Agricultural Economics Society Conference, Dublin, Easter 2009.

Linking biodiversity, land-use and incomes at the farm level: an interdisciplinary modelling approach.

Szvetlana Acs[1], Martin Dallimer[2], Nick Hanley[1],

Kevin J. Gaston[2], and Paul R. Armsworth[2]

[1]Department of Economics, University of Stirling, Stirling FK9 4LA, UK.

[2] Biodiversity and Macroecology Group, Department of Animal and Plant Sciences, University of Sheffield, Sheffield S10 2TN, UK.

Abstract

Recent decades have witnessed substantial losses in biodiversity in Europe, partly driven by the ecological changes associated with intensification of agricultural production. These changes have particularly affected biodiversity in marginal areas, such as the uplands in UK, since habitat change has been greater than in lowland zones. Livestock farming is the main land use in these areas, and economic viability of farmers substantially relies on income coming from agricultural subsidies and agri-environmental payments. The production decisions have an effect on biodiversity, although the precise links are subject of much debate. To assess the effects of policy changes on farm incomes and biodiversity, we developed ecological-economic models for three typical farm types in the Peak District National Park in UK. We analyse the effect of decoupling and agri-environment schemes on birds. The results show that the impact of these policies varies across farm types and across biodiversity indicator. This means that from a biodiversity point of view whatever future policy options are chosen will result in winners and losers.

Keywords: decoupling, agri-environmental policy, ecological-economic model, biodiversity

1. Introduction

`

Recent decades have witnessed substantial losses in biodiversity in Europe, partly driven by the ecological changes associated with intensification of agricultural production (Benton *et al.* 2002; Donald *et al.* 2006). These changes have particularly affected avian (bird) diversity in marginal areas such as uplands in UK, since these areas continue to experience widespread habitat change that is greater than in lowland zones (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). 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).

In common with Europe as a whole, farming remains the dominant land-use in the UK uplands, even though it operates on the margins of agricultural productivity (Donald *et al.* 2006). 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; National Trust 2005; Acs *et al.* 2008).

There is a strong need in integrated ecological-economic models in order to address the problem of economic viability of farmers together with biodiversity conservation more effectively, given the shortcomings of single disciplinary models (Shogren et al. 2003; Watzold *et al.* 2006). So far, few integrated models have been developed to address the issues of biodiversity management (i.e. Johst et al. 2002; Perrings & Walker 2004; Watzold et al, 2007), and the use of ecological-economic models is still not wide spread (Watzold *et al.* 2006).

In this paper, using the Peak District National Park (PDNP) in the UK as a case study, we developed integrated ecological-economic models in order to explore the effect of policy reform on biodiversity and farm incomes, using three different indicators of biodiversity, based on avian species richness. The models are based on three different types of farms which are typical for the UK uplands.

2. Methodology

2.1. Farm surveys

2.1.1 Socio-economic farm surveys

The initial step in the research was a farm survey to investigate how land is managed on hill farms in the Peak District, and to provide inputs to the models. The survey was designed and carried out with the help of experienced farm business researchers through the winter months of 2006/2007. It comprised 44 farm visits. Farms were chosen on the basis of their location and their access to moorland grazing (defined as livestock farms within two km of the moorland line). The survey included questions on land area, land types and use, production activities and subsidy payments received during the reference period of 2006.

Sheep, dairy and beef cattle production were found to be the dominant activities in the uplands of the Peak District, utilising two main types of land: moorland and inbye land. "Moorland" is defined as unenclosed semi natural rough grazing, situated at higher altitude, providing the poorest grazing. The "inbye" land is agriculturally improved, more productive land situated at lower altitude. Based on the survey results, six types of typical upland farms can be distinguished depending whether a part of the farm has moorland coverage or not[1]: Moorland Sheep & Beef (MSB), Moorland Sheep & Dairy (MSD), Moorland Sheep (MS), Inbye Sheep & Beef (ISB), Inbye Sheep & Dairy (ISD) and Inbye Beef (IB). In terms of subsidy payments, the Single Farm Payment (SFP) and Hill Farm Allowance (HFA) are received by most farmers. However, in addition, many farmers participate in different agri-environment schemes. For the purposes of this paper, we focus on three of these farm types: MSB, MSD, ISB (additional analysis of other farm types in terms of the impacts of policy reform on land use can be found in Acs et al, 2008).

2.1.2. Bird surveys

[1] This distinction was important for ecological measurement and modelling purposes.

Bird surveys were carried out on the same farms as socio-economic surveys in order to have full overlap in the data. We are therefore able to make a direct connection between farm management practices and bird diversity and abundance for each farm type. On average 95 ha. (SD 66.7ha) of farmland was surveyed per property, with an average 1651m (SD 561m) of transect walked. 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 this land holding and suitable access points. To minimise the potential for recording birds outside the survey farm, transects were, where possible, placed 200m from a property boundary. Birds were only included as present on a property if they were seen or heard within the property boundary, irrespective of the distance from the transect. Where needed, parallel transects were placed 400m apart to avoid double-sampling the same parts of the farm. In this situation, birds were only recorded within 200m of the transect line. All areas of the main enclosed holding of the farm were surveyed with the exception of areas of woodland. Bird surveys were carried out on two separate visits to each farm between 28th March and 5th July 2007, with the second visit at least six weeks after the first. To ensure that the maximum number of species was encountered, visits began between an hour and three hours after sunrise.

A list of all bird species encountered on each farm during both visits was compiled. The number of species observed on each surveyed farm was used directly as the measure of species richness (equivalent to the species density of Gotelli & Colwell 2001). Species were classified into two further groups: Upland Species and Species of Conservation Concern. 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 species 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. 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). Fields were characterised according to whether they were improved grassland (JNCC 2007), whether the field was cut for silage or hay in the year of the survey, the proportion of the field boundaries that were vegetated with hedges or woodlands (as opposed to unvegetated fences and walls), the number of trees present, the number of grazing animals, the proportion of rush cover and the proportion of fields with wet features.

The landscape context within which each property was found was characterised 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 500m buffer around each property.

2.2. Economic modelling

Mathematical models were developed for three typical farm types (Moorland Sheep and Beef (MSB), Moorland sheep and dairy (MSD) and In-Bye Sheep and Beef, ISB (more details are given in Acs et al, 2008). The general structure of these models has the form of a standard mathematical programming (MP) model (Hazell & Norton, 1986), where some equations contain non-linear expressions:

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

Subject to $Ax \leq b$

and $x \geq 0$

where:

Z =gross margin at farm level

x = vector of activities

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

A = matrix of technical coefficients

b = vector of resource endowments and technical constraints

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

The models incorporate all livestock and grass production activities carried out on the upland farms and can thus be calibrated to represent any particular farm situation in terms of basic resource endowments. Based on our survey the three typical farm types for the uplands are represented by the averages of these farm types. The three different models included calibration on the main production category (sheep, beef, dairy), on different land types, housing capacity for livestock and household labour availability.

Five management variables which are outputs from the farm model were chosen which were though, a priori, to have an influence on bird diversity on the uplands.

These variables are: sheep density, beef density, dairy density, fertiliser use and the number of grass cuts for silage production. These variables make a link between economic and ecological models: this linkage being achieved using regression results relating these five management variables to species richness, as detailed below.

2.2. Ecological modelling

In order to quantify the effects that farm management variables had on avian species richness we used multiple regression, with three alternative measures of species diversity (Total Species, Moorland Species, Species of Conservation Concern) as the response variable and management activities, habitat characteristics and landscape characteristics as explanatory variables (Dallimer et al, 2009). In all cases, the Information Theoretic approach (Burnham & Anderson 2002; Johnson & Ohmland 2004; Whittingham *et al.* 2006) was used based on Akaike Information Criteria (AIC). Full results are reported in Dallimer et al, 2009. For inclusion in the economic model, a simplified version of these models was estimated, including just the managerial link variables thought to be relevant to diversity: sheep and cattle numbers per hectare, fertlizer inputs and number of grassland cuts per year. Given that a linear relationship between grazing pressure and diversity is unlikely, we specified models with quadratic terms for sheep and cattle densities per hectare. The regional location of any farm site (Dark Peak, Eastern Moorland, South-West Peak) was also included to account for regional gradients in habitat quality in both farmland and moorland. The general format of the model is shown in equation 1, and parameter estimates are shown in Table 1.

$$B_n = b_1 * Rr + b_2 * S + b_3 * S^2 + b_4 * C + b_5 * C^2 + b_6 * F + b_7 * Cut \qquad \textit{Equation 1}$$

Where:

Variables	Explanation
Bn	Bird density per ha (n = lapwing, curlew etc)
Rr	Region (r = DP, EM, SW)*
S	Sheep per ha
C	Cattle per ha
F	Fertiliser per ha
Cut	Average number of cuts per ha

* DP=Dark Peak, EM=East Moors, SW=South West Peak

2.3. Integrated models and scenarios

The ecological regression models were integrated into economic models by adding them as separate equations that provide the relationships betweens species diversity and farm management variables. These parameters for farm management variables were taken from the estimations of ecological regression models as in Table 2. This link could then also be used to estimate the effect of certain target levels for each species, and to calculate the shadow prices of achieving these targets. The aim of this paper, however, is to investigate the impacts of the recently introduced agricultural policy reform (decoupling) and that of agri-environmental policy (AES) on production decisions and biodiversity. To illustrate this, the ecological-economic models were used to analyse four different scenarios for each typical farm type:

1. Headage Payment (HP) scenario: the policy situation as it existed before the introduction of the SFP, the subsidy payment being made per head of livestock production for sheep, beef and dairy cattle (Nix 2007).
2. Single Farm Payment (SFP) scenario: a policy situation where the flat rate payment will account for 100% of payments, as planned for 2012. This payment is based on the type of land available and is detached from production, although it does impose certain constraints on farm activities (Nix 2007).
3. Headage Payment with AES (HP&AES) scenario: same as HP scenario but including the compliance constraints and payments for the new agri-environment schemes: Entry Level Stewardships (Defra 2005a) and Higher Level Stewardships (Defra 2005b).
4. Single Farm Payment with AES (SFP&AES) scenario: same as SFP scenario including the new agri-environment schemes, namely entry and higher-level stewardship.

These four scenarios are simulated for each of the three farm types. The impact of i) decoupling, ii) AES, and iii) decoupling moderated with AES on the three definitions of species richness is shown. The decoupling effect is illustrated by the move from HP to SFP scenario, the effect of AES is shown by the move from the SFP to SFP&AES scenario; and the effects of decoupling moderated by AES is shown by the move from the HP&AES to SFP&AES scenario.

3. Results

3.1. Model testing

In order to test the reliability of model output concerning bird densities we compared predictions in the base case for the three different farm types to actual field data. For this we used “Survey adjusted” farm models, which means that the livestock numbers are adjusted to the socio-economic survey, the average of individual farms within each farm type. All the models predicted avian richness within the range of the densities observed. Calibration results for the farm models, in terms of predicted land use and intensities in the base case, are reported in Acs et al (2008).

3.2. Integrated modelling results

From the perspective of upland biodiversity, the impacts of policy reform which we focussed on are those on livestock density, fertiliser use and cutting frequency, since the literature suggests links between these variables and biodiversity indicators (see Dallimer et al, 2009). The optimal value of these variables for each farm type across the four policy scenarios (HP, SFP, HP&AES and SFP&AES) can be seen in Table 3. Note that cattle numbers do not change much, since in most runs cattle are stocked up to the capacity constraint implied by housing.

Based on these three scenarios we can calculate the impact of different farm management practices influenced by policies on avian density. First the effect of pure decoupling is shown, then the impact of AES and finally that of decoupling moderated by the new AES scheme, Environmental Stewardship.

3.2.1 Effects of decoupling

Decoupling was analysed using the transition from headage payment to Single Farm Payment, without any mitigating effects of AES. Results are shown in Figure 1:

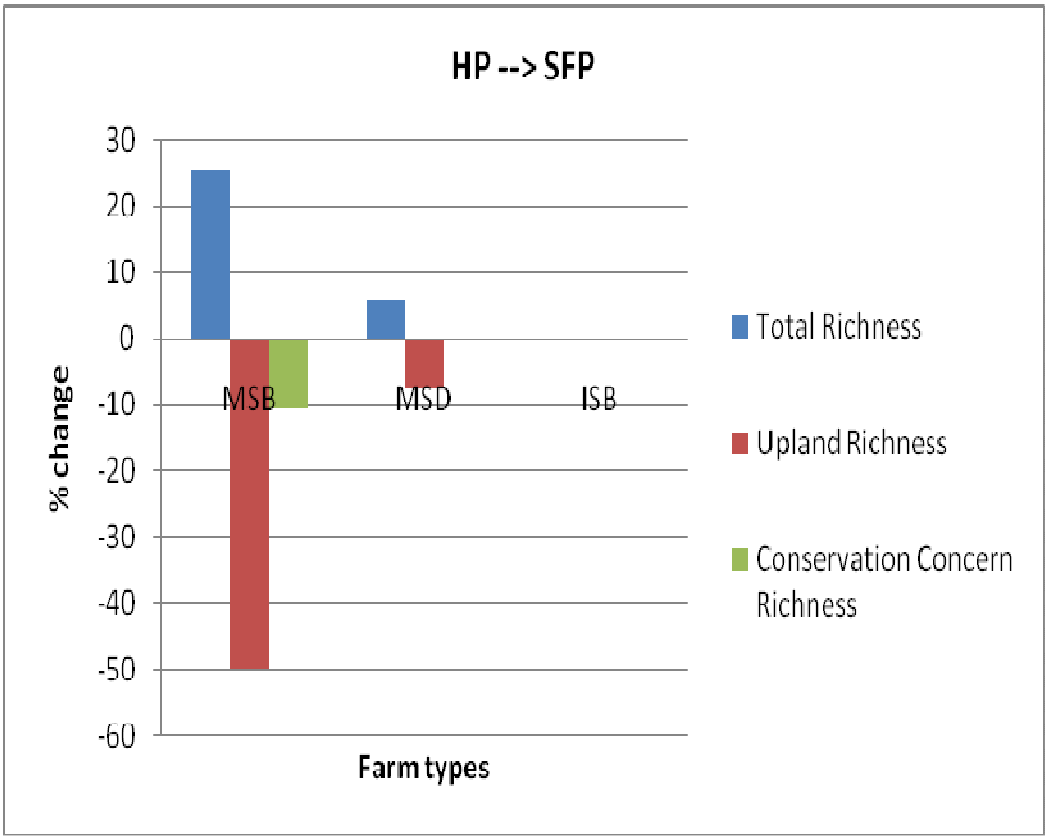

Figure 1: effects of decoupling on three biodiversity indicators

As may be seen, total richness increases for the MSB and MSD farm types (no impacts on diversity were found for the ISB farm type). However, for the upland species and species of conservation concern indicators, decoupling results in a loss of biodiversity. These effects are driven by changes in stocking rates and in intensity of land use.

3.2.2. Effect of decoupling moderated by agri-environmental policy

The effect of decoupling and AES was analysed by going from HP&AES scenario to the SFP&AES scenario. This is perhaps the most interesting scenario considered, since it mirrors recent actual changes in policy. As may be seen in Figure 2, both gains and losses occur to biodiversity, with increases in total species richness on the MSB and ISB farm types accompanied by decreases in upland species numbers, and in the number of species of conservation concern. For the MSD farmtype, all diversity indicators worsen.

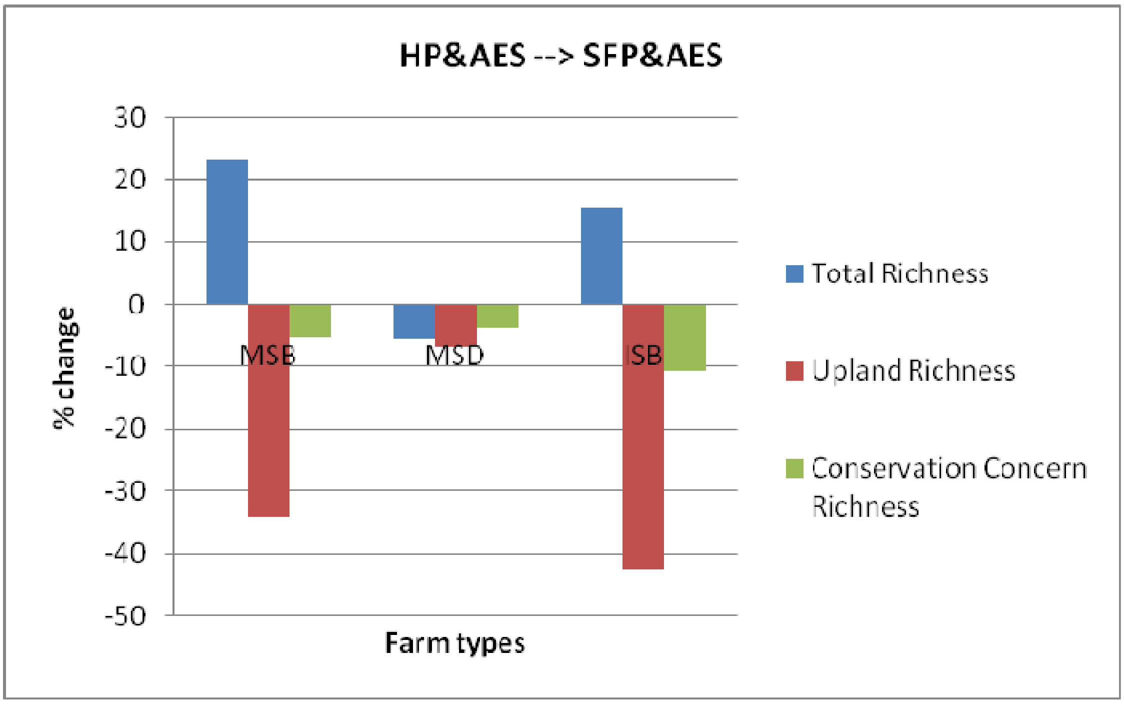

Figure 2: effects of decoupling when accompanied by agri-environment payments

4. Conclusions

Our results show that the impacts of individual policies on biodiversity depend on policy design, and differ across farm types. This is an interesting result, which suggests that policy initiatives which are uniform across farm types and bird species will not always produce results which are helpful for biodiversity conservation. Changes in sheep numbers, in fertiliser use and the frequency of silage cuts all help determine abundance for indicator species. Some bird species emerge as "winners" in this analysis of policy change, and some as losers. This suggests that policy reform would need to be informed both by a prioritising of biodiversity objectives, and awareness of how the opportunity costs of biodiversity protection varies across farms. However, many other factors, such as ecological (eg habitat), whole farm (eg number of farm workers) and socio-economic (eg farmer characteristics) variables also play role in driving biodiversity levels, which should be considered when taking decisions at policy level. Indeed, in research reported elsewhere, we show that the farm management variables which link the ecological and economic models here play a relatively small role in determining the variation in species, with factors such as habitat features, land ownership, predator control activities and the availability of on-farm labour all being relatively more important (Dallimer et al, 2009). Variations in response across individual sites would thus likely seem to be considerable.

This paper has taken a rather simple approach to studying interactions between hill farming and bird diversity, and results must be seen as indicative only. Yet the general message seems clear: policy change produces both winners and losers in terms of biodiversity. We also find that de-linking of support from production does not improve biodiversity conservation in many of the cases studied. Future developments will include estimating the response of farmers to agri-environmental schemes which pay for environmental outputs rather than management change, and quantifying the trade-offs between farm income and biodiversity across farm types and for different species. We will also be investigating the use of mechanisms which encourage spatial coordination between moorland and inbye farmland, for birds whose abundance depends on conservation actions on both types of habitat.

Acknowledgements

We thank ESRC and NERC for funding this work under the RELU programme, and Phil Robertson and Paul Wilson for their work on the farm survey.

Table 1. Regression coefficients from ecological models

	constant	Sheep/ha	Cattle/ha sqd	Fertiliser input	Number of cuts	Dummy, East Moors	Dummy, South-west Peak	Sheep/ha 2	Cattle/ha 2	R2
Total richness	3.28	0.14	-0.07	0.00	-0.12	-0.03	-0.02	-0.05	0.02	0.08
Upland richness	1.27	0.07	-0.06	0.00	-0.00	-0.05	-0.02	-0.04	0.01	0.04
Conservation concern	2.24	0.07	-0.00	0.00	-0.00	-0.03	-0.07	-0.00	0.00	0.06

Table 3. Farm production variables for each scenario and farm type.

Management		MSB				MSD				ISB			
Variables		HP	SFP	HP&AES	SFP&AES	HP	SFP	HP&AES	SFP&AES	HP	SFP	HP&AES	SFP&AES
Gross margin	£/ha	84	61	96	78	285	264	318	333	373	297	399	371
Sheep	nos/inbye ha	3.38	0.91	3.31	1.96	4.05	3.87	0.79	0.33	3.64	3.64	2.95	0.66
Cattle	nos/inbye ha	1.06	1.06	1.06	0.28	0.58	0.58	0.58	0.58	0.69	0.69	0.69	0.69
Fertiliser	N kg/inbye ha	146	38	148	18	21	21	21	21	24	24	24	25
Cuts	nos/inbye ha	0.95	0.64	0.91	0.57	0.53	0.53	0.38	0.38	0.43	0.43	0.41	0.31
LU	nos/ha	0.38	0.21	0.37	0.23	0.74	0.72	0.48	0.44	1.06	1.06	0.96	0.62

References

Acs, S., Hanley, N., Dallimer, M., Gaston, K.J., Robertson, P., Wilson, P. & 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.

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.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers and L. Thomas. 2001. Introduction to Distance Sampling: estimating abundance of biological populations. Oxford University Press, Oxford, U.K.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. & Thomas, L. 2004. Advanced Distance Sampling. Oxford University Press, Oxford, U.K.

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

Dallimer, M., Szvetlana Acs, Nick Hanley, Paul Wilson, Kevin J Gaston and Paul R Armsworth (2009) "What explains property level variation in avian diversity?" *Journal of Applied Ecology*, in press.

Defra (2005a). *Entry Level Stewardship Handbook.* Defra, London.

Defra (2005b). *Higher Level Stewardship Handbook*. Defra, London.

Defra (2005c). *Farm Incomes in the United Kingdom*. Defra, 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.

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.

Hazell, P.B.R and Norton, R.D. *Mathematical Programming for Economic Analysis in Agricutlure* (Macmillan Publishing Company, New York, 1986)

Johst, K., M. Drechsler, and F. W¨atzold. 2002. An ecological-economic modelling procedure to design effective and efficient compensation payments for the protection of species. *Ecological Economics* 41:37–49.

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

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

National Trust (2005). *Impact of CAP Reform on the English Uplands: A National Trust Discussion Paper*. The National Trust, London.

Nix, J., 2007. Farm Management Pocketbook. 37th Edition, The Andersons Centre

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.

Perrings, C., and B. Walker. 2004. Conservation in the optimal use of rangelands. *Ecological Economics* 49:119–128.

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.

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.

Shogren, J. F.,G.M. Parkhurst, and C. Settle. 2003. Integrating economics and ecology to protect nature on private lands: models, methods and mindsets. Environmental Science and Policy 6:233–242.

Thomas, L., Laake, J.L., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Hedley, S.L., Pollard, J.H., Bishop, J.R.B. and Marques, T.A. 2006. Distance 5.0. Release 2, Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.stand.ac.uk/distance/.

Watzold, F., M. Drechsler, C.W. Armstorng, S. Baung Artner, V. Grimm, A. Huth, C. Perrings, H.P. Possingham, J.F. Shogren, A. Skonhoft, 2006. Ecological-Economic Modeling for Biodiversity Management: Potential, Pitfalls, and Prospects. *Conservation Biology,* Volume 20, No. 4, August 2006

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