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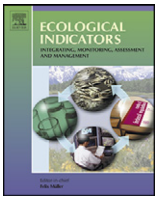

Modelling the European Farmland Bird Indicator in response to forecast land-use change in Europe

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ABSTRACT

The European Farmland Bird Indicator (EFBI) has been adopted as a Structural and Sustainable Development Indicator by the European Union. It is an aggregated index integrating the population trends of 33 common bird species associated with farmland habitats across 21 countries. We describe a modelling method for predicting this indicator from land-use characteristics. Using yearly historical land-use data of crop areas derived from the FAO databases (1990–2007) and published population data of farmland birds at the national level for the same period, we developed a series of multiple regression models to predict the trend of the EU state specific indicator, and the EFBI. These models incorporated up to 4 parameters and were selected based upon the significance ($p < 0.05$) of the model inputs with respect to the predictive variable. 17 separate models were developed in total for each of 14 EU countries plus Norway and Switzerland, and a separate model for the EU level indicator. The selected models were then implemented to predict the EFBI in the year 2025, using scenarios of land-use change generated by the CAPRI agricultural model. The uncertainty of using the regression models is discussed with respect to predicting the likely impacts of land-use change on bird populations. This work lays the framework for future modelling of farmland birds at the international scale.

1. Introduction

In 2001, EU Heads of State and Government meeting at the EU's Spring Summit in Gothenburg, made a commitment to "halt the decline of biodiversity by 2010". This commitment will be tested against biodiversity indicators, one of which is the wild bird indicator, that includes trends in farmland birds (Gregory et al., 2005). Because the decline of farmland birds in Europe has been widely attributed to changes in the availability of key resources, such as food and nest sites, as a consequence of agricultural intensification (Siriwardena et al., 1998; Chamberlain et al., 2000; Newton, 2004; Butler et al., 2007; Fox and Heldbjerg, 2008; Reif et al., 2008), and because agriculture is entering a period of rapid economic and policy change, it is therefore important to develop a robust methodology for forecasting potential impacts of these changes on farmland bird populations, so that policies can be implemented that are consistent with achieving this target.

The precise mechanisms for the observed decline are complex but have been successfully modelled to some extent for individual countries both mechanistically (Bradbury et al., 2001; Stephens et al., 2003) and with simple rule-based approaches (Smart et al., 2008). At present these mechanisms are complex, and too detailed for effective modelling at the European scale. This is in part due to the idiosyncrasies of landscape form and function, but also owing to the high development of our understanding of species movements, and the difficulties of modelling the fine scale movement of individual bird species at an international scale. Even if we could model population abundance and characteristics of several species at field scale, it may be impossible to scale such a model up to the European level whilst at the same time maintaining the low level of parameterisation needed to provide low uncertainty, together with the required coverage of detailed landscape information. In addition, landscapes are dynamic not static systems, the management of which is dependent upon a range of socio-economic, policy and environmental controls.

Every species has a set of key ecological requirements that must be provided in a landscape for it to survive and prosper there. The value of a particular land-use type to a given species can be categorised in terms of the quantity or quality of its ecological

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requirements provided by that land-use. Furthermore, the likely impact of land-use changes on a given species can be quantified by assessing the impact of that change on the provision of the species' key ecological requirements (Butler et al., 2007), with the degree of impact depending on the relative merits of the land-use that is lost compared to the land-use introduced. Each species has a different set of ecological requirements and therefore the value of a particular land-use, and the impact of any given land-use change, will vary between species.

Given that each land-use type has an associated value for each species in terms of ecological requirement provision, a change in the prevalence of that land-use or the intensity of its management will result in an equivalent change in the availability of those ecological requirements, and hence the abundance of the species. Changing to more intensively managed landscapes, or increasing the area under crop types that provide fewer key ecological requirements, is likely to lead to population declines in that landscape because of consequent reductions in the availability or abundance of those key ecological requirements. Conversely, increasing the area of beneficial crops, or reducing management intensity may lead to population growth in response to increases in the quantity or quality of key ecological requirements. The health of farmland biodiversity under future land-use scenarios should therefore reflect changes in the area under those crops that are beneficial and detrimental to each species and changes in the intensity of management of those crops.

The assumption is that farmland bird populations respond to changes in land-use (area and intensity). There are a number of indicators for intensity of agricultural activities at European level (e.g. ELISA) that could have been used to develop our modelling approach, yet these are not available for the past or the future. As part if an EU funded project (SENSOR), we wished to model the response of farmland bird populations to changes in predicted land-use change. This meant that we were constrained by the output variables from the 'Common Agricultural Policy Regionalised Impact analysis' (CAPRI), which is an EU-wide quantitative agricultural sector modelling system (Britz, 2005) used within the SENSOR project.

This paper therefore develops models for predicting farmland bird population trends driven by changes in the quantity or quality of ecological requirements available in the landscape under scenarios of land-use change derived from the CAPRI agricultural model.

2. Materials and methods

2.1. Data assimilation

To determine the impact of land-use change on farmland bird populations, we first assessed the impact of past land-use changes on the farmland bird indicator. We considered the farmland bird indicator as analogous to country level bird population statistics, and therefore could be composed of different species and land-use for each model. Using crop area data between 1990 and 2007 for 16 European countries and the European farmland bird indicator data (EUROSTAT, 2008) for the same countries over a similar time period, we explored the relationships between bird population trends and proportional changes in crop area. Parameter estimates from these models were then used to forecast the impacts of modelled land-use changes in a total of 27 countries (EU27).

2.1.1. Criteria of selection of land-use data

Land-use types, extracted from the FAO database for the period 1990–2007 (FAOSTAT.org), were selected firstly on the basis of their presence in the CAPRI model output, secondly on production within Europe, and thirdly on the basis of significant correlation with the European farmland bird indicator at the country level for each land-use type. The initial database contained 42 land-use types for country level yield and area of production, running from 1990 to 2007. Data were rejected on the basis of correlative significance ($p > 0.05$). Data relating to annual area for 5 land-use types (fallow, wheat, sugar beet, potato and sunflower) and fertiliser application (total NPK) were selected as the initial explanatory variables for modelling farmland bird populations. It was assumed that changes in farmland bird populations are likely to have been driven by changes in agricultural area or of management intensity rather than absolute values, so the slope of the linear regression line through each set of data points was used as the predictor variable. To standardise the datasets across crops and countries, annual area was expressed as the percentage of the area under production in 2002 and fertiliser data as the percentage of the value in 2002. Thus all values converge to 100% in the year 2002; the CAPRI model uses 2002 as the base year and the year 2002 was the nearest reference point. The slopes of the linear regression lines through each set of data points were used to indicate the change of the farmland bird indicator relative to 2002 for the year 2025.

2.1.2. Farmland bird data

The pan-European farmland bird indicator of the European Union (EUROSTAT) is an aggregated index of population trend estimates of a selected group (33 species, Table 1) of breeding bird species dependent on agricultural land for nesting or feeding. This robust indicator, developed by Gregory et al. (2005), was specifically designed to provide a signal of biodiversity health to policy customers to help them develop and then review policy measures. Individual country indicators are also available for 18 EU states, for a reduced number of bird species. Indices are calculated for each species independently and are weighted equally when combined in the aggregate index using a geometric mean. Aggregated EU indices are calculated using population-weighted factors for each country and species. The EU aggregate figure is an estimate based on 18 Member States plus Norway and Switzerland.

2.1.3. Assumptions about land-use change

Land-use areas were predicted by the external agricultural model CAPRI (Britz, 2005), and rate of change was calculated relative to the base year of 2002. CAPRI offers a detailed depiction of the agricultural sector on a regional level in the EU, and around 50 agricultural primary and secondary products. CAPRI is an economic model, and includes a world economic and market module. Policies are, of course, an important driver of change in the CAPRI model. Policies were assumed to remain as they are in the base year. The CAPRI model in this example predicts the effect of abolishing market support and direct payments in agriculture. SID0 is the reference scenario, where in principle all policy variables are kept as they are today. The baseline scenario assumes that population, participation in the labour force, total R&D expenditure, oil price and world demand for EU goods increases moderately. The scenario for land-use in 2025 describes assumptions made about reform of the Common Agricultural Policy which include a liberalization of agricultural markets, removal of direct farm income support and no return of saved subsidy into research and development (Kuhlman et al., 2008). This scenario utilises changes in socio-economic drivers from 2005 to 2025. The principal varying parameters were demographic change using the EUROSTAT medium projection (EUROSTAT); rate of participation in the labour force (Carone, 2005); growth of world demand outside Europe (UN Statistics Division); price of petroleum on the world market (PROMETHEUS model) and expenditure on research and development (EUROSTAT). This scenario therefore gives a

Table 1

List of species used within the European Farmland Bird Indicator, this indicator is an aggregated index integrating the population abundance and the evenness of a selection of bird species associated with specific habitats. It is based on trend data from 18 EU Member States which is derived from annually operated national breeding bird surveys spanning different periods, obtained through the Pan-European Common Bird Monitoring Scheme (PECBMS).

Common name	Latin name
Eurasian Skylark	Alauda arvensis
Tawny Pipit	Anthus campestris
Meadow Pipit	Anthus pratensis
Greater Short-toed Lark	Calandrella brachydactyla
Linnet	Carduelis cannabina
White Stork	Ciconia ciconia
Rook	Corvus frugilegus
Cirl Bunting	Emberiza cirlus
Yellowhammer	Emberiza citrinella
Ortolan Bunting	Emberiza hortulana
Common Kestrel	Falco tinnunculus
Crested Lark	Galerida cristata
Thekla Lark	Galerida theklae
Barn Swallow	Hirundo rustica
Red-backed Shrike	Lanius collurio
Woodchat Shrike	Lanius senator
Black-tailed Godwit	Limosa limosa
Calandra Lark	Melanocorypha calandra
Corn Bunting	Miliaria calandra
Yellow Wagtail	Motacilla flava
Black-eared Wheatear	Oenanthe hispanica
Eurasian Tree Sparrow	Passer montanus
Grey Partridge	Perdix perdix
Rock Sparrow	Petronia petronia
Whinchat	Saxicola rubetra
Common Stonechat	Saxicola torquata
European Serin	Serinus serinus
European Turtle-dove	Streptopelia turtur
Spotless Starling	Sturnus unicolor
Common Starling	Sturnus vulgaris
Common Whitethroat	Sylvia communis
Eurasian Hoopoe	Upupa epops
Northern Lapwing	Vanellus vanellus.

prediction of the effects of agricultural policy on land-use in the year 2025, and provides suitable inputs for a model of national farmland bird population. The output variables from the CAPRI model were then used as inputs for the regression models.

2.2. Analyses

The relationship between land-use change and population trends were investigated from 1990 to 2007 using a standard regression model and including the intercept using Minitab® v15.1.20.0 statistical software (Fig. 1). A backwards stepwise regression method was used. Backwards elimination of parameters started with all predictors in the model and removed the least significant variable for each step. A threshold for retaining predictor variables in the model of $p < 0.1$ was set at this stage. Specifically, models were developed against the farmland bird indicator (dependent variable), for 5 land-use types (independent variables: areas of spring wheat, sugar beet, fallow, sunflower and tonnage of total fertiliser consumption), land-use was indexed to a value of 100 for the year 2002. This was so that future predictions made using the CAPRI model could use 2002 as the base year. The final set of models ($n = 17$) had a maximum of 3 parameters (including the intercept). Models were developed for each EU member state, and for the European Union as a whole using the composite indicator (EU27). The relationships between land-use and farmland bird indicator trend data were analysed using individual crop data and data based on broad agricultural land-use classifications from the CAPRI model (Britz, 2005), to check for autocorrelation amongst model inputs. Model fit statistics and parameter estimates are provided for calculating farmland bird species' population indices based on land-use change. Projected uncertainty bounds (95% confidence limits) were calculated from the fitted regression parameters for the period 1990–2005 (Fig. 2). The indicator was then calculated for the year 2025 based on the CAPRI model output using the slope derived from the calibration dataset. The farmland bird indicator was mapped at the spatial resolution of NUTS-0 regions. The time horizon for modelling was 2025, with 2002 as the base year. All spatial data processing used ESRI Arcgis v. 9.2.

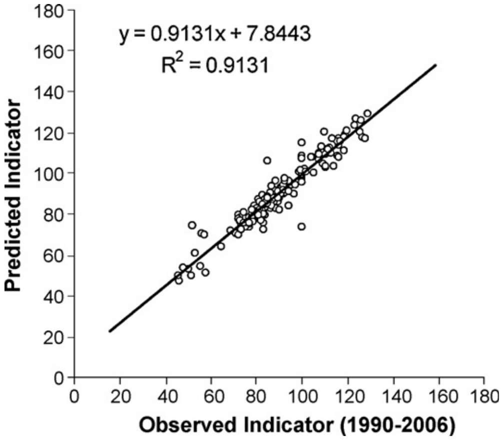

Fig. 1. Predicted farmland bird indicator for each country and for all years versus observed farmland bird indicator results for the period 1990–2007 ($r^2 = 0.93$). The arbitrary units are based on the index of farmland bird species relative to the base year (1990) value of 100.

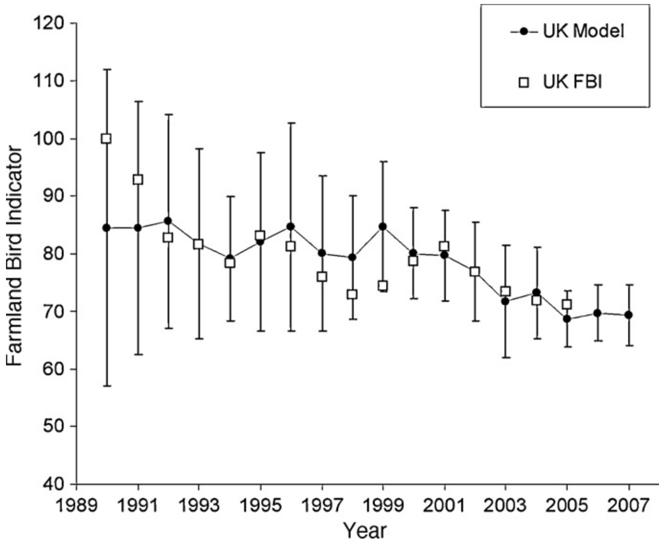

Fig. 2. Predicted values of the UK farmland bird indicator (UK Model). 95% confidence limits are plotted to illustrate the uncertainty of the prediction. The observed indicator values for the UK from Eurostat (UK FBI) are shown for the period 1990–2005.

3. Results

The linear regression models (17 in total) for 16 regions of Europe, and a European scale model (Table 2) predict the respective farmland bird indicators very well, explaining over 92% of the variance in Farmland bird indicator (Fig. 1) for 1990–2007. The parameters of the models developed for each country and Europe in this study are presented in Table 2. Apart from Switzerland and Italy, all models were significant ($p < 0.05$) and

Table 2
Results of GLM analyses of the Farmland Bird Indicator in 14 EU member states, Norway, Switzerland and across Europe between 1990 and 2007.

State	Parameter name	Value	Std. Err	t	p	Adj. r^2
Belgium	Intercept	182.905	22.334	8.190	0.000	0.771
	Potatoes	−0.815	0.241	−3.380	0.005	
	Fallow	−0.300	0.072	−4.152	0.001	
Czech Republic	Intercept	274.351	58.585	4.683	0.002	0.893
	Wheat	−1.803	0.579	−3.114	0.014	
Denmark	Intercept	56.725	3.795	14.949	0.000	0.960
	Fertiliser	0.183	0.025	7.331	0.000	
Estonia	Wheat	0.290	0.096	3.021	0.014	0.378
	Potatoes	0.472	0.054	8.760	0.000	
Finland	Intercept	87.829	1.942	45.226	0.000	0.625
	Fallow	0.039	0.011	3.568	0.003	
France	Intercept	61.422	6.073	10.115	0.000	0.773
	Sunflower	0.188	0.042	4.456	0.001	
Germany	Intercept	212.862	30.036	7.087	0.000	0.411
	Wheat	−1.144	0.327	−3.494	0.004	
Ireland	Intercept	81.34	12.95	6.27	0.003	0.260
	Fallow	0.337	0.141	2.39	0.075	
Italy	Intercept	−16.17	92.153	−0.175	0.869	0.981
	Fallow	1.04	0.942	1.109	0.329	
Latvia	Intercept	85.721	12.000	7.144	0.000	0.676
	Sugar Beet	0.321	0.141	2.272	0.049	
Norway	Fallow	0.490	0.034	14.466	0.000	0.389
	Sugar Beet	0.787	0.012	65.303	0.000	
Poland	Intercept	8.785	21.14	0.415	0.699	0.821
	Sugar Beet	0.824	0.210	3.919	0.017	
Spain	Intercept	165.150	10.904	15.145	0.000	0.485
	Potatoes	−0.385	0.088	−4.388	0.007	
Sweden	Intercept	173.909	27.977	6.216	0.000	0.759
	Wheat	−0.506	0.138	−3.657	0.003	
	Fallow	−0.439	0.187	−2.343	0.036	
Switzerland	Intercept	−35.509	64.467	−0.551	0.605	0.882
	Wheat	1.348	0.634	2.126	0.087	
United Kingdom	Intercept	13.830	20.55	0.672	0.512	0.876
	Potatoes	0.630	0.196	3.215	0.006	
Europe	Intercept	32.347	6.436	5.026	0.000	0.9279
	Potatoes	0.402	0.047	8.501	0.000	

were therefore used to predict the farmland bird indicator in these countries in light of land-use change predictions derived from the CAPRI model. The EU-wide model was used to predict the indicator in countries for which no country-specific model could be derived either due to no farmland bird indicator data being available (Austria, Bulgaria, Cyprus, Greece, Hungary, Lithuania, Portugal, Romania, Slovenia, Slovakia and Malta) or failure to derive a working model (Italy and Switzerland) (Fig. 3). Model predictions in 11 countries demonstrated an increase in the value of the farmland bird indicator whilst it was predicted to decline further in 15 countries. Across Europe, the overall farmland bird indicator was predicted to decline between 2002 and 2025. This was due to the prediction by the CAPRI model of relative decreases in wheat, sunflower, potato, sugar beet areas and fertiliser in most countries and predicted increases in fallow area (Fig. 4). Iceland, Luxembourg and Switzerland are not mapped onto the CAPRI output and are therefore excluded in the prediction map (Fig. 5).

4. Discussion

Using this approach, we could accurately predict the farmland bird indictor in 16 countries based on land-use patterns in those countries between 1990 and 2007. Parameter estimates from the models developed (Table 2) can be used to predict population trends under future land-use change scenarios. For example, when output from the CAPRI agricultural model for a future land-use scenario was used to examine the potential of the models to predict farmland bird populations in 2025, bird populations were expected to increase in 11 countries but decline in 15 others and across Europe as a whole. Based on the CAPRI predictions of land-use in the year 2025 our model predicts widespread biodiversity loss, indicating a general failure of the EU to achieve this policy goal.

There are a number of limitations to this approach: (1) the models may only confidently be used for predicting changes in the farmland bird indicator when the scale of land-use change falls within the bounds of data on which models developed and validated, i.e. maximum and minimum rates of land-use change between 1990 and 2005, (2) considerable uncertainty exists not only in the expected land-use predicted by the CAPRI model, but also in the predictive capacity of the regression models (Fig. 2) and (3) the CAPRI model is a very highly parameterised model, and therefore subject to considerable parameter uncertainty. Despite these limitations, the farmland bird indicator was successfully modelled, using few parameters, with a macro-scale approach.

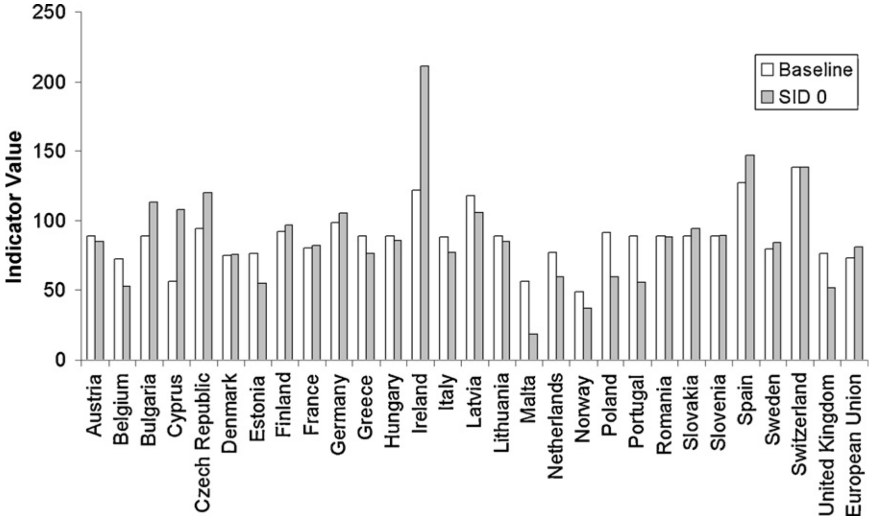

Fig. 3. Predicted farmland bird indicator values for the year 2002 (Baseline) and 2025 (SID0) for all EU states based on CAPRI model output. The SID0 scenario is the reference case based on CAPRI model output, it assumes 100% direct support, continued market Support, and zero research and development reinvestment.

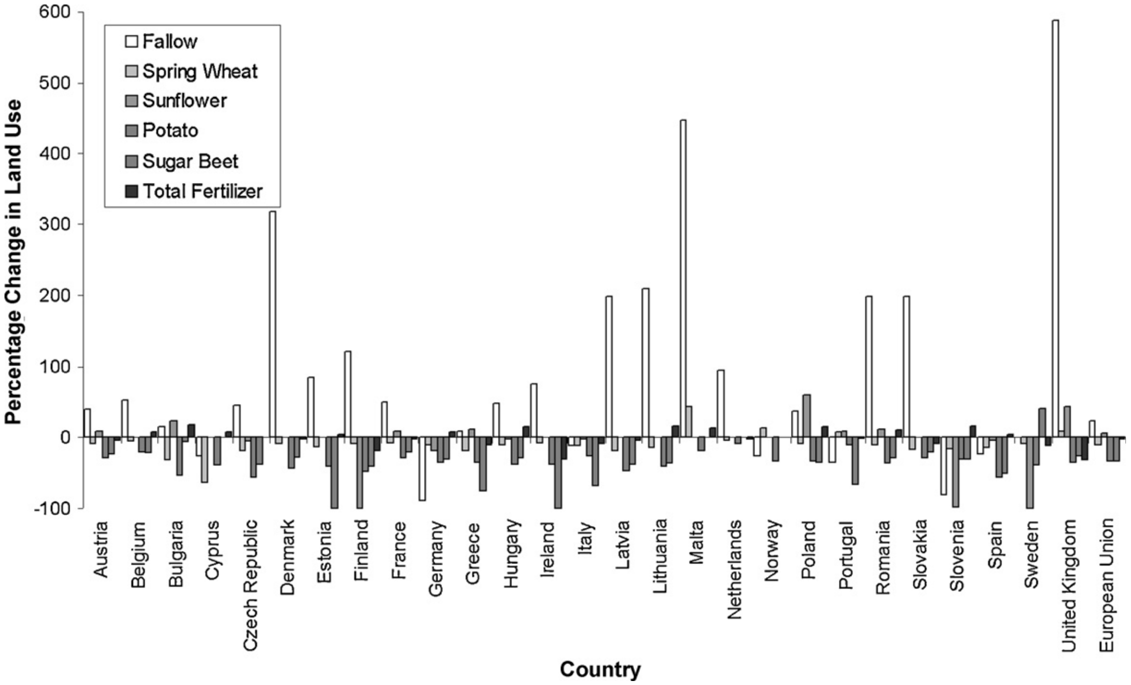

Fig. 4. Relative percentage change from 2002 to 2020 for land-use area as predicted by CAPRI (Britz, 2005).

Farmland bird species selected for the FBI show very contrasting ecological requirements, which in turn can make forecasts very difficult. Differences in the distribution of species may also determine contrasting trends of the indicator among countries. A reduced parameter approach may yield working models but may also produce some peculiar outcomes. For example, potato area was identified as a useful predictor of the UK farmland bird indicator. Although knowledge of the foraging and nesting requirements of birds included in the FBI suggested that this is a spurious predictor variable, the relationships may indicate that potato area is a proxy variable for the intensity of country level agriculture, and may be linked to agronomics more than habitat availability. This result may have revealed a fruitful area for future studies by raising the question of at which point do economic impacts start to give way to local impacts? Identifying this particular threshold may assist the development of a better understanding of scale impacts on European bird populations. The modelling approach used here yielded a well fitted model to the European scale data. We accept that such a model cannot take into account the lag and latency that may exist in population recovery of many farmland bird species. We also accept that such models cannot be applied at the farm scale, or for assisting in community level management of habitats. These models may serve useful however in the translation of EU level policy advice into country level biodiversity impacts through future predictive land-use change models such as CAPRI. An investigation into the response functions generated in this study, and the spatial variability in the variables of significance may assist in the development of other, large scale approaches. Finally, small scale, rule-base approaches are not a realistic approach to modelling bird populations at the EU

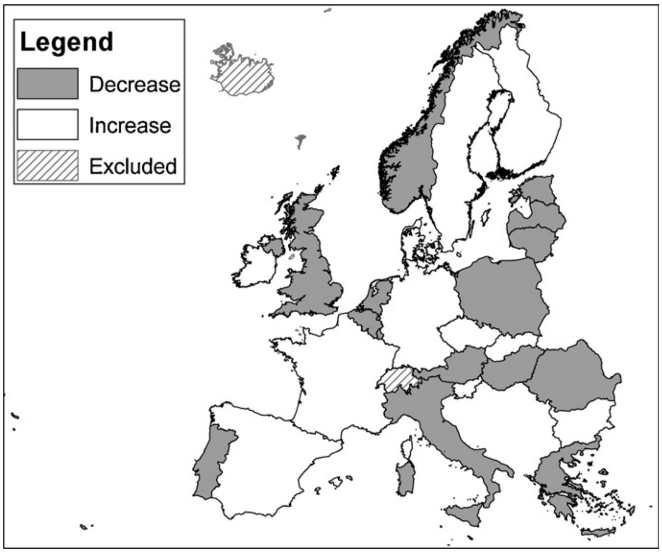

Fig. 5. Predicted relative change of the European Farmland Bird Indicator in 2025 relative to the baseline indicator values in 2002, based on agricultural land-use change modelled by CAPRI. Data for Iceland, Luxembourg, and Switzerland are not presented as they are not modelled by CAPRI.

level, as the inherent uncertainties are very likely to produce highly uncertain results.

The projected population trend data for 2025 is indicative of the sensitivity of regression models to values outside of their range of calibration, and should therefore be used with caution, especially given the uncertainties in predicted future land-use scenarios.

We suggest that future studies should aim to address the uncertainty of the underlying data, in particular the bird population observations, as well as uncertainty in the farm statistics, and for incorporation of these uncertainties into future attempts at modelling. The UK is just one example of a country with a very simple model, other country models may be more accurate following a similar exercise using a longer time series, this should be possible as more data becomes available. Also, the migration of passage birds and life cycle in other countries may also be a factor. A second generation model may take into account land-use change in countries visited by migratory species.

5. Conclusions

We have shown that trends in the area of crops can be used to predict current and future populations of farmland birds across Europe. This approach therefore has some merit in predicting farmland bird responses to future scenarios of changes in agriculture. We believe the parsimonious model developed here will prove a valuable tool for assessing the potential implications of agricultural policies for the target of halting the decline on farmland birds.

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