# An Ecological-Economic Model for Agri-Environmental Policy Decision Support

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**Abstract:** Operational models of economic activity, particularly at the farm scale, have become commonly used, and widely accepted methods and applications exist. Operational models of ecological systems probably have less of a history but processes of species interaction and succession are well documented. Relationships between economic farm-scale variables and resultant ecological diversity, however, are less well documented as are modelling frameworks that combine both economic and ecological operational systems. This paper explains how a farm-level economic modelling framework may be linked to an ecological modelling system with the objective of allowing *ex ante* assessment of the ecological impact of certain key agricultural management parameters. A modelling framework for interrogating ecological-economic vegetation systems is introduced and the decision support concept demonstrated. Data pertaining to a survey of farm sites are used to demonstrate the types of relationships which emerge between agricultural management parameters and grassland vegetation and a specific case-study site is selected for ecological and economic assessment under potential policy scenarios. The results of the analysis highlight the relevance of such an integrated modelling system for agri-environmental policy decision support.

***Keywords***: Grassland management; Species diversity; Ecological-Economic modelling, Policy decision support.

## 1. INTRODUCTION

Agricultural policy has undergone significant reform within recent years, not only in terms of implementation, but more importantly, in terms of direction and fundamental objectives. Specifically, the focus of agricultural policy is now geared heavily towards environmental protection rather than agricultural productivity, through agri-environmental policy (AEP).

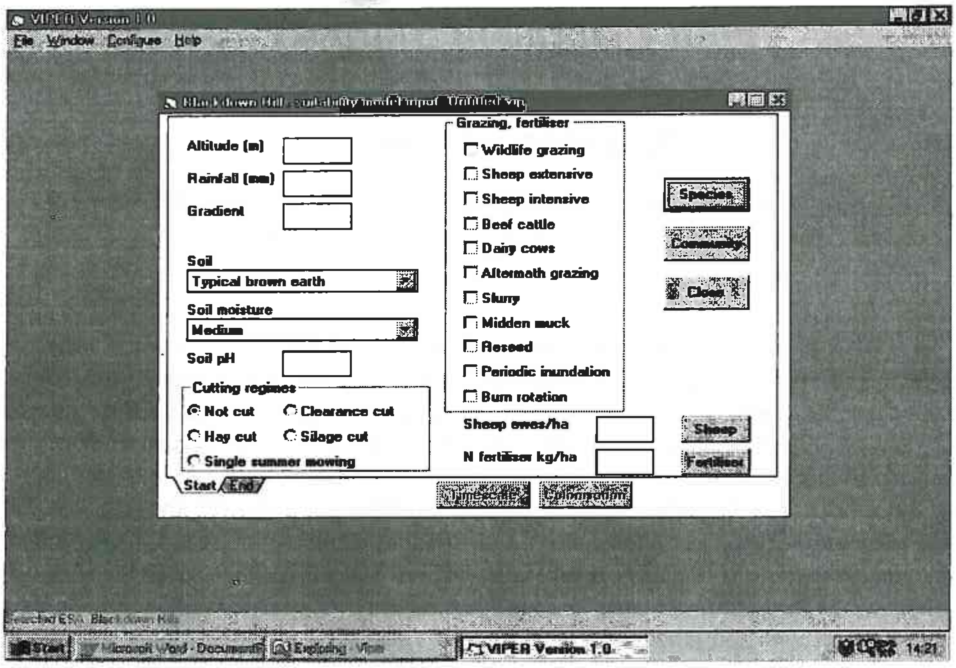
Sound formulation of AEP requires knowledge about the specific relationships that exist between farm management practices, base environmental conditions and species composition of prevailing ecosystems. When determining the desired outcome of a certain environmental policy, the policy maker must be able to find out *how* to successfully derive that environmental outcome (through manipulation of farm management), and *where* the outcome is most likely to be achieved (under which base environmental conditions). One could achieve this by overlaying ecological ordination maps with biplots of management information to visually determine which management practices, on which sites, were most likely to be associated with which vegetation or vegetation dynamic.

However, identifying the relationships between such management and environmental conditions and the resultant diversity of grassland vegetation in this fashion is fairly inefficient. The requirement to physically overlay ordinations of alternate variables and distributions of species allows potential errors of human judgement to occur and essentially makes the identification of such relationships fairly qualitative. It would be better to develop a systematic set of relationships between species, environment and management, which could be represented in an operational, quantitative model.

## 2. ECOLOGICAL-ECONOMIC MODEL

This present study combines an ecological model developed by Sanderson et al. [1995] with an economic model developed by Oglethorpe [1996]. First, the ecological model, provides the operational capacity to look at the ecological effects of physical land-use change. This model was formulated using published data detailing the environmental and management relationships determining the presence of, or which were associated with, specific grassland communities listed within the National Vegetation Classification (NVC) [Rodwell, 1991 & 1992]. Sanderson et al. [1995] catalogued these relationships between environmental/management variables and each grassland community and created a model linking site specific information with ecological diversity.

This model, the Vegetation Investigation Programme for ESA Research (VIPER) (where ESA stands for Environmentally Sensitive Area), can be run, inputting the environmental characteristics of a particular site regarding soil type, altitude, rainfall and gradient, and also the prevailing management characteristics at that site. First, the user specifies the region for their analysis and then calibrates the model according to base environmental and management conditions (e.g. see Screen 1).


Soil: Typical brown earth

Soil moisture: Medium

Cutting regimes: ● Not cut

**Screen 1.** Calibration

Once the model is calibrated it can be run to predict the species and plant communities most likely to be present at such a site and then used to test scenarios of management change to make comparative static predictions about how desired states of nature might be achieved.

However, the VIPER only serves as a predictive tool for the ecological effects of agri-environmental policy. Clearly, the reasons for farmers actually adopting new strategies under changing external conditions (such as policy change) are due to economic forces, where relative prices and income variability change the economic efficiency of different enterprises and their associated input use. Thus, appraisal of agri-environmental policy requires not only an analysis of the ecological effects of physical land-use change (type and intensity) but also requires appraisal of the economic costs of the policy.

A model developed to do just this, based on the subjective expected utility hypothesis, was developed by Oglethorpe [1996]. This model incorporates a MOTAD framework (Minimisation Of Total Absolute Deviations, [Hazell, 1971] which produces an estimated trade-off function between income and associated income variance. Through incorporation of farmer-specific risk aversion parameters within this function, a model of subjective expected utility can be derived, the maximisation of which allows definition of the utility maximising farm plan [Oglethorpe, 1996]. Validation of this model, for a large number of farm situations, has shown it to allow accurate simulations of farm-level activity (both in terms of economic return and land-use intensity) under various historically observed situations. It has also proved to be superior in this regard to a comparable profit-maximising model [Oglethorpe, 1995]. This subjective expected utility maximising model (hereafter referred to as the SEUM) can therefore be used in conjunction with the VIPER to assess the economic and ecological effects of agri-environmental policy change.

The SEUM can be calibrated for a specific farm/farmer situation and can be used to create predictions regarding changes in the intensity of production driven by economic response to potential policy change. These predictions, in the form of output from the SEUM can be used as an input to the VIPER in the form of a new farm management scenario, given that base environmental conditions for the farm are known. Typically, agri-environmental policy involves reductions in farm intensity in return for compensatory payments. However, the compensatory payments involved are often difficult to justify and may not follow a correct opportunity cost pricing procedure. This two-model system allows a more precise estimation of possible compensatory payments by predicting the amount of farm income foregone when reductions in land-use intensity are introduced to generate changes in ecological diversity. The ecological-economic modelling system also aids identification of the intensity at which the desired species mix can be attained and thus what costs must be borne to achieve that species mix. The following section outlines a case-study procedure where the modelling system is used to assess the economic cost of ecological changes driven by management change. The models could be used in this way to predict the effect of a variety of different policy scenarios.

## 3. MODEL ANALYSIS

The procedure for this analysis follows four key stages. First, the SEUM is calibrated[1] to simulate the initial land use and intensity of production for a certain farm situation for which validation data are available. Second, the VIPER is run to predict the species most likely to be associated with the management conditions implied by this simulation, and the base environmental conditions of the site in question. Comparing the species mix predicted by the VIPER with the species actually observed on this site then creates a validation test for the VIPER.

Third, once verified as a suitable predictor of observed species composition, the VIPER is then run under alternative, reduced intensity, management strategies. The output from these runs provide predictions as to which NVC Communities and grassland species might be associated with those management plans. As a final stage of the analysis, the previously calibrated SEUM is then run constrained by each of these management regimes to suggest how farm income may change under such reduced intensity of land use. In this way, various policy scenarios, which reduce farm intensity to differing degrees can be assessed as to their economic cost and ecological benefit.

For the following analysis, data relating to a case-study farm were selected from an existing dataset [Oglethorpe, 1996]. This data provided the necessary farm-specific calibration information to generate a 'base' simulation of the performance of the farm (a model run against which further model runs could be compared). The farm was located within the Tyne River Catchment in the north-east of England, UK.

The total area of the farm studied was 200 ha. This was subdivided, according to categorisations made by the surveyed farmer, into a total "Hill Grazing" area of 160 hectares. This was further split between an area of rough grazing extending to 72 hectares and a further 88 hectares of permanent pasture, both sustaining similar livestock numbers under similar grass management regimes (no nitrogen applications). The remaining 40 hectares of land, classified as "Inbye" (permanent pasture lying at relatively low altitudes, compared to hill grazing land, close to the farm steading), was used for grass conservation, aftermath grazing and winter keep. This area received a more intensive management plan and provided winter fodder through an annual crop of silage, plus sheltered winter grazing for livestock. A breakdown of land use, intensity of production and financial returns predicted under base conditions for the farm, using the SEUM, is provided in Table 1.

In terms of financial performance, Management and Investment Income (MII) is fairly low at £6738 compared to regional average figures [Challinor and Scott, 1994]. This reflects the poor prices attained by the farmer in the survey year and the low number of lambs being finished on farm (6% of lambs finished against 32% in the regional average figures. As a consequence, the farm is heavily dependent on livestock subsidies, which account for 42% of gross revenue.

**Table 1.** Model simulation of the base situation for the case-study farm.

| | | |
|---|---|---|
| **Land Use** (hectares) | Hill Grazing | 160 |
| | Inbye Keep | 18 |
| | Inbye Silage | 22 |
| **Livestock Numbers** (head) | Hill Ewes | 750 |
| | Suckler Cows | 37 |
| | Finished lambs | 38 |
| | Store lambs | 600 |
| | Cast Ewes | 165 |
| | Suckled Calves | 37 |
| **Intensity Measures** | | |
| *Mean N Use (kg N/ha):* | Hill Grazing | 0 |
| | Inbye Grazing | 140 |
| | Inbye Silage | 220 |
| *Ewe Equivalents/ha:* | Hill Grazing | 5.43 |
| | Inbye Grazing | 6.72 |
| **Revenue (£)** | Finished Stock | 1200 |
| | Store Stock | 28056 |
| | Cull Stock | 3630 |
| | Subsidies | 24145 |
| | **Total Revenue (£)** | 57031 |
| **Variable Costs (£)** | Fertilisers | 2017 |
| | Forage/Fodder | 6423 |
| | Concentrates | 3454 |
| | Replacements/Vet/Med. | 10688 |
| | **Total Variable Costs (£)** | 22582 |
| | **Total Farm Gross Margin (£)** | 34245 |
| **Fixed Costs (£)** | Labour | 9083 |
| | Machinery | 2718 |
| | Depreciation | 3313 |
| | Interest | 398 |
| | Rent | 6000 |
| | Overheads | 6200 |
| | **Total Fixed Costs (£)** | 27711 |
| **MANAGEMENT AND INVESTMENT INCOME (£)** | | 6738 |

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[1] 'Calibration' here refers to the process of identifying key farm parameters such as land area and capability, labour availability, livestock housing, etc. and adjusting the model accordingly.

The key management data required from this model simulation for VIPER analysis are the intensity measures of nitrogen application and stocking density. The stocking rates given in Table 1 represent the maximum grazing intensity that might occur on that land at any one time of the year. For example, since suckler cows have access to the hill grazing area at certain times of the year, it is possible that there will be times when all hill ewes and all suckler cows are grazing that area of land. At this point, the stocking intensity will be at a maximum for the year and is thus taken to be the rate at which the VIPER analysis is done. The site specificity of the data required to run the VIPER necessitated two separate analyses to be done regarding the possible extensification of the hill grazing area and the more intensively managed inbye land. This was because the actual locations of the two areas differed quite markedly in terms of altitude, gradient and soil type, which are vital deterministic characteristics for the distribution of grassland species [Rodwell, 1991 & 1992]. The hill grazing area lay to the north of the farm buildings and the inbye to the south. The two areas were separated by a wide tract of unmanaged land embracing Hadrian's Wall. Hence, rather than dwell on repetitive analysis, the more diverse Inbye land is reported upon here, for brevity.

To conduct the analysis, the VIPER was initially run to predict the vegetation under the prevailing baseline environmental and management conditions according to the survey data supplied and the simulation provided by the SEUM. As mentioned above, the output from the VIPER initially provides a prediction of the NVC Communities, and top ten species, most likely to be associated with those conditions. This output is then compared to the species actually observed at each site, to provide model verification. The verification for the case study site is presented in Table 2.

**Table 2.** VIPER predicted top ten species against observed species (in order of abundance).

| VIPER Predictions |
|---|
| *Holcus lanatus, Lolium perenne, Trifolium repens, Dactylis glomerata, Cerastium fontanium, Ranunculus acris, Festuca rubra, Poa trivialis, Plantago lanceolata, Ranunculus repens* |
| Observed |
| *Agrostis tenuis, Cerastium holosteoides, Lolium perenne, Poa annua, Trifolium repens, Poa pratensis, Festuca rubra, Holcus lanatus, Alopecurus geniculatus, Bellis perennis,* Cynosurus cristatus, *Deschampsia cespitosa, Juncus effusus, Lolium multiflorum, Phleum pratense, Poa subcaerulea, Ranunculus acris, Rhytidiadelphus squarrosus, Urtica dioica.* |

As shown, five of the top ten species predicted were also recorded under survey as present at the site; *Holcus lanatus*, *Lolium perenne*, *Trifolium repens*, *Ranunculus acris* and *Festuca rubra*. A further three of the predicted species matched the observed species but only by the main species genus (*Cerastium fontanium*, *Poa trivialis* and *Ranunculus repens*). The two remaining species predicted, *Dactylis glomerata* and *Plantago lanceolata* were not matched. In addition, *Lolium perenne* and *Trifolium repens*, species which are associated with more intensively managed (often reseeded) swards, are shown to be highly dominant in both lists. Also, although *Dactylis glomerata* is predicted but not matched, it has similarities with the observed species *Phleum pratense* in that they have both been traditionally used in seed mixtures for upland pastures and are thus associated with similar management conditions. This suggests that the VIPER has at least responded correctly to the key management criteria identified in the calibration process.

The dominant NVC communities and habitat suitability indices predicted by the VIPER are presented in Table 3.

**Table 3.** VIPER predicted NVC communities and Habitat Suitability Indices (HIS).

| Predicted NVC Communities | NVC Code | HSI |
|---|---|---|
| *Lolium perenne-Cynosurus cristatus* | MG6 | 0.216 |
| *Holcus lanatus-Juncus effusus* | MG10 | 0.202 |
| *Holcus lanatus-Deschampsia cespitosa* | MG9 | 0.202 |
| *Lolium perenne* leys | MG7 | 0.199 |

The top four NVC communities predicted are all Mesotrophic Grasslands [Rodwell, 1992] and, unlike the hill grazing area where one single community was highly dominant, these communities all have similar dominance with regard to their HSIs. The two communities associated with *Lolium perenne*, MG6 and MG7, are particularly common on lowland permanent pastures in Britain and respond well to inorganic nitrogen applications. However, they tend to be succeeded by a variety of weeds when overgrazed or trampled by cattle, or succeeded by coarser vegetation such as the *Holcus lanatus-Juncus effusus* community (MG10) when grazing is relaxed, particularly when field drains become overgrown and choked as a result [Rodwell, 1992]. Consequently, we might expect an extensification of the farm plan on the inbye land to lead to MG10 and MG9 (predicted with identical HSIs) gradually replacing MG6 and MG7 as nitrogen applications and livestock numbers are withdrawn.

The VIPER was then run under a number of decreasing intensity management scenarios, to predict the likely stable-state NVC Communities and species composition associated with those management plans. For each of these management scenarios, the SEUM is then run to determine the opportunity cost of lost production of these reductions in land-use intensity which reflect the compensatory payments required, should such management changes be instigated through agri-environmental policy.

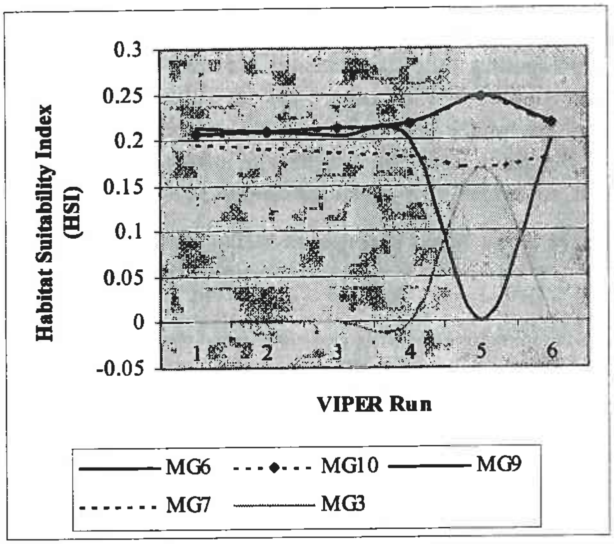
A detailed analysis of the changes in vegetation likely to be present under specific changes management were considered through a series of model runs. Since the base management of the land involved the use of inorganic nitrogen, the different management scenarios considered involved reductions in both stocking rate and nitrogen application. The specific scenarios used for each VIPER run are summarised in Table 4, showing how the management plan was extensified according to these two parameters and any other management changes considered. The remaining base environmental and management were left unchanged under each plan.

**Table 4.** Management scenarios for VEMM runs of reduced intensity on the Inbye Area.

| VIPER Run | Nitrogen (kg/ha) | Stocking rate (EE/ha) | Other changes from base management |
|---|---|---|---|
| 1 | 75 | 5.0 | - |
| 2 | 50 | 4.0 | - |
| 3 | 25 | 3.0 | - |
| 4 | 0 | 2.0 | - |
| 5 | 0 | 1.0 | No Slurry |
| 6 | 25 | 2.0 | - |

Runs 1 to 5 follow steady falls in both nitrogen application and stocking rate with the removal of slurry (or muck) spreading under run 5 representing the last reduction in nitrogen possible, where organic sources are no longer applied. Run 6 however, includes a mix of runs 3 and 4, and was carried out to simulate a possible ESA management scenario where typical agreements require similar levels of intensity to be adhered to on inbye land [MAFF, 1995].

Figure 1 shows how the Habitat Suitability Indices (HSIs) of the NVC communities previously predicted might change under these different management plans and any other communities which might emerge as a result of the reduced intensity. The results in Figure 1 concur with Rodwell's intimation that reduced intensity might lead to dominance of MG10 and MG9 over the *Lolium* communities. MG6 actually drops out of the top four most likely communities under the very extensive plan of run 5 and is replaced by (MG3). This species-rich community is synonymous with hay-meadows in Northern England [Rodwell, 1992] and is associated with many rare species, but has declined since the war as a result of agricultural intensification. It is therefore likely to be highly valuable regarding its environmental or conservation merit. The other four communities have no direct association with rare species, however, over numerous samples Rodwell [1992] shows that MG9 and MG10 have a greater floristic diversity. In Table 5, details of the floristic diversity for each of these four communities are given showing the number of species attaining different constancy scores.



MG6 = *Lolium perenne-Cynosurus cristatus*
MG10 = *Holcus lanatus-Juncus effusus*
MG9 = *Holcus lanatus-Deschampsia cespitosa*
MG7 = *Lolium perenne*
MG3 = *Anthoxanth. odoratum-Geranium sylvaticum*

**Figure 1.** Viper Predicted NVC Communities and Habitat Suitability Indices under Reduced Intensity Scenarios

**Table 5.** Floristic diversity of NVC communities.

| Number of species with | MG6 | MG7 | MG9 | MG10 |
|---|---|---|---|---|
| Constancy 5 | 3 | 2 | 1 | 2 |
| Constancy 4 | 3 | 1 | 1 | 2 |
| Constancy 3 | 6 | 5 | 5 | 3 |
| Constancy 2 | 10 | 13 | 16 | 12 |
| Constancy 1 | 32 | 19 | 57 | 39 |
| Total Number of Species | 54 | 40 | 80 | 58 |

Source: Rodwell [1992].

From this data it is clear that the diversity of grassland species is likely to be enhanced by the increasing dominance of communities MG10 and in particular MG9. Therefore, even without reducing management intensity to the level described under run 5, an environmental enhancement may be possible through the suggested ESA prescription as described by Run 6. In this case MG9 and MG10 surpass MG6 and MG7 in dominance thus creating an increase in the diversity of vegetation likely to emerge. Such a policy prescription must be assessed as to its economic viability. Although costs associated with fertiliser applications would recede under reduced intensity, the reductions in stocking rate would again undoubtedly cause a loss in income to the farmer. These potential losses in income were therefore estimated using the SEUM, calibrated to represent the base situation for the case-study farm, and run under the constraints imposed by the reductions in management intensity. Table 6 summarises the changes in Management and Investment Income (MII) predicted by the SEUM to occur at the different management scenarios (representing the decreasing levels of intensity identified by VIPER runs 1 to 6 in Table 4). A value is given for the change in MII per ewe equivalent left on the farm under each scenario, compared to initial MII, representing a possible compensatory payment.

**Table 6.** Predicted Changes in MII across Scenarios

| Management Scenario | MII (£) | Change from base MII per EE left |
|---|---|---|
| *Base* | *6738* | |
| 1 | 6406 | 0.38 |
| 2 | 5977 | 0.82 |
| 3 | 5512 | 1.32 |
| 4 | 5036 | 1.83 |
| 5 | 4971 | 1.92 |
| 6 | 5509 | 1.32 |

MII therefore shifts fairly linearly with the first four reductions in management intensity, but this is associated with some 'noise' in terms of grazing enterprises, when the results are examined more closely. In particular, there are several substitutions between cattle and sheep enterprises between the first two scenarios and between the scenarios 2 and 3, and 3 and 4, there is a shift out of one sheep activity to another (utilising a different breed and feeding regime). These shifts in grazing patterns would be likely to have further environmental consequences, which we could return to the VIPER to analyse.

Under scenario 5, the marginal fall in MII becomes less, representing a total fall of £1.92 per ewe equivalent remaining in comparison to base. This is primarily because slack land becomes available, meaning stocking density requirements can be achieved without further (or as many) losses in livestock numbers.

Under management scenario 6, representative of a typical potential ESA management agreement on inbye land, the MII falls by £1229, which equates to a loss of £30.75 per hectare of inbye on this farm. This value falls somewhat short of the comparative Lake District ESA payment made for such a restriction on inbye land of £55 per hectare [MAFF, 1995]. However, as stipulated in ESA agreements, a fundamental rule of adopting any scheme is that stocking rates on the remaining land must not be increased [MAFF, 1995]. A closer examination of the results showed that the financial consequence of scenario 6 included a counterbalancing expansion of sheep numbers on the hill grazing area of the farm (the remaining 160 ha) hill ewe flock. A re-run of the model not permitting leasing-in of ewe quota suggests that this restriction would create a fall in MII of £3063, equating to a loss of £76.58 per hectare of inbye land.

This analysis suggests therefore that changes to the management of the case-study farm could derive positive environmental benefits at costs not dissimilar from payments made within similar environmentally sensitive area management schemes. The floristic diversity of the inbye land is likely to be enhanced under management scenario 6 and it may be possible that certain rare species may emerge if management was restricted in line with the more limiting prescription outlined in scenario 5.

## 4. CONCLUDING COMMENTS

The analysis presented in this study has shown how two distinct modelling frameworks originating from different subject areas can be combined to produce useful supportive information for policy decision making. Environmental goods and potential enhancements, as perceived by ecologists, have been identified and a costing system for the supply of those goods has been demonstrated. The results concurred well with existing policy measures designed to create similar environmental goods thus suggesting the modelling framework as a plausible tool for the analysis of potential environmental policy change.

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