The economic value of Scottish ecosystem services

Short report to the OPERAs Project

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Overview

Scotland's distinctive assemblage of species and habitats characterises a great stock of natural capital from which people derive great benefit. Ecosystem services are crucial to the production of many vital goods underpinning and enhancing human well-being, including water quality and quantity, agricultural production, habitat for wildlife biodiversity, recreational areas, etc. However, the absence of markets for many such goods results in a lack of readily observable prices, which means that the true value of benefit flows to people is underestimated in national economic frameworks and traditional decision-making. Accurate valuation of natural capital related goods is a vital requirement for delivering efficient use of both market and non-market resources. In recent years, economists have attempted to address this challenge to decision making through a number of high profile studies, such as the pioneering work of the UK National Ecosystem Assessment (UK-NEA). We take application of methods of economic valuation presented in the UK-NEA further by considering additional essential ecosystem services (e.g. water quality) and, moreover, modelling the high degree of inter-dependency between natural systems.

The general aim of this work is to contribute to the improvement of decision-making relating to the management of Scotland's natural environment. Agriculture and forestry have a particularly important role in shaping landscapes and ecosystems in Scotland. We look at these management practices and the effect that they have on the wider delivery of ecosystem services. We acknowledge that the linkages which typify systems become both more complex and arguably more important when we consider the inter-relations between the natural world and economic activity. In essence, the novelty of our approach is that we appreciate that changes in natural capital related goods can be driven by many factors at the same time. For example, shifts in policy and continuing climate change may simultaneously affect land use. Furthermore, such land use change may in turn generate an array of impacts, all of which need to be analysed if we are to assess the true consequences of alternative policies. Additionally, by working with, rather than in ignorance of, natural variation the decision maker can target resources to those areas which yield the greatest net value and hence maximize the efficiency of resource use. A major weakness of existing approaches is that the decision maker has no clear means of knowing how any chosen end-point might be attained. While the final destination might appear clear, the route through which it is to be achieved is opaque.

Integrated model

First, we bring together natural scientists, geographers, economists and computer scientists to form an interdisciplinary team. We develop an innovative computer program which considers the linkages across different ecosystem services and derived goods. This integrated model attempts to represent the real-world system of major drivers and integrated flows to ascertain the true impacts of land use change. The model is programed to allow computerised assessments of the consequences of applying policies at any location and at any time. Optimal policies can be identified as those which yield the highest net benefits from available resources subject to various constraints.

The approach used is one of statistical modelling where observations of real world data are used to establish the nature of the relationships between cause and effect. In our case, econometric models relate the value of ecosystem service-reliant goods to natural environment, policy and economic market conditions. We attempt valuation for six

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component systems which are interconnected through their model outputs and inputs: agriculture, greenhouse gas emissions and sequestration on agricultural land, forestry and timber yield, water quality, outdoor recreation and biodiversity. For these analyses, Great Britain has been divided into a regular grid (2 km resolution) and, using econometric models, different flows of benefits to human well-being can been quantified at each grid cell; these include, for example, estimates for the market value of crops and livestock (£/yr) and non-market value of outdoor recreation (£/yr). These valuations are not exclusively in monetary terms e.g. biodiversity is measured in species richness. The integrated model, implemented in MATLAB, links the component systems together in a way such as to allow each component to process inputs into outputs at high speed and enable automated data synchronisation between systems.

Crucially, the integrated model allows us to see how changes in one system propagate changes through the other systems. In the first stage of our analysis we consider the inevitability of changes in UK temperature and precipitation. We use probabilistic projections of climate change, and absolute future climate, from UK Climate Projections data (UKCP09). UKCP09 reflects scientists' best understanding of how the climate system operates, how it might change in the future, and allows a measure of the uncertainty in future climate projections to be included. Specifically, we consider the medium greenhouse gas emissions scenario.

Summaries of the component systems are provided below.

Component systems

Agriculture Our agricultural model examines crop and livestock production, and estimates farm incomes. The structural econometric model assumes that each farmer maximizes profits per unit of land by solving a constrained optimisation problem. Decision-making is subject to physical environment, policy and price conditions (the latter of which we currently hold constant). To estimate the model, a quantitative analysis was undertaken to relate historic UK agricultural land use (cereals, oilseed rape, root crops, temporary grassland, permanent grassland and rough grazing, and other), livestock head counts (dairy cows, beef cows and sheep) and income records together with local and regional environmental factors (such as terrain, soil, climate) and land management policy (land designations, such as National Park). Holding all other factors constant, we can predict farmer decisions following natural variation in the climate. Average temperature and accumulated rainfall during the growing season influence crop types and stocking intensities for livestock. Specifically, we have found that for the period from 2013 to 2063, forecast climate change will result in a gradual increase in arable farming within lowland areas with some conversion of intermediate areas into cropping systems (particularly cereals) (Fig. 1). The same driver results in a decrease in lowland livestock intensities. Within upland areas, however, the predicted higher temperature and lower rainfalls allow for a conversion out of the lowest earning rough grazing category and into higher intensity livestock activities on temporary and permanent grasslands (Fig. 2). Taken together, these changes tend to drive up measures of farm income across the majority of Scotland (Fig. 3; Table 1).

Greenhouse gas emissions and sequestration Agriculture is a substantial emitter of greenhouse gases through for example, machinery use, mineral and organic fertiliser use, and livestock. While the majority of arable crops are consumed immediately, carbon sinks on land persist in living biomass (forests, perennials and tree-cropping systems), in addition to soil carbon. The ‘Cool Farm Tool’ was employed to calculate greenhouse gas flows from agricultural land, the composition of which was defined by our agricultural model. For the present analysis, this model predicts emissions from spatially-explicit environmental conditions (e.g. climate) and representative fertiliser use and management practices under different types of agricultural land use. Inspection of the current distribution reveals that emissions are dominated by the livestock sector. The increase in stocking densities predicted in upland areas result in increased net emissions in these areas over the 2013-2063 period (Fig. 4).

Forestry Temperature and precipitation are important factors for tree growth and timber yields. Expected forest growth is established using our modification of the Forestry Commission’s ‘Ecological Site Classification’ model. Specifically, the yield class (YC) for representative species for coniferous (Sitka Spruce, SS) and broadleaf (Penduculate Oak, POK) are considered. YC is the mean cubic metres growth, for each hectare of tree species for each year's growth. This represents the potential growth, under optimal management, if trees are present. YC is linked to the following explanatory variables: mean temperature and precipitation during the growing season; average slope and elevation; biodiversity; soil characteristics (water regime, pH, water capacity; carbon in soil). The relationship between YC and local characteristics can be represented by very complex non-linear functions and assumptions of linearity will result in biased outcomes. Therefore, we rely on semi-parametric regression models which enable the distribution of explanatory variables to be kept flexible, changing in accordance with the data. We expect that productivity of SS will increase at higher altitudes in Scotland as a result of warmer temperatures. POK productivity is also expected to increase in most areas.

Biodiversity We acknowledge that neither a single species nor a single taxonomic group can provide a perfect measure for wider biodiversity. However, it is recognised that birds, being positioned relatively high in Scottish food webs, do provide a defensible proxy for wider biodiversity health. Furthermore, they are almost certainly the group for which the best spatial and temporal data exists within the UK. A model of bird diversity was developed using Breeding Bird Survey data collected at a 1km square resolution between 1999 and 2011. These data were related to land use data from this period, together with various other predictors. Diversity was modelled for various categories of birdlife: (i) all species; (ii) farmland birds (of particular interest given declines in this group); (iii) woodland and upland habitat birds; (iv) birds on the red and amber lists of conservation concern; (v) birds on the green list (those not of conservation concern). Composition of the bird community represented by the presence and abundance of bird species in each survey square and year range was summarized using Simpson's Diversity Index, calculated in each year. Deciduous woodland has one of the largest estimated effects of land use upon bird biodiversity, namely increasing such woodland raises diversity. There is a negative linear effect for coniferous woodland, emphasising the importance of the difference between woodland compositions for bird diversity. Shifts in upland farming will, on the whole, be marginally beneficial for biodiversity (Fig. 5). However, it should be noted that Simpson's index is not without its drawbacks as it reflects the overall diversity of species and does not necessarily convey the loss of individual species within an area if there is a coincident influx of other species to that area.

Extensions to current analyses

We have considered a 'Business As Usual' type scenario: in essence, what happens due to climate change whilst keeping all other variables fixed, with the fundamental economic assumption that farmers will attempt to maximise their profits. Our next step is to consider an afforestation policy and how this might be implemented. Considering forestry has relationships with water quality, recreation, timber profits, greenhouse gases and biodiversity, it forms a highly suitable framework from which to assess and apply policy decisions. On-going work considers two further scenarios: a 'Market Value' scenario in which afforestation takes place but its location is guided purely by the value of the market priced goods concerned (agricultural outputs and forest timber values); a 'Full Values' scenario in which afforestation takes place but its location is guided by all values (market and non-market).

A notable design feature of the integrated model is its modularity: a component system can be removed, improved, added or replaced in a way that maintains consistency with all or any other system. This means that as more sophistication is added we are able to optimise for more features. It also allows for continuous improvement in estimating scenarios and refining results. We are currently making adjustments to our water quality and recreation models (see appendix).

Acknowledgements

This synopsis reflects on-going work by an interdisciplinary team from the University of East Anglia, University of Aberdeen, British Trust for Ornithology, and Forestry Commission. The team is led by Prof Ian J. Bateman, OBE. This report has been compiled by Amii R. Harwood.

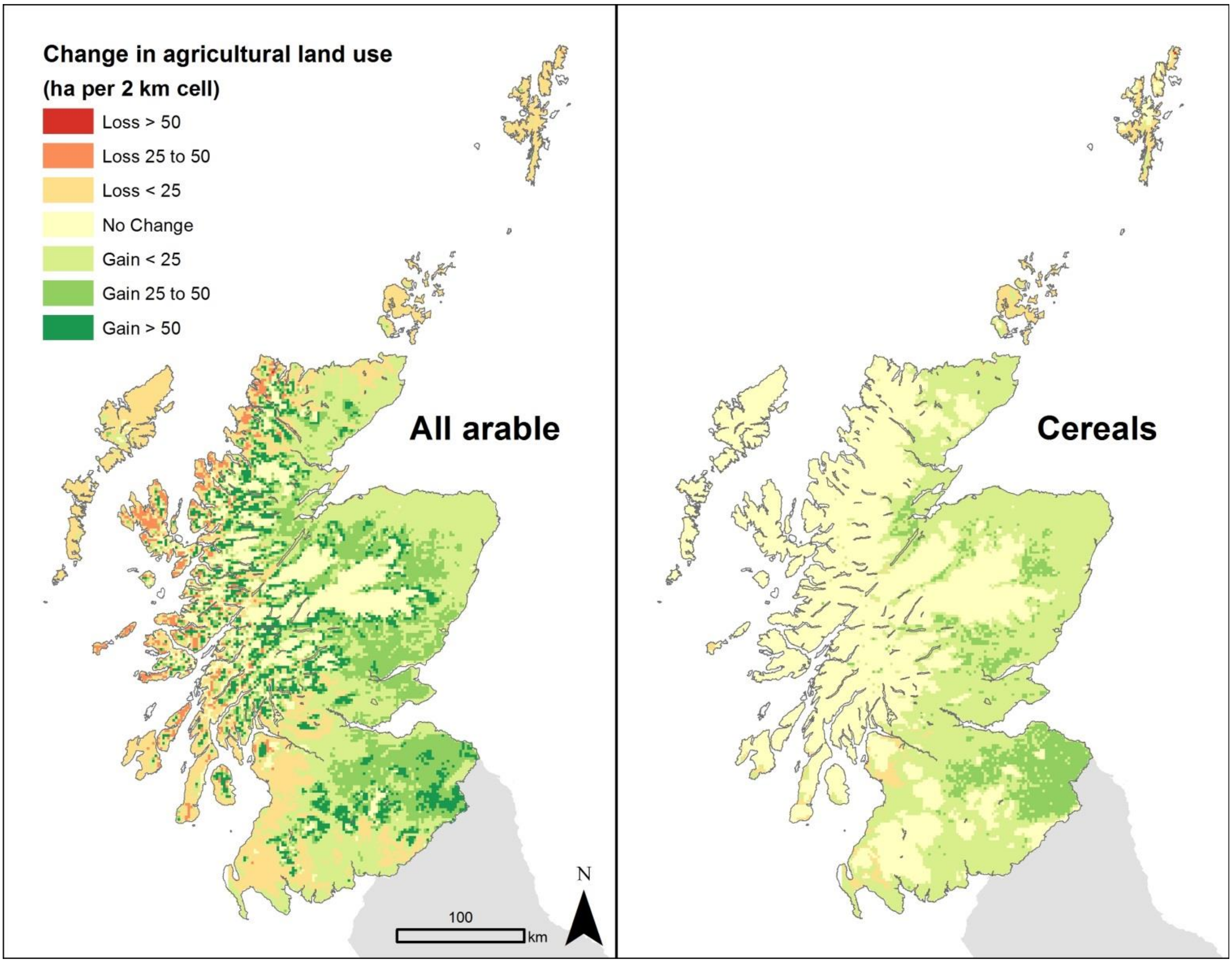


Fig. 1 Change in arable land use across Scotland as a result of climate change from 2013 to 2063.

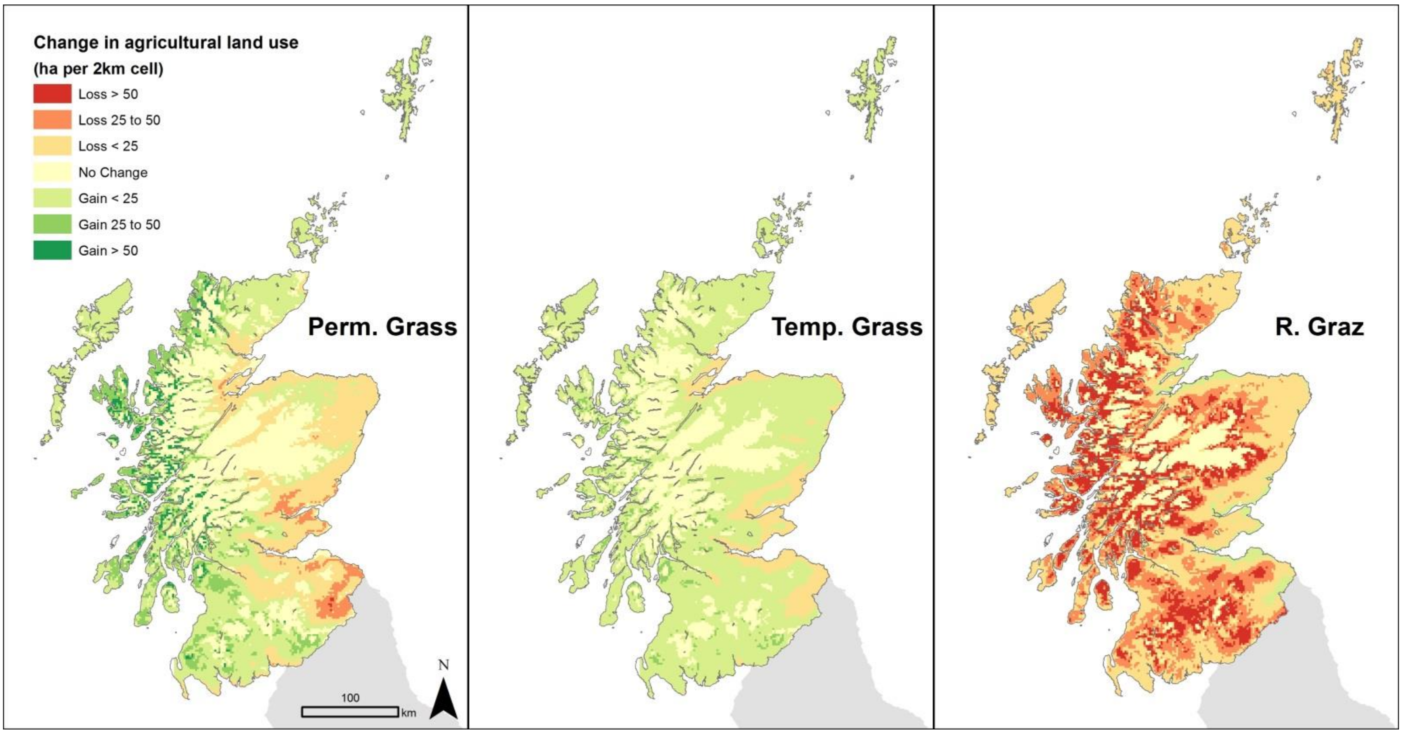


Fig. 2 Change in agricultural land use associated with livestock as a result of climate change from 2013 to 2063.

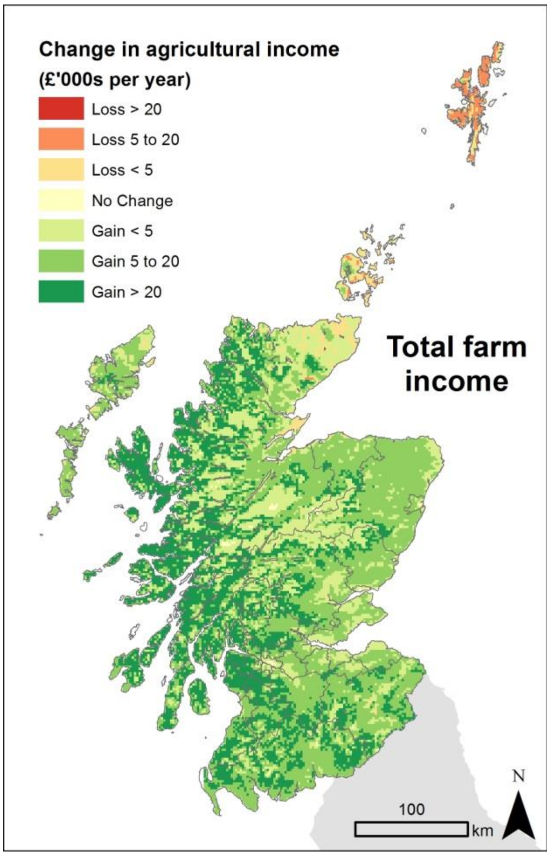


Fig. 3 Impact of climate change on agricultural income (measured as Farm Gross Margin)

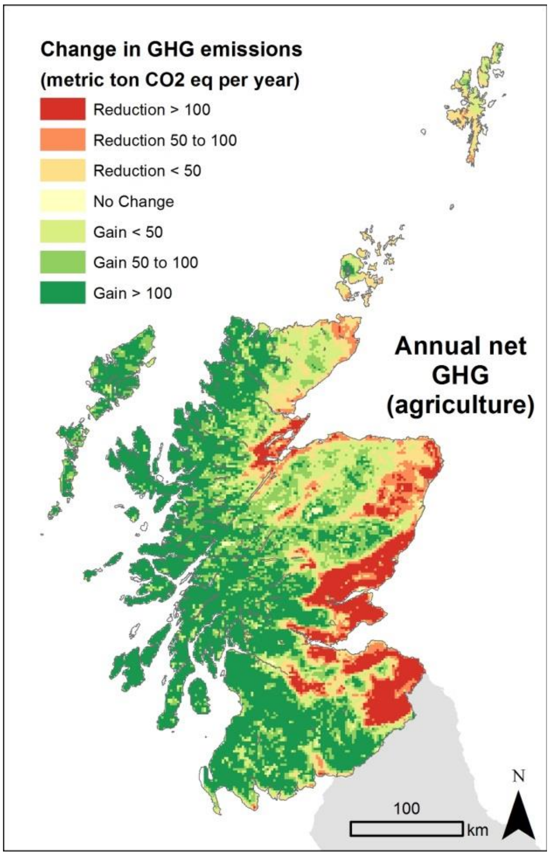


Fig. 4 Impact of climate change, and associated changes in agricultural land use and management regimes, on greenhouse gas (GHG) emissions

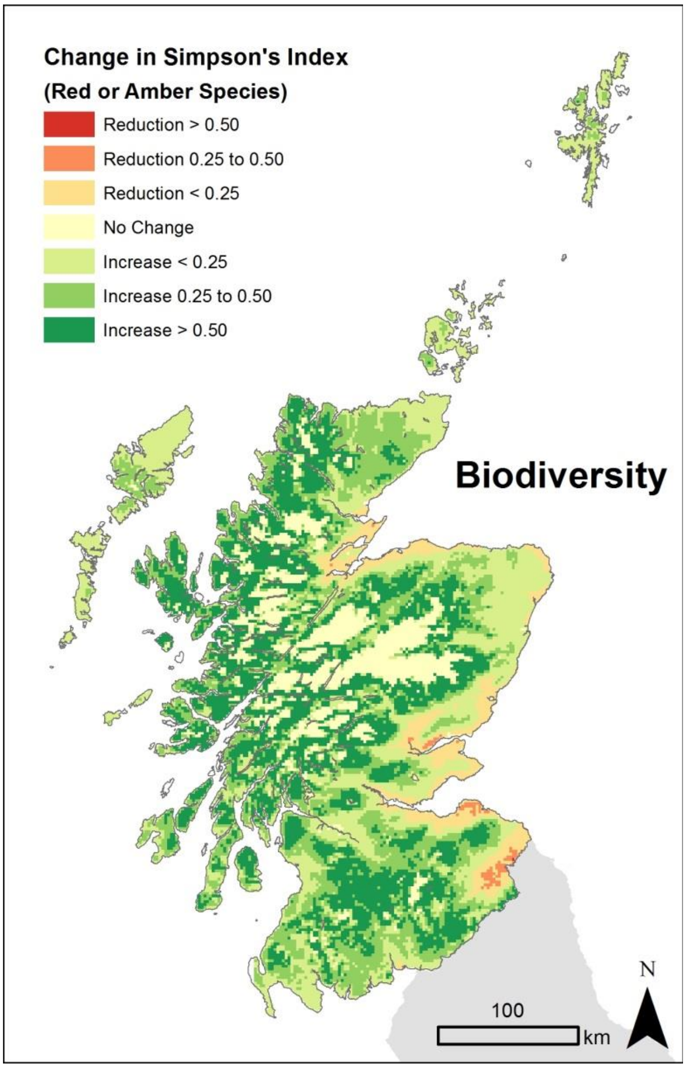


Fig. 5 Impact of climate change, and associated changes in agricultural land use, on birds currently accorded red or amber conservation status

Table 1 Predicted change in annual agricultural income from different land uses (£'000s per year, 2013 prices)

Region	Regional Groupings	Cereal	Root crops	OSRape	Other farm	Dairy cattle	Beef cattle	Sheep	Total
North East	NE Scotland	11,416	3,403	-26	6,876	5,561	-2,350	-2,487	**22,394**
North West	Eilean Siar	-3	40	0	-2,522	7,367	767	-146	**5,503**
	Highland	9,257	2,125	44	30,303	56,222	8,908	-409	**106,449**
	Orkney Islands	-205	268	0	-635	649	21	-244	**-145**
	Shetland Islands	-402	108	0	-1,407	191	214	-472	**-1,766**
South East	Fife	2,781	994	113	546	-1,395	-879	-389	**1,771**
	Lothian	4,628	1,131	211	295	-982	-955	-518	**3,809**
	Scottish Borders	13,476	2,261	778	6,540	-1,675	-2,193	-1,613	**17,573**
	Tayside	11,334	2,295	231	12,173	61	-1,251	-511	**24,332**
South West	Argyll & Bute	81	122	0	2,756	34,901	5,141	-276	**42,725**
	Ayrshire	717	409	0	1,399	14,915	1,512	-942	**18,009**
	Clyde Valley	4,190	624	101	2,544	7,209	583	-973	**14,279**
	Dumfries & Galloway	4,793	1,638	0	1,667	20,511	1,412	-1,859	**28,161**
	East Central	1,677	497	4	4,451	5,210	796	-81	**12,554**
		63,742	15,915	1,457	64,985	148,744	11,725	-10,920	**295,649**

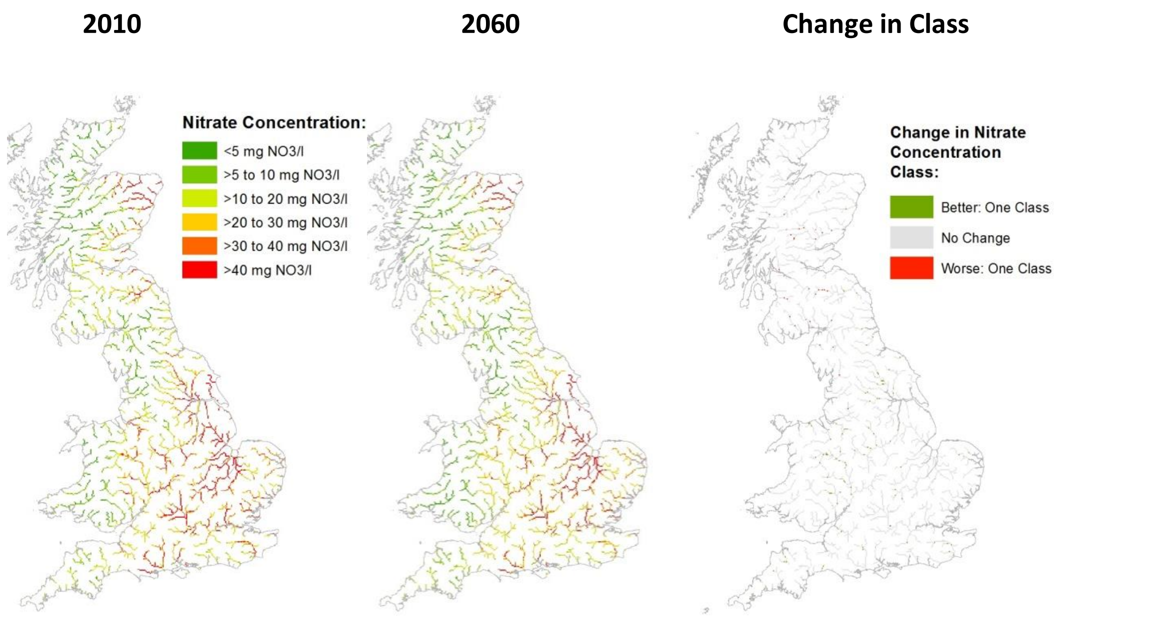
Appendix

Component systems under development

Water quality We link land use and the ecological status of river bodies in Great Britain. Modelling proceeds through two key steps. First, using data on observed nitrate and phosphate concentrations in rivers in England and Wales (General Quality Assessment classification scheme), statistical models are estimated that relate nutrient inputs on land (primarily from agriculture and sewage) to concentrations in rivers (Fig. A). Subsequently, using data on the ecological status of river bodies in Great Britain compiled under the Water Framework Directive, the statistical relationship between ecological status and nutrient concentrations is established. Our statistical modelling exercise shows highly significant relationships between land use, nutrient concentrations and on to ecological status. Our model enables us to make predictions for the ecological status of Scottish river bodies under agricultural land use change. Those ecological statuses feed directly into the Water Recreation Model.

Recreation The water recreation model examines the relationship between ecological quality of rivers, the characteristics of associated potential recreation sites, and the preferences of individuals in evaluating the 'use' and 'non-use' value of such sites. Using a bespoke random utility model, evidence is presented that utility from the 'use' of natural resources declines with distance from an individual's home, and that the nature of values emanating from river quality attributes, differ with regard to 'use' and 'non-use' categorisations. In particular, the model finds that although incremental improvement in the ecological status of rivers is associated within increasing 'non-use' utility, only an achievement of the highest ecological status was found to provide meaningful increases in 'use' utility. This suggests that 'non-use' utility may be a significant component of the welfare gains that arise from lesser improvements in the ecological status of rivers.

Fig. A Comparison in Nitrate Concentration Class between 2010 and 2060 under the Business as Usual scenario



Background information

Table A presents a breakdown of current Scottish agriculture (compared to UK and other country totals).

Table A Agricultural Land Use in the UK (by country) – June 2010 Census (After ERSA 2011)

	Scotland	England	Wales	N. Ireland	UK
Number of holdings(1)	**52,279**	105,450	40,618	24,471	222,818
	Area (ha)	Area (ha)	Area (ha)	Area (ha)	Area (ha)
Total crops and fallow	**572,131**	4,067,159	86,530	56,916	4,782,736
Grass:					
Under 5 years	**423,178**	586,690	103,247	118,386	1,231,501
5 years and over	**955,382**	3,288,366	1,020,506	660,949	5,925,203
Total grass	**1,378,560**	3,875,056	1,123,753	779,335	7,156,704
Rough grazing:					
Sole right grazing	**3,191,593**	493,048	229,614	140,337	4,054,592
Common Grazing(5)	**583,728**	427,889	180,305	36,438	1,228,360
Total rough grazing	**3,775,320**	920,937	409,919	176,775	5,282,951
Woodland	**399,379**	295,295	69,128	10,161	773,963
Other land	**101,391**	156,737	20,384	6,369	284,881
Total agricultural area	**6,226,781**	9,315,184	1,709,714	1,029,556	18,281,236
Total land area(6)	**8,023,862**	13,293,767	2,122,466	1,412,972	24,853,067

(1) Refers only to holdings actively engaged in agriculture but excludes sheep stock clubs in Scotland and non-commercial holdings in England.
(5) Inclusion of common grazing land brings total agricultural area in Scotland to a higher level than that published in the June agricultural census publication.
(6) As at December 2009. Data source: UK Standard Area Measurements (SAM), published by Office for National Statistics, 2009. This definition refers to extent of realm.

Source:

ERSA (2011). Economic Report on Scottish Agriculture 2011 Edition. A National Statistics publication for Scotland. Scottish Government Rural Payments and Inspections Directorate, Rural and Environment Science and Analytical Services. ISBN 9781780452111. Available online: http://www.scotland.gov.uk/Publications/2011/06/15143401/0