting representing 25 stakeholder organisations and 10 research institutions.

2. Historical Drivers of Change Workshop at the Moors for the Future: Upland Ecosystem Services Conference. 10/11/06. Castleton. In collaboration with the Hubacek-led RELU team, we organised parallel RELU workshop sessions at this conference. Paul Rose from JNCC and the RELU Strategic Advisory Committee opened the session. Paulette Posen from the Bateman-led RELU project also participated. The session included a short overview of the project and discussion with the full conference. Then, our project team members ran a workshop session for half of the delegates in which stakeholders and scientists were working together to build historical time-lines of land use and agricultural change in the Peak District. 110 delegates were registered for the conference representing 28 different stakeholder organisations and 14 different research institutions.

3. Earlier in the project, participating farm businesses received bespoke reports regarding the ecological and economic condition of the farm. These have subsequently been used by farmers to inform HLS applications. In July 2009, we ran an evening meeting with local farm businesses in Hathersage where we presented results from the farm models and the ecological and economic surveys and elicited feedback from the farm businesses on the accuracy of model predictions, on the usefulness of the project and on how the science agenda was administered. This feedback was collected in person and using questionnaires and choice experiments.

4. A RELU Policy and Practice Note about the project is currently with the publishers and will see wide circulation. Because this format must address a general audience, we are also producing bespoke summary reports in response to questions asked by particular local stakeholder groups as part of an initiative supported by the ESRC Follow-on Fund.

In addition, we have presented project results in evidence to the Campaign for Rural England, in an education session run for the Board of Natural England, to a visiting MEP, etc. and have visited and held meetings with the NFU, RSPB, PDNPA, NE, etc. throughout the work.

CAPACITY BUILDING AND TRAINING

In the course of the project, we have trained two interdisciplinary post-docs and a PhD student and have contributed to the training of other interdisciplinary post-docs, PhDs and a research fellow funded through other RELU projects and sources. The project has also established a new interdisciplinary collaboration among the investigator team and between the investigator team and a network of stakeholder organisations that continue to support new research activities and grant applications.

Some specific examples of training activities

- Outreach activities were designed in a way that would provide all project staff, and particularly the PDRAs and PhD student, with important practise in meeting with and engaging stakeholders. Specifically, these activities have included joint presentations made by junior and senior project staff to stakeholders about the project, having younger research staff lead workshop activities, having natural scientists shadow experienced farm surveyors conducting the socio-economic survey, etc.
- We employed a local farmer as a consultant at the start of the project to run an 3-hour education session for new project staff on site on a local farm.
- The PDRAs on the project participated in interdisciplinary training events offered by RELU (e.g.,the BAAS-RELU RA Training Event at the BA Festival of Science 11-13th Sept 2007 in York).
- Project staff organised, ran and participated in two meetings of RELU researchers on Farm Production Modelling, one in Sheffield on 1/10/07 and one in Stirling on 30/06/08. These training and ideas workshops are described in more detail above. The goal of the meetings was to bring together researchers drawn from across projects working on farm production modelling. The invitations to participating project specifically invited one investigator and one PDRA. Six RELU PDRAs participated in this event in the 2007 meeting and 4 participated in the 2008 meeting.
- To develop the project's collaboration with RELU Exchange Fellow (Shortle) the project helped support a visit by Shortle's PhD student, Simanti Bannerjee, to the UK (including field visits to the Peak District as well as meetings and seminars in both Sheffield and Stirling), and supported a return visit by project PDRA, Szvetlana Acs, to Shortle's group in Penn State in 2008. During this visit, Acs received instruction in a range of new modelling techniques including non-linear programming.
- Acs also undertook a training course in mathematical modelling using Matlab in order to support the development of this work in 2008
- Dugald Tinch received training in relevant econometric techniques from a range of external visitors to and workshops held in the University of Stirling in 2008. Tinch also participated in activities organised through the Scottish Graduate

Programme in Economics, including giving a presentation about his work on the project to SGPE in January.
- In 2008, Tinch received training in the use of relevant programmes and statistical analysis has been sought and gained from Sergio Colombo (IFAPA Granada), Mikołaj Czajkowski (Warsaw Ecological Economics Center, University of Warsaw). A workshop on the use of multinomial logit models by Danny Campbell (Queens Belfast) held at the University of Stirling was both organised and attended by Dugald.
- Martin Dallimer was the first member of the project staff to come out of contract in 2009. Dallimer received career development support through University of Sheffield's formal Staff Review and Development Scheme, which helped him secure a new contract from the University of Sheffield when his tenure on the RELU project expired. This new follow-on position is again on an interdisciplinary project (funded through EPSRC's SUE 2 programme) that brings together natural and social sciences.
- Szvetlana Acs came to the end of her RELU contract more recently and was subsequently employed as a consultant on a DEFRA contract on Future Farming run by Cranfield University in collaboration with NDH that built on the RELU modelling work.
- The project continues to support independent fellow, Althea Davies. Davies has participated in project meetings and discussions throughout the year. Davies also gained experience of choice experiment methodologies when participating in a valuation workshop run in February. The project has also provided detailed historical data on land cover change in the Peak District to support her fieldwork.

CONFERENCES / NETWORKS

A detailed list of over 30 conference and seminar presentations by project staff is provided above, as is a description of our outreach activities with a network of stakeholder and practitioner groups.

FUTURE RESEARCH PRIORITIES

Are there lines of research arising from this project which might profitably be pursued (not necessarily with ESRC funding)?

Analyses of models and data produced in the project are ongoing and future manuscripts are planned and in preparation.

Hanley has been awarded a grant through ESRC's Follow-on Fund to extend the project's Knowledge Exchange activities in ways described above as well as participated in the DEFRA contract mentioned above.

Future grant applications that build on different elements of the work (e.g., the trade-off in policy design between requiring spatial cooperation among farms to produce ecological benefits but competition among farms to achieve cost efficiency and overcome problems of adverse selection) are currently in development.

Ethics

All project activities with human participants (e.g., surveys with farmers, choice experiments) were subject to review according to the University of Sheffield's Ethics Policy through Sheffield's Ethics Review System (http://www.shef.ac.uk/ris/gov_ethics_grp/ethics/system.html). On each occasion, Ethics approval was granted before research activities began. Measures to anonymise project data to protect human participants before data archiving were agreed with RELU Data Support Services and discussed with RELU DSS as the project developed and agreed standards have been maintained in the archived version of the data.

1.8 Confidentiality

If the report needs to refer to material which may be sensitive, this should be put in an annex clearly marked as confidential. A covering letter should be added to the report emphasising this.

Not applicable.

REFERENCES

Alvarez-Farizo, Begonˇ a, and Nick Hanley. 2006. ''Improving the Process of Valuing Non-Market Benefits: Combining Citizens' Juries with Choice Modeling.'' Land Economics 82 (3): 465–78.

Anderson, P. (1983) The Semi-Natural Vegetation of The Peak District National Park. Peak Park Joint Planning Board, Bakewell, Derbyshire, UK.

Anderson, P., Yalden, D.W., 1981. Long-term changes in the extent of heather moorland in upland Britain and Ireland: palaeoecological evidence for the importance of grazing. Biological Conservation 20, 195–213.

Barr, C.J., Bunce, R.G.H., Clarke, R.T., Fuller, R.M., Furse, M.T., Gillespie, M.K., Groom, G.B., Hallam, C.J., Hornung, M., Howard, D.C. & Ness, M.J. (1993) Countryside Survey 1990: Main Report, vol. 2. Department of the Environment, London.

BTO 2005. http://www.bto.org/birdtrends2005

Defra (2005). Farm Incomes in the United Kingdom. Department of Environment, Food and Rural Affairs, London.

Haines-Young, R., Barr, C.J., Firbank, L.G., Furse, M., Howard, D.C., McGowan, G., Petit, S., Smart, S.M. & Watkins, J.W. (2003). Changing landscapes, habitats and vegetation diversity across Great Britain. Journal of Environmental Management, 67, 267–281.

Haines-Young, R., Barr, C.J., Black, H.I.J., Briggs, D.J., Bunce, R.G.H., Clarke, R.T., Cooper, A., Dawson, F.H., Firbank, L.G., Fuller, R.M., Furse, M.T., Gillespie, M.K., Hill, R., Hornung, M., Howard, D.C., McCann, T., Morecroft, M.D., Petit, S., Sier, A.R.J., Smart, S.M., Smith, G.M., Stott, A.P., Stuart, R.C. & Watkins, J.W. (2000) Accounting for Nature: Assessing Habitats in the UK Countryside, Department of Environment, Transport and the Regions, London.

Moss, C.E. (1913) The Vegetation of the Peak District. Cambridge University Press, Cambridge, UK.

Ordnance Survey. (1952) Vegetation: Grasslands of England & Wales: Sheet 2 England and Wales – south of Kendal. Director General of the Ordnance Survey Office, Chessington, Surrey, UK.

Peak District Rural Deprivation Forum. 2004. Hard Times: A Research Report into Hill Farming and Farm Families in the Peak District. Peak District Rural Deprivation Forum, Hope, Derbyshire, UK.

Sim, I.M.W., Gregory, R.D., Hancock, M.H. & Brown, A.F. (2005) Recent changes in the abundance of British upland breeding birds. Bird Study, 52, 261–275.

Thompson, D.B.A., MacDonald, A.J., Marsden, J.H., Galbraith, C.A. (1995). Upland heather moorland in Great Britain : a review of international importance, vegetation change and some objectives for nature conservation. Biological Conservation 71, 163-178.

Tudor, G., Mackey, E.C., 1995. In: Thompson, D.B.A., Hester, A.J., Usher, M.B. (Eds.), Upland Land Cover Change in Post-war Scotland Heaths and Moorlands: Cultural Landscapes. HMSO, Edinburgh.

relu
Rural Economy and
Land Use Programme

Rural Economy and Land Use Programme
Centre for Rural Economy
School of Agriculture, Food and Rural Development
Newcastle University
Newcastle upon Tyne NE1 7RU

Telephone: 0191 222 6903
Fax: 0191 222 5411
Email: relu@ncl.ac.uk

www.relu.ac.uk

The Sustainability of Hill Farming

A Rural Economy and Land Use Programme research project to examine the impacts of agricultural policy reform on hill farm economics, biodiversity and upland landscapes.

Policy and Practice Notes

Note No. 13
December 2009

The Rural Economy and Land Use Programme is a UK-wide research programme carrying out interdisciplinary research on the multiple challenges facing rural areas. It is funded by the Economic and Social Research Council, the Biotechnology and Biological Sciences Research Council and the Natural Environment Research Council, with additional funding from the Scottish Government and the Department for Environment, Food and Rural Affairs.

Upland ecosystems support traditional rural industries like hill farming, are home to species and habitats of conservation concern, and provide a wealth of ecosystem goods and services. The landscapes that we see today have been shaped over many years by the management practices of farmers and others, partly influenced by government policies on agricultural support. However, these policies are in a state of flux. Policy-makers need information regarding how ongoing policy changes are likely to affect farming communities and upland ecosystems and whether these policies will deliver what the public wants from the hills.

What happened to the hills?

Upland ecosystems have been shaped by centuries of human exploitation. Indeed, many emblematic upland habitats, such as heather moorlands, depend on ongoing land management through grazing and burning. For many people, upland landscapes provide an important "sense of place". However, the uplands are very dynamic environments and are undergoing significant upheavals.

This project examined hill farming in the Peak District National Park as a case study. An examination of historical records for the Peak District reveals that since 1900:

- Sheep numbers maintained by farms in the hill parishes increased five-fold.
- Medium-sized farms decreased in numbers as large farm businesses and hobby farmers emerged.
- Farming simplified as traditional mixed enterprises disappeared, resulting in increased specialisation in livestocking.
- Upland ecosystems demonstrate considerable turnover among habitat types.

What do people want from the hills and who is going to pay for it?

Currently, agricultural subsidies provide the primary means by which the public "contract" with farmers to supply the types of benefits from the hills that people want to see. However, the long-term future of subsidy payments is uncertain and depends on public support. The project therefore assessed what people wanted from upland landscapes and whether they would be willing to pay to achieve that vision and found that:

- Visitors to the Peak District National Park would be willing to pay an additional parking fee to support greater conservation of key habitats, especially for moorland, where people would be willing to pay an average of £4 per visit.
- Residents of towns surrounding the National Park are willing to pay to maintain current levels of conservation.
- Estimates of people's willingness to pay can be affected when respondents are given time to reflect on their choices, taken to visit exemplar sites, or provided with expert witness testimony regarding the National Park.

View of the Peak District landscape from Stanage Edge Copyright M Dallimer

What has been the effect of agricultural supports?

Delivering rural policy in the hills today depends on agricultural subsidies, and socioeconomic surveys of hill farm businesses showed that farms rely on this support to be viable. However, subsidies for hill farms have been undergoing major changes. Previously farmers were given a subsidy payment for each animal they produced (a "headage payment"), but now they are paid a Single Farm Payment on an area basis, decoupled from production – ie the payment is not related to how many livestock they keep. This policy encourages:

- a reduction in stocking densities with a shift away from beef cattle.
- a reduction in the application of chemical fertilisers to inbye land.
- a reduction in the amount of labour employed on the farm.
- further specialisation by farms in what they produce.
- little abandonment of land, with farming likely to continue in a way that keeps the land in "good agricultural condition".

But the strength and direction of these incentives varies for farms in different regions and producing different combinations of produce (ie only sheep, sheep and beef, or sheep and dairy). The switch to the Single Farm Payment results in minor changes to average farm incomes with some farms seeing slight increases and others losses.

What part do agri-environment schemes play?

Agri-environment schemes, such as existing Environmentally Sensitive Area contracts, provide additional support, upon which many farmers have come to depend. These payments are designed to encourage farmers to provide "public goods", such as improved habitat for particular species or public access for recreation. However, agri-environment policies are also undergoing major changes.

Currently, they play a role in moderating the likely effects of the change to the Single Farm Payment by:

- reducing the impact on farm incomes of decoupling.
- encouraging further reductions in upland beef cattle, although they have a variable impact on sheep numbers.

The evidence from ecological surveys that agri-environment schemes improve the state of upland birds as an indicator of biodiversity is mixed:

- The types of land management actions specified in agri-environment agreements explain little of the variation in patterns of bird species richness.
- Farms inside agri-environment agreements, if anything, have fewer not more species.

However, the influence of agri-environment schemes becomes clearer when looking at individual species of conservation concern. Greater densities of key species were found on fields where more of the farm and the surrounding area is included in agri-environment agreements.

How could we design agri-environment policies better?

Further work is being undertaken in the project to examine how agricultural subsidy schemes can be designed more effectively to provide benefits for biodiversity.

- There might be benefits in allowing payment rates to vary across space or to vary with the amount of biodiversity benefit provided.
- The cost effectiveness of agri-environment schemes could be enhanced by recognising the different costs which farmers face in "producing" environmental benefits.
- Ecological effectiveness could be improved by designing incentives which encourage spatial coordination across several farms.

Further information

The research has been carried out at the University of Sheffield, University of Stirling and University of Nottingham, in collaboration with the Moors for the Future Partnership.

Key Contacts:
Dr Paul Armsworth, University of Tennessee, Knoxville
(formerly University of Sheffield)
Email: p.armsworth@utk.edu
Professor Nick Hanley, University of Stirling
Email: n.d.hanley@stir.ac.uk

Useful resources:

Acs, S., Hanley, N., Dallimer, M., Gaston, K.J., Robertson, P., Wilson, P. & Armsworth, P.R. 2009. The effect of decoupling on a marginal agricultural system. *Land Use Policy*, in press advanced copy available online, doi:10.1016/j.landusepol.2009.07.009

Dallimer, M., Acs, S., Hanley, N., Wilson, P., Gaston, K.J. & Armsworth, P.R. 2009. What explains property-level variation in biodiversity? Taking an inter-disciplinary approach. *Journal of Applied Ecology*, 46, 647-656.

Dallimer, M., Acs, S., Tinch, D., Hanley, N., Gaston, K.J. & Armsworth, P.R. 2009. 100 years of change: examining agriculture, habitat change and stakeholder perceptions through the 20th century. *Journal of Applied Ecology*, 46, 334-343.

Tinch, D., Hanley, N., Dallimer, M., Posen, P., Acs, S., Gaston, K.J. & Armsworth, P.R. 2009. Historical perspectives on the development of multifunctional landscapes: a case study from the UK uplands. In: *Multifunctional Rural Land Management: Economics and Policies*. Brouwer, F. & van der Heide, M. (eds.). Earthscan, London, UK, pp. 277-294.

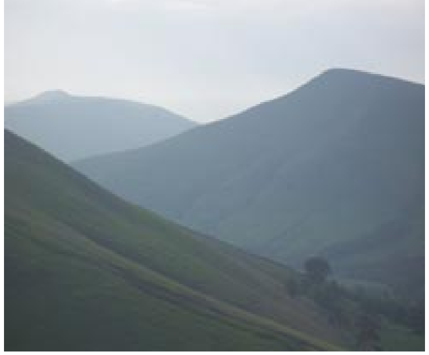
Project Website: www.biome.group.shef.ac.uk/RELU/People.htm

Hill Farm Economics, Landscapes and Biodiversity in the Peak District

An interdisciplinary research project conducted as part of the Rural Economy and Land Use Programme (RELU)

An interdisciplinary research project conducted as part of the Rural Economy and Land Use Programme

Project Outline



People

Feedback:f.eigenbrod@sheffield.ac.uk

Hill Farm Economics, Landscapes and Biodiversity in the Peak District

An interdisciplinary research project conducted as part of the Rural Economy and Land Use Programme (RELU)

Project Outline

Moorlands support traditional hill farming communities, are home to species of international conservation concern and provide emblematic landscapes with high recreational value. This collaboration launched in 2006 between researchers in the Universities of Sheffield, Stirling and Nottingham and the Moors for the Future initiative aims to discover how we can manage moorland ecosystems in a way that delivers sustainable hill farming communities while also protecting the environment. Taking the Peak District as a case study, we will examine how farmers respond to policy changes and how they can design business plans to cope with these changes most effectively. We will explore the impact that hill farming has on moorland species and predict how those impacts are likely to change over the next 20 years.

To do this, we will
· conduct questionnaire surveys with local farmers regarding the economics of hill farming and ongoing policy changes
· survey moorland birds to assess how they respond to different land management practices
· develop new modelling techniques that allow us to assess how the actions of one farmer affect those of neighbours and how upland bird species rely on a diversity of habitats across the landscape.
· conduct valuation workshops with the general public to discover what it is they most value about moorlands.

Finally, we will combine these results to evaluate how effectively different policies balance the multiple demands on moorlands.

For further details, please contact one of the researchers working on the project.