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 which combine both economic and ecological operational systems. This paper explains how a utility maximising 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. Two models, initially designed for independent analyses, are introduced. 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. 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 environmental policy decision support.

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

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. This transformation is now becoming endorsed globally by such bodies as the World Commission on Environment and Development (WCED) who, in the Bruntland Report (WCED, 1987), recognised the need for new forms of economic development to be initiated which would sustain environmental capacities for future generations.

Since the development of such initiatives, many countries, particularly member states of the OECD, have formulated national environmental policies specifically aimed at encouraging agricultural producers to adopt less intensive farming systems (HANLEY, 1995). Clearly, therefore, goals relating to the biodiversity and sustainability of farm eco-systems are becoming as relevant as the more pecuniary objectives of agricultural policy such as price support and farm income stability. Further, the relative importance of such environmental objectives has meant that appraisal of the success of agricultural policy often now requires assessment of both the economic response and the subsequent environmental consequences. Thus, in order to assess the likely outcome of agri-environmental policy change, we are not only required to analyse physical and financial economic activity but also to examine whether the desired environmental outcome is likely to be attained as a result of that activity.

In many cases, agri-environmental policies are designed to allow generation of, or to sustain, certain ecologically valuable habitats. As a simple example, under the Sites of Special Scientific Interest (SSSI) Schemes, set up after the 1949 UK Agriculture Act and re-notified as a result of the 1981 Wildlife and Countryside Act in the UK, specific areas of land providing habitats for rare, and often endangered, plant (and wildlife) species are designated as protected areas under which agricultural management practices are regulated. In addition to the SSSIs, other site-specific environmental protection schemes have been initiated throughout the past two decades by Government and NGOs throughout the UK (for example, by English Nature, Scottish Natural Heritage, and National Park Authorities). A common characteristic of many of the schemes initiated by these organisations is that, in order to achieve their goals, the policy is directed at the farmer as the agent to produce the desired environmental goods. These goods may take a fairly general form, requiring the promotion of more 'traditional' farming practices, or they might be concerned with the regeneration of a specific vegetation community. However, the common thread is that the farmer is specifically required to alter his management strategy in accordance with the relevant regulations. Also, a further common basis of these farm-specific policies arises in their formulation: various criteria regarding site and situation must at some stage be recognised in order for management plans to be drawn up and specific farms or farming regions to be targeted as the ones most likely to provide the desired environmental goods.

Identification of the measures necessary to provide the desired environmental outcome, essentially follows a two step procedure: first to identify the specific management practices, that second, will provide the means for achieving the environmental goods. Possible examples of this procedure could include: using stokking rate restrictions to form a combination of grassland species best suited for creating nesting habitats for endangered bird species; limiting grass cutting operations to promote the emergence of declining wild flower populations within herb rich pastures; discouraging pestici-

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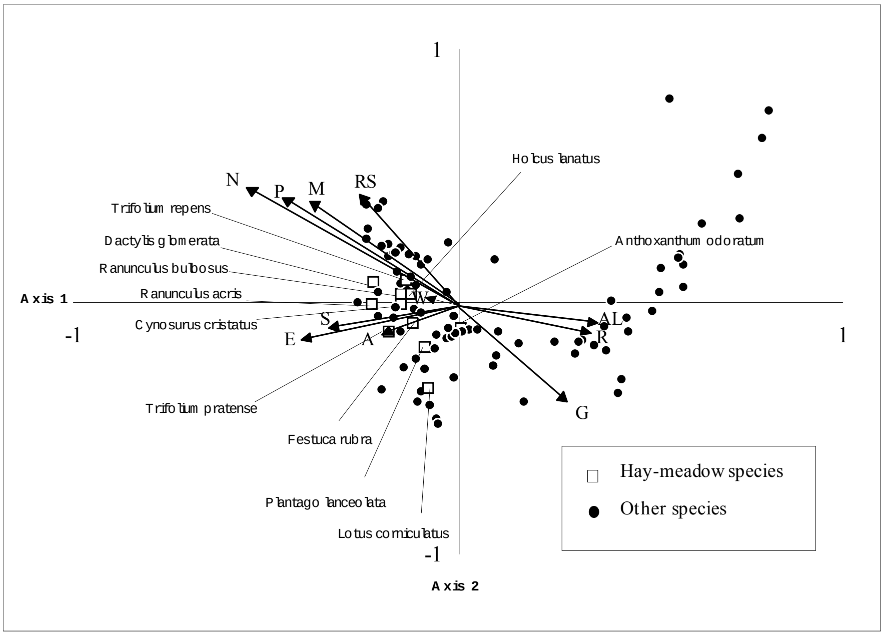
de usage, simply to create safer surroundings within recreational areas. The key point is that the ultimate environmental goal has to be achieved through successful management of the grassland community, and for this to be done it is necessary to know with what management practices and under which base environmental situations the desired species mix and hence, the environmental good, can be created. Since management practices are essentially formulated through decisions taken by the farmer on socio-economic grounds, there is clear linkage of the economic driving force of management change to the ecological consequences.

Formulation of such agri-environmental policy therefore requires knowledge about the specific relationships that exist between farm management practices, base environmental conditions and species composition of prevailing grasslands. 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). For example, one of the present priority objectives of Environmentally Sensitive Area (ESA) management agreements in the UK (MAFF, 1992) is to promote the creation or sustainability of herb-rich hay meadows. In the North of England, typical species of grasses associated with hay meadows include *Cynosurus cristatus, Anthoxanthum odoratum*, *Festuca rubra*, *Dactylis glomerata* and *Holcus lanatus* (ANDERSON and SHIMWELL, 1981; RODWELL, 1992). Herbs such as *Ranunculus acris* / *R. bulbosus* are also often much in evidence within such pastures later in the growing season, as are *Trifolium pratense* and *T. repens* and *Plantago lanceolata* and *Lotus corniculatus* (ANDERSON and SHIMWELL, 1981; RUSHTON *et al*, 1995).

How these eleven grassland species relate to varying intensities of environmental and management variables is therefore of key concern when attempting to target farms likely to produce the required environmental good. In order to do this, it is necessary to overlay farm management information, environmental situation data and species composition data relating to specific farm sites. Using such combined information it should be possible to relate management strategies to likely species composition, depending on base site environmental characteristics.

Presentation of information of this kind is possible through the use of ordination techniques which summarise complex multi-dimensional species by sites data into a simple graph. OGLETHORPE (1996) used canonical correspondence analysis (TER BRAAK, 1986) to analyse species and environment data from a survey of farms in NE England. *Figures 1* and *2* show the ordination results of this study with reference to the eleven hay-meadow species itemised above, showing the relationships which emerge between species and farm site (environmental or management) variables. The arrows in *Figure 1* show the importance of the labelled environmental or management variable on the overall distribution of all the species. Although not presented in *Figure 1* (for legibility), all arrows can be traced back through the origin providing a reflection of themselves in the opposite quadrant. Individual species whose ordinates lie close to the tip of each arrow (arrowhead) in an orthogonal (perpendicular) plane are positively associated with that variable, whilst species which lie perpendicularly close to the tip of the reflection of the arrow (arrow-tail, in the opposite quadrant) are inversely related to that variable. The perpendicular distance from the species to the arrow is of no importance, all which matters is the distance from that perpendicular line to the arrowhead or tail (orthogonal distance). The longer the arrow for any environmental or management variable, the greater its importance in determining the overall distribution of all the species (i.e. in *Figure 1*, Nitrogen fertiliser is a more important determining variable than Winter Grazing). Also, as we move along an arrow towards the origin, the weaker the positive (or inverse, if in the opposite quadrant) the relationships become. Thus, in *Figure 1*, *Trifolium pratense* and *Festuca rubra* are both positively associated with the management variable stocking rate, but the former has a stronger positive relationship with the variable than the latter. Where environmental variables do not follow some ordinal scale, arrows are not applicable and simple ordination points reflect the variables' importance. This is demonstra-



KEY: N = Nitrogen Fertiliser, S = Stocking Rate, P = Pesticides, E = No. Livestock Enterprises, M = Muck/ Slurry Manuring, A = Aspect, RS = Reseeding, G = Gradient, W = Winter Grazing, R = Rainfall, AL = Altitude

Figure 1: **Key Species found in Hay-Meadow Communities in NE England and Associated Management/Environment Characteristics: First and Second Axes from Canonical Correspondence Analysis**

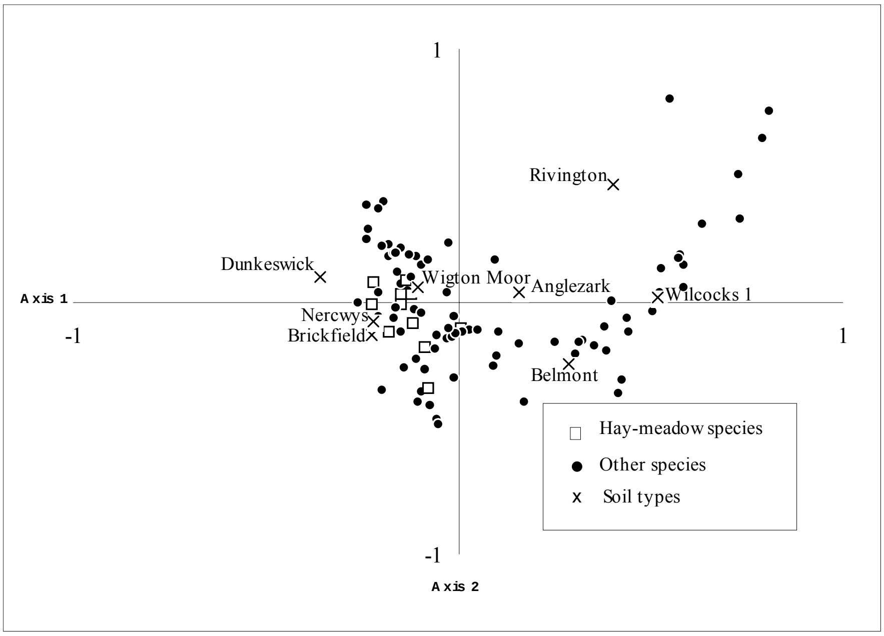


Figure 2: **Key Species found in Hay-Meadow Communities in NE England and Associated Soil Types: First and Second Axes from Canonical Correspondence Analysis**

ted in *Figure 2* where the nominal variable of soil type is illustrated. Simply, species whose ordinates lie close to the soil types, on the ordination, are most likely to be associated with that soil type.

Looking at the results, all the hay-meadow species lie fairly close in ordination space and are more or less concentrated in the third quadrant. Four of the grass species identified by Anderson and SHIMWELL (1981) as dominant within hay-meadow communities (*Cynosurus cristatus*, *Festuca rubra*, *Dactylis glomerata* and *Holcus lanatus*) lie particularly close to one another and their existence is associated with low but positive levels of organic and inorganic fertiliser applications, moderate use of pesticides and low stocking rates. In addition, they are positively associated with aspect[1] towards south, but slightly negatively associated with gradient. This would seem an intuitive result in that hay production is naturally better suited to south-facing slopes (for drying purposes), but the level of mechanisation required to cut, turn and bale hay is not compatible with particularly steep gradients.

Also, of the managerial input variables, the hay meadow species are least associated with reseeding activity. This suggests that rather than having been manufactured within new pastures, hay-meadow communities are more likely to occur on old and established pastures. The soils types on which hay-meadow communities are likely to arise can be seen in *Figure 2*. Specifically, Nercwys and Brickfield soils seem most likely to be associated with hay meadows, although Dunkeswick and (in particular) Wigton Moor soils also lie close to the four dominant grass species noted by ANDERSON and SHIMWELL (1981).

Therefore, in order to achieve optimal establishment of a hay meadow community, these results suggest that farm policy should be directed at farms with fields at relatively low altitudes, southerly facing but gentle slopes, and with soil types such as Nercwys, Brickfield, Dunkeswick and Wigton Moor. The type of management adopted needs to be fairly low input, especially with regard to fertiliser and pesticide application, but perhaps less extensive in terms of stocking rate, provided a diversity of livestock types are permitted to graze.

This generalised prescription is similar to the actual restrictions currently applied within ESA management agreements in the UK (e.g. MAFF, 1992), and thus demonstrates the consistency and reliability of the results. The key point is, however, that any grassland community can be identified as the desired environmental good (which may provide the means for deriving another environmental good, such as a specific nesting habitat). The results could be used in just the same way to allow the policy maker to decide *where* and *how* to achieve both species and location specific environmental goods.

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.

Ecological-Economic Models

There are various examples of such integrated ecological-economic models cited in recent literature. TSCHIRHART and CROCKER (1987) and COSTANZA et al. (1993) provide conceptual examples of work of this type, whereas more useable models are demonstrated by BOCKSTAEL et al. (1995) and HIGGINS et al. (1997). This study utilises a model developed by SANDERSON et al. (1995), which 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 factors determining the presence of, or which were associated with, specific grassland communities listed within the National Vegetation Classification (NVC) (RODWELL, 1991 and 1992). The NVC handbooks provide maps

[1] Introducing Aspect as a variable required dummy variables to be used to represent the importance of various ranges of aspect and to prevent the occurance of, for example, 359 degrees being interpretted as substantially different from 0 degrees. In agricultural husbandry terms (from exposure to daylight) in the UK, benefit declines as we move from aspect range E to S, S to W, W to N and then N to E. The dummy variables used were therefore: 3, for aspects from 90 to 179 degrees from N; 2, for aspects 180 to 269 degrees from N; 1, for aspects 270 to 359 degrees from N; and 0, for aspects 0 to 89 degrees from N.

showing the distribution of grassland communities over the whole of Great Britain, specifying the type and intensity of land use likely to be associated with each community. Each community is composed of a certain set of grassland species, which are ranked according to their likely abundance within that community. Each species is not necessarily exclusive to one single community but the rate of abundance of species between communities is variable, and is unique for each species/community pairing. SANDERSON et al. 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 Environment Management Model (VEMM), 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. However, rather than attempting to encapsulate relationships for all grassland communities, all environmental conditions and all potential management strategies for the whole of Britain, the VEMM was constructed for a specific study in the catchment area of the River Tyne, in North East England (RUSHTON et al., 1995). As a result, the model incorporates data on a subset of 27 grassland communities, containing a total of 534 different plant species (RODWELL, 1991 and 1992) and is relevant to the whole agricultural area of the river catchment, an area of over 200,000 ha.

The VEMM was validated against observed field data, separate from the data used for model construction, but taken from two specific sites within the Tyne river catchment. The first a fairly intensively managed upland farm site extending to 96 hectares, the second, an area of moorland encompassing about 15 km^2. At the upland site, significant correlation ($P < 0.001$) between observed species composition and that predicted by the VEMM occurred for four out of five areas within the farm. For the area of moorland however, significant correlation between observed species composition and that predicted by the VEMM occurred for all land (SANDERSON et al., 1995).

Given the relative robustness of the VEMM, it would appear to be a relevant tool to use for policy scenario analysis whereby changing management strategies, driven by a changing agricultural or environmental policy arena, could be analysed as to their potential effect on grassland species diversity.

However, this would only really serve 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. In order to provide this, an economic simulation model could be used in conjunction with the VEMM to provide, for each ecological prescription, a pricing of the changes in management required to bring about the ecological change at the whole farm scale.

Within the field of agricultural economics, economists have striven to generate operational models which simulate agricultural activity at the farm-level. This work has achieved some success and many examples of linear or quadratic programming models have been documented in the literature. However, these models have been less widely used in conjunction with farm or field level ecological models, particularly for whole farm policy analysis. This is possibly due to the sensitivity of ecological systems (and thus of the ecological models) to changes in agricultural management parameters, such as fertiliser use or livestock densities, compared with economic models. The combined economic model must therefore be able to predict accurately marginal changes in such factors so that the correct economic response to the change in management can be estimated. Thus there can be a conflict between the sensitivity of ecological models and the relative unresponsiveness of economic models, caused by use of linear production functions.

In order to overcome this, the economic model needs to be constructed with the aim of using it in combination with ecological models and formulated in such a way that small changes in certain parameters are possible. Thus, agricultural management parameters such as fertiliser use or livestock density need to be available within the model at varying levels of intensity and economic response functions to those intensity levels need to be employed. Such a model, based on a subjective expected utility hypothesis, was developed by OGLETHORPE (1995).

Like the VEMM, this model was initially constructed for analysis in the River Tyne Catchment, but was latterly extended to be able to be calibrated for farms within the UK. The 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 acurate simulations of farm-level activity (both in terms of economic return and land-use intensity) under various historically observed situations, and has 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 VEMM 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 VEMM 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 thus 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.

Model Analysis

The procedure for this analysis follows four key stages. First, the SEUM is calibrated[2] to simulate the initial land use and intensity of production for a certain farm situation for which validation data are available. Second, the VEMM is run to predict the NVC Communities, and top ten 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 VEMM with the species actually observed on this site then creates a validation for the VEMM.

Third, once verified as a suitable predictor of observed species composition, the VEMM 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.

Map 1: **The Tyne River Catchment (black), North-East England, UK.**

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, as highlighted in Map 1 (the study area used as the initial focus for construction of both models).

The total area of the farm, 200 ha, was subdivided, according to categorisations made by the surveyed farmer, into a total "Hill Grazing" area of 160 hectares 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. The enterprises carried out on the farm included sheep and suckler cow production whereby the sheep utilised the hill grazing area all year round and had short-term access to the inbye pasture at lambing time. The herbage grazed from inbye land by the hill ewes at lambing time was assumed to be negligible. Cattle, however, had access to both the hill and the inbye through summer months and were housed for five months during winter. 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 small proportion of lambs being finished on farm (6% of lambs finished against 32% in regional average figures (CHALLINOR and SCOTT, 1994). As a consequence, the farm is heavily dependant on livestock subsidies which account for 42% of gross revenue.

The key management data required from this model simulation for VEMM analysis are the intensity measures of nitrogen application and stocking density. The average nitrogen application for the inbye keep area is calculated as the weighted average of nitrogen applied to both grazing pasture and silage aftermaths and the resultant stocking rate also takes into account the grazing supplied by the aftermath. Stocking rates are measured in Ewe Equivalents (EE) in preference to the standard measure of grazing livestock units, simply due to the data input requirements of the VEMM (SANDERSON and RUSHTON, 1995). Specifically, the VEMM requires that all stocking rates are reported in terms of a 0.15 grazing livestock unit, equivalent to a UK lowland breeding ewe plus following lambs.

[2] '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.

Table 1: **Model Simulation of the Base Situation for the Case-Study Farm**

PHYSICAL		FINANCIAL	
Land Use (hectares)		**Revenue** (£)	
Hill Grazing	160	Finished Stock	1200
Inbye Keep	18	Store Stock	28056
Inbye Silage	22	Cull Stock	3630
		Subsidies	24145
Livestock Numbers (head)		**Total Revenue** (£)	57031
Breeding Animals			
Hill Ewes	750	**Variable Costs** (£)	
Suckler Cows	37	Fertilisers	2017
Sale Animals		Forage/Fodder	6423
Finished lambs	38	Concentrates	3454
Store lambs	600	Replacements/Vet/Med.	10688
Cast Ewes	165	**Total Variable Costs** (£)	22582
Suckled Calves	37		
		Total Farm Gross Margin (£)	34245
Intensity Measures			
Total Nitrogen Use (kg N)	5603	**Fixed Costs** (£)	
Average N Use (kg N/ha):		Labour	9083
Hill Grazing	0	Machinery	2718
Inbye Keep	140	Depreciation	3313
Inbye Silage	220	Interest	398
Ewe Equivalents/ha:		Rent	6000
Hill Grazing	5.43	Overheads	6200
Inbye Keep	6.72	**Total Fixed Costs** (£)	27711
		MANAGEMENT AND INVESTMENT INCOME (£)	6738

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 VEMM analysis is done.

The average nitrogen application shown in *Table 1* for inbye keep is derived as a weighted average of the different rates and areas suggested by the model output available for grazing. In terms of the 40 hectares of inbye land, the basic solution of the model suggested that the optimal grass management plan was to have 18.1 hectares as keep, applying nitrogen at a rate of 0 kg/ha on 11.8 hectares and 125 kg/ha on the remaining 6.3 hectares. The remaining 21.9 hectares of inbye land was utilised for silage/aftermath production, applying nitrogen at a rate of 220 kg/ha. Since "inbye keep" encompasses all land available for grazing on the inbye land at any time of the year, this must include aftermath grazing. Thus, the weighted average nitrogen application for grazing land over the entire 40 hectares on inbye is therefore 140 kg N/ha.

The site specificity of the data required to run the VEMM 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.

In the following sections, the VEMM is initially run to predict the vegetation under the baseline environmental and management conditions prevailing at each site (hill and inbye) according to the survey data supplied and the simulation provided by the SEUM. In each case, this 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 VEMM is 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.

Extensification of the Hill Grazing Land

The base environmental conditions (climate, topography and soils) and management strategy (taken from *Table 1*) for the initial run of the VEMM are summarised in *Table 2*.

The output from the VEMM is summarised in *Tables 3* and *4*. *Table 3* lists the ten most highly ranked species predicted to be associated with the base conditions of the hill grazing area. These predicted species also have a predicted 'constancy', the average number of times the species would be likely to be observed in a survey of five standard (NVC) vegetation quadrats on that specific parcel of land. The species and constancies predicted are compared with the species observed at the site (21 in total) along with the constancies recorded from the five quadrat survey taken on the hill grazing area.

Table 2: **Base Environmental Conditions and Management Strategy on the Hill Grazing Area for VEMM Calibration**

VEMM Variables	Level/Option
Environment	
Elevation	245 metres
Gradient	9 degrees from horizontal
Rainfall	950 mm
Soil Drainage	Medium
Soil Type	Stagnohumic gley
Grazing Pressures	
Ewe Equivalents/ha*	5.5
Grazing Period	All Year
Beef Cattle (Yes/No)	Yes
Grass Management	
Nitrogen Application (kg/ha)	0
Slurry/Muck Application (Yes/No)	No
Cut for Fodder (Hay/Silage/No)	No
Aftermath Grazing (Yes/No)	No
Additional Management	None

* Note: the VEMM requires approximation to the nearest 0.5 EE/ha (Sanderson *et al*, 1995)

Table 3: **VEMM Predicted Top Ten Species and Constancies against Observed Species and Constancy on the Hill Grazing Area.**

VEMM Predictions		Observed	
Species	Constancy	*Species*	Constancy
		Agrostis tenuis	5
Festuca ovina	2.87	*Festuca ovina*	5
		Nardus stricta	5
Polytrichum commune	2.79	*Potentilla erecta*	5
		Anthoxanthum odoratum	4
Juncus squarrosus	2.72	*Festuca rubra*	4
		Luzula multiflora	4
Potentilla erecta	2.58	*Rhytidiadelphus squarrosus*	4
		Carex nigra	3
Rhytidiadelphus squarrosus	2.44	*Galium saxatile*	3
		Rumex acetosella	3
Agrostis canina	2.31	*Poa subcaerulea*	2
		Bromus mollis	1
Galium saxatile	2.17	*Carex paniculata*	1
		Conopodium majus	1
Lophocolea bidentata	2.11	*Deschampsia cespitosa*	1
		Holcus lanatus	1
Nardus stricta	2.10	*Hypnum cupresseforme*	1
		Juncus acutiflorus	1
Carex nigra	2.08	*Luzula campestris*	1
		Pleurozium schreberi	1

Of the species predicted, six of the top ten predicted by the VEMM were also observed at the site. These were, *Festuca ovina*, *Potentilla erecta*, *Galium saxatile*, *Nardus stricta*, *Carex nigra* and *Rhytidiadelphus squarrosus* . Two more of the predicted species *Juncus squarrosus* and *Agrostis canina* matched the observed species but only by the main species genus (against *Juncus acutiflorus* and *Agrostis tenuis*, respectively). One of the remaining species predicted, *Polytrichum commune*, is not matched, but other mosses are recorded such as *Hypnum cupresseforme* or *Pleurozium schreberi.*

As a model simulation of species diversity, this VEMM output appears good ($P < 0.001$ when tested for significance using a hypergeometric distribution) and although the constancies associated with the predicted species are generally lower than the observed, this may be a result of them reflecting averages across different samples, rather than one specific survey result. The key characteristic of the constancy scores is that the order of the predicted species and the observed species is also fairly well matched. *Festuca ovina* and *Potentilla erecta* are highly ranked in both lists, also, *Rhytidiadelphus squarrosus* and *Galium saxatile* come roughly mid-way. However, a disparity in the constancy ranking is apparent with the predicted constancy of *Nardus stricta* being amongst the lowest whereas it has the highest possible constancy in the observed data.

Table 4 lists the NVC communities predicted by the VEMM to be associated with the base conditions of the hill grazing area and the habitat suitability index (HSI) associated with that community. In simple terms, the HSI can be treated as the probability that a certain NVC community will be found on a specific parcel of land with specific base environmental and management conditions.

The dominating community is the Calcifugous grassland *Juncus squarrosus-Festuca ovina* (U6) which has an HSI more than double the next most dominant community. This community is commonly found throughout the uplands of Britain on a diversity of bog, grassland and heath, with the abundance of species being particularly dependant on soil type and grazing intensity (RODWELL, 1992). Specifically, MILTON (1940) found that increased grazing intensity on this type of grassland, particularly by cattle, may discourage the abundance of species such as *Juncus squarrosus*. As a result, we might expect the reverse to occur as stocking rates are reduced.

Two of the other communities predicted, U5 and M6, tend to be less dependant on variation in the intensity of management (RODWELL, 1991 and 1992) but more on the *type* of livestock that are grazed, regarding the herbage selectivity of different animals. Thus, we would possibly expect little variation in their HSIs to occur under reduced or increased stocking intensity. M23, however, is characterised by rapid succession when grazing is withheld, particularly by *Molinina* or *Filipendula* dominated communities (RODWELL, 1991).

In terms of individual species, most are found to belong to more than one NVC community, although at differing levels of constancy. Further, some species are found to be affiliated with many alternate communities and can also be found to be constant throughout quite a few single communities. For example, RODWELL (1991, 1992) shows that *Festuca ovina* is found to be constant throughout 13 Calcicolous grassland, 10 Calcifugous grassland, 1 Mire and 4 Heath communities, as well as being present in a further 39 communities of varying classification. Reporting any change in the abundance of an individual species under changing management conditions will therefore explain little about prevailing NVC communities and habitat suitability of that management plan. Thus, the most efficient method of reporting the effects of changing management is to look at how the NVC community dominance and HSIs reported in *Table 4* are likely to change, as management intensity changes.

As summarised in *Table 1*, the base management conditions implied a stocking rate of 5.5 ewe equivalents per hectare and zero nitrogen applications on the hill grazing area. Since nitrogen can be re-

Table 4: **VEMM Predicted NVC Communities & Habitat Suitability Indices (HSI) on the Hill Grazing Area.**

Predicted NVC Communities	NVC Code	HSI
Juncus squarrosus-Festuca ovina grassland	U6	0.370
Nardus stricta-Galium saxatile grassland	U5	0.178
Carex echinata-Sphagnum recurvum/auriculatum mire	M6	0.165
Juncus effusus/acutiflorus-Galium palustre rush-pasture	M23	0.145

duced no further, the key management instrument with which to extensify the farm plan, is stocking rate. Therefore, a detailed analysis of the changes in vegetation likely to occur under changes in stocking rate was derived through a series of VEMM runs, adjusting the stokking rate implied at each juncture. The results of this analysis are presented in *Table 5* where, under each scenario, stokking rate is altered but the other prevailing base environmental and management variables presented in *Table 2*, remain unchanged.

The results presented in *Table 5* show an increased dominance of U6 under reduced grazing intensity which concurs with the earlier hypothesis made above regarding claims made by MILTON (1940) and RODWELL (1992). However, at particularly low grazing intensities, the *Juncus effusus/acutiflorus-Galium palustre* rush-pasture community drops out of the four most highly ranked NVC communities and is replaced by the mire community *Molinina caerulea-Potentilla erecta* (M25). This concurs with the suggestion by Rodwell (1991) that M23 is relatively easily succeeded by other communities such as those dominated by *Molinina* vegetation.

In order to assess which of these management scenarios would create the "best" outcome from a policy standpoint, we may want to consider the environmental enhancement or increase in aesthetic quality brought about by the changes. In terms of ecological or environmental enhancement (although purely subjective) one could judge the quality of a parcel of land by the likely abundance of rare species associated with the NVC communities, predicted to be present under particular management scenarios.

RODWELL (1991, 1992) shows that the grassland community *Juncus squarrosus-Festuca ovina* (U6) is directly associated with the rare species *Barbilophozia lycopodioides*, whereas the communities U5, M6 and M23 have no rare species directly associated with them. *Molinina caerulea-Potentilla erecta* (M25) however, is directly associated with three rare species; *Agrostis curtisii*, *Erica vagans* and *Lobelia urens*. Therefore, since the abundance of U6 is predicted to increase with decreasing stocking rate, U5, M6 and M23 all decline in abundance with decreasing stocking rate, and M25 is predicted to emerge at low stokking rates, the overall reduction in livestock intensity would be likely to create an increase in the number of rare species observed. The predicted environmental enhancement on the hill grazing area, from this point of view, is therefore likely to be positive over decreasing stocking rate.

However, the success of any policy designed to generate such positive environmental externalities, must be weighed-up against the cost of implementing such a scheme. The reductions in stocking rate implied by the analysis would undoubtedly cause a loss in income to the farmer. Since it is the farmer who must be persuaded to adopt the specific management plan required to deliver the environmental goods, then we need to consider the appropriate compensation that would be required to make up any shortfall in income.

The SEUM was therefore run under the constraints imposed by the reductions in stocking intensity to suggest how income might change under each scenario. The constraints on stocking rate were imposed solely regarding the hill grazing area but the grazing requirements of the livestock regarding proportions of herbage derived from different types of pasture were left unchanged. This meant that although the inbye land itself was free of grazing restrictions, because the livestock grazed on the farm utilised both areas, reductions in numbers forced by the restrictions of the hill grazing also meant lower stocking rates on the inbye. For example, if the hill grazing land, under a certain restriction, could only sustain 50% of the cattle previously supported, then only this proportion of cattle would be grazed on the inbye land. No substitutability between alternate diets for particular animals was permitted. However, since changes in vegetation cover are likely only to occur over long periods of time, substitutability of new farm enterprises, given the availability of existing farm infrastructure (such as housing capacities and so on), was permitted to occur on slack inbye land to counterbalance potential losses in income. A possible consequence of this is that stocking rates on the inbye land might actually increase up to the point where these existing farm resources are exhausted. Also, due to the heavy reliance on livestock subsidies, trade in ewe quota was permitted whereby the option to lease any unused quota could be employed to further reduce potential revenue deficits. Therefore, although only a proportion of land was assumed to be policy constrained, the analysis was carried out at the whole-farm scale, generating more useful decision support results than might be provided by a partial analysis.

Table 6 summarises the changes in management and investment income (MII) predicted by the SEUM to occur over the decreasing levels of intensity on the hill grazing area. A value is also given as to the change in MII per ewe equivalent left on the entire farm, compared to the initial income. The negative of this value reflects a possible compensatory headage payment which would be at least required to encourage the farmer to adopt the specific management plan. Also included in the table are the numbers of ewe quotas leased out and any change in stocking rate on the inbye land created by the uptake of alternative livestock enterprises. All stocking rates are again given in ewe equivalents (EE) per hectare.

Initially, when stocking rates on the hill grazing area are reduced to 4 EE/ha this forces both the numbers of hill ewes down by 33% to 503 ewes and the num-

Table 5: **VEMM Predicted NVC Communities and Habitat Suitability Indices (HSI) at Individually Reduced Stocking Rates on the Hill Grazing Area.**

	Habitat Suitability Index (HSI) Stocking Rate (Ewe Equivalents/ha)				
NVC Community	5.5	4.0	3.0	2.0	1.0
Juncus squarrosus-Festuca ovina (U6)	0.370	0.392	0.418	0.447	0.462
Nardus stricta-Galium saxatile (U5)	0.178	0.172	0.163	0.154	0.148
Carex echinata-Sphagnum recurvum/auriculatum (M6)	0.165	0.162	0.157	0.153	0.152
Juncus effusus/acutiflorus-Galium palustre (M23)	0.145	0.139	0.131	0	0
Molinina caerulea-Potentilla erecta (M25)	0	0	0	0.124	0.120

Table 6: **Predicted Changes in Management and Investment Income (MII), Leased Ewe quota and Inbye Stocking Rate over Reduced Stocking Rates on the Hill Grazing Area.**

Hill Grazing Stocking Rate	MII (£)	Change from Base MII per EE left	Ewe Quota Leased Out	Inbye Stocking Rate
5.5 *(Base)*	*6738*			*6.72*
4.0	4350	-3.76	247	5.81
3.0	2630	-8.42	458	6.36
2.0	890	-15.98	368	2.45
1.0	-3380	-48.18	500	1.25

ber of suckler cows down by 14%. This suggests that there will be slack grazing available on the inbye land due to less suckler cows requiring herbage. However, a shadow price (marginal value product) on a substitute upland sheep activity, generated by sensitivity analysis of the SEUM, suggests that the cost of that activity would have to fall by £0.43 to be introduced into the basic solution. This is because, as an alternative, nitrogen applications on the inbye land can be reduced to accommodate the restricted stocking rates without slack grazing becoming available. As a consequence, the weighted average nitrogen application on inbye land falls to 93 kg/ha and the resultant stocking rate on the inbye falls to 5.81 EE/ha. Since there is a reduction of 247 ewes, and no substitute sheep activity is brought in, all 247 ewe premium entitlements are leased out. The result is a fall in MII of £2388 which equates to a loss of £3.76 per ewe equivalent remaining on the farm.

When stocking rates on the hill grazing area are reduced to 3 EE/ha, hill ewe numbers are reduced by a further 42% to 292 ewes but the number of suckler cows actually rises by 3 cows. This demonstrates a substitution between existing enterprises in order to accommodate the reduction in overall stocking rate on the hill grazing area. There is, however, an overall fall in stock numbers on the farm due to a larger proportionate reduction in the number of hill ewes. As a result, the total amount of silage required for winter feed falls, and although the stocking rate on the inbye land increases as a result of the increase in cow numbers, the weighted average nitrogen application on the inbye land falls to 81 kg/ha. This is because there is a smaller proportion of the land used for aftermath grazing (at a nitrogen application rate of 220 kg/ha) and a larger proportion of the land used solely for grazing (at zero nitrogen). The consequence of this change in management for MII is a fall of £4108 compared to the initial situation, equating to a loss of £8.42 per ewe equivalent remaining on the farm. Again, because no slack grazing arises on the inbye land due to changes in optimal nitrogen application, no substitute sheep activity is brought in, and the 458 available ewe premium entitlements are all leased out.

At a restricted stocking rate of 2 EE/ha on the hill grazing area, the substitute upland sheep activity becomes feasible due to further reductions in nitrogen applications only being possible by creating slack grazing. Nitrogen is still applied to 7.3 ha of the inbye land but only for silage/aftermath production creating a weighted average nitrogen application on the inbye land of 40 kg/ha. Suckler cow numbers are reduced to 7 under this scenario and 47 upland breeding ewes are employed, creating an overall reduction in the grazing intensity on inbye land to 2.45 EE/ha. However, there is also a re-substitution of 43 hill ewes for the reduction in suckler cows made possible due to the differing ratios of herbage required from grazing or silage for each animal type and the differing shadow prices on alternate grassland management activities. As a consequence of these changes and substitutions in stokking management, the number of ewe premium entitlements available for leasing out falls by 20% compared to the previous case. Under this scenario MII falls by £5848 as compared to the initial situation, reflecting a loss of £15.98 per ewe equivalent remaining on the farm.

At the lowest stocking rate considered on the hill grazing area, at 1 EE/ha, cattle are entirely removed in the optimal solution and hill ewes are reduced to 200. Due to the release of inbye grazing forced by the removal of suckler cows, we would expect an expansion of the upland sheep activity to utilise this slack herbage. However, a characteristic of this new enterprise is that the less hardy upland ewes require in-wintering. The farm initially had only limited housing available for the in-wintering of sheep (capacity of 50 ewes) and therefore, expansion of this enterprise under existing farm infrastructure was limited to this maximum of fifty ewes. Therefore, only 3 additional upland ewes are employed as compared to the previous scenario and slack grazing occurs on the inbye land (stocking rate = 1.25 EE/ha). Whereas potential shortfalls in income were previously reduced by inclusion of this activity, this substitution effect is no longer available and income can only be regenerated by the leasing out of ewe premium entitlements (500). As a result, there is a large fall in MII to the point where the farm incurs a loss of £3880 which represents a fall of £48.18 per ewe equivalent remaining on the farm when compared to the base situation.

In terms of financial compensation, these figures suggest that in order to achieve a management plan likely to promote the emergence of rare species through regeneration of NVC community M25 (*Table 1* implies a stocking rate of no more than 2 EE/ha), the farmer would require a compensatory payment of approximately £16 per ewe equivalent remaining on the farm. Alternatively, and possibly more conventionally, the financial loss incurred in this change of management could also be interpreted on a per hectare basis. When moving from the model result given by the base run and that given at the stocking restriction of 2 EE/ha, a loss of £5848 is recorded. Over the 160 hectares of hill grazing land, to which the stocking restrictions apply, this loss equates to a value of £36.55 per hectare.

Interestingly, the payment made to farmers within the Lake District Environmentally Sensitive Area (geographically, the nearest Environmentally Sensitive Area (ESA) scheme to this case-study farm), which also requires a restriction to 2 ewes per hectare on similar hill grazing land, is £35 per hectare[3] (MAFF, 1995). This suggests both that the SEUM is fairly accurate with regard to the prediction of the likely compensation required, and, assuming the VEMM predictions are correct, that a comparable ESA scheme on this hill grazing land would be likely to enhance the diversity of rare grassland species.

Extensification of the Inbye Land

As with the hill grazing area, the base environmental conditions (climate, topography and soils) and management strategy (*Table 1*) for initial calibration of the VEMM are summarised in *Table 7*.

The output from the VEMM under these base conditions is summarised in *Tables 8* and *9*. *Table 8* lists, and give constancies for, the ten most highly ranked species predicted by the VEMM to be associated with the inbye area. These are compared with the species observed at the site (19 in total) along with the constancies recorded under the ecological survey.

As shown, five of the top ten species predicted by the VEMM 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.

Although still a fair reflection of observed species diversity, this VEMM output is slightly less accurate than the species diversity reported for the hill grazing area given in *Table 3*. However, *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 thusassociated with similar management conditions. This suggests that the VEMM has at least responded correctly to the key management criteria for the inbye land.

Table 7: **Base Environmental Conditions and Management Strategy on the Inbye Area for VEMM Calibration.**

VEMM Variables	Level/Option
Environment	
Elevation	220 metres
Gradient	5 degrees from horizontal
Rainfall	750 mm
Soil Drainage	Medium
Soil Type	Stagnogley
Grazing Pressures	
Ewe Equivalents/ha	6.5
Grazing Period	All Year
Beef Cattle (Yes/No)	Yes
Grass Management	
Nitrogen Application (kg/ha)	155
Slurry/Muck Application (Yes/No)	Yes
Cut for Fodder (Hay/Silage/No)	Silage
Aftermath Grazing (Yes/No)	Yes
Additional Management	None

Table 8: **EMM Predicted Top Ten Species and Constancies against Observed Species and Constancy on the Inbye Area.**

VEMM Predictions		Observed	
Species	Constancy	*Species*	Constancy
Holcus lanatus	3.60	*Agrostis tenuis*	5
		Cerastium holosteoides	5
Lolium perenne	3.25	*Lolium perenne*	5
		Poa annua	5
Trifolium repens	3.01	*Trifolium repens*	5
		Poa pratensis	4
Dactylis glomerata	2.78	*Festuca rubra*	3
		Holcus lanatus	3
Cerastium fontanium	2.78	*Alopecurus geniculatus*	1
		Bellis perennis	1
Ranunculus acris	2.76	*Cynosurus cristatus*	1
		Deschampsia cespitosa	1
Festuca rubra	2.60	*Juncus effusus*	1
		Lolium multiflorum	1
Poa trivialis	2.57	*Phleum pratense*	1
		Poa subcaerulea	1
Plantago lanceolata	2.56	*Ranunculus acris*	1
		Rhytidiadelphus squarrosus	1
Ranunculus repens	2.21	*Urtica dioica*	1

The dominant NVC communities and habitat suitability indices predicted by the VEMM for the inbye area are presented in *Table 9*.

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.

[3] £25/ha for fell without heather plus £10/ha flat rate for Tier 1.

Table 9: **VEMM Predicted NVC Communities and Habitat Suitability Indices on the Inbye Area.**

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

Table 10: **Management Scenarios for VEMM Runs of Reduced Intensity on the Inbye Area.**

VEMM Run	Nitrogen (kg/ha)	Stocking Rate (EE/ha)	Other Changes from Base Management
1	75	5.0	None
2	50	4.0	None
3	25	3.0	None
4	0	2.0	None
5	0	1.0	No Slurry or Muck
6	25	2.0	None

As with the hill grazing area, a detailed analysis of the changes in vegetation likely to be present on the inbye land under specific changes management were considered through a series of VEMM runs. However, since the base management of the inbye 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 VEMM run are summarised in *Table 10* showing how the management plan was extensified according to these two parameters and any other management changes considered. The remaining base environmental and management variables presented in *Table 7*, were left unchanged under each plan.

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). *Table 11* shows how the 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 *Table 11* 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 *Anthoxanthum odoratum-Geranium sylvaticum* (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 12*, details of the floristic diversity for each of these four communities are given showing the number of species attaining different constancy scores.

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.

Again however, 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 on the inbye land. In a similar fashion to the hill grazing area, the constraints on stocking rate were imposed solely regarding the inbye area but the grazing requirements of the livestock regarding proportions of herbage derived from different types of pasture were left unchanged. This meant that although the hill land itself was free of grazing restrictions, because the livestock grazed on the farm utilised both areas, reductions in numbers forced by the restrictions of the inbye also meant lower stocking rates on the hill. Again, no substitutability between alternate diets for particular animals was permitted. Also, although this would lead to slack herbage being available on the hill land, expansion of the hill flock is limited by the number of ewe quotas available under the base scenario. Therefore, in order counterbalance potential losses in income, leasing-in of additional ewe quota was permitted.

Table 11: **VEMM Predicted NVC Communities and Habitat Suitability Indices under Reduced Intensity Scenarios on the Inbye Area.**

	Habitat Suitability Index (HSI) VEMM Run					
NVC Community	1	2	3	4	5	6
Lolium perenne-Cynosurus cristatus (MG6)	0.213	0.210	0.205	0.200	0	0.201
Holcus lanatus-Juncus effusus (MG10)	0.206	0.210	0.214	0.219	0.247	0.218
Holcus lanatus-Deschampsia cespitosa (MG9)	0.206	0.209	0.214	0.219	0.247	0.218
Lolium perenne (MG7)	0.195	0.191	0.186	0.182	0.169	0.183
Anthoxanthum odoratum-Geranium sylv. (MG3)	0	0	0	0	0.169	0

Table 12: **Floristic diversity of NVC Communities MG6, MG7, MG9 and MG10.**

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

Source: RODWELL (1992)

Table 13: **Predicted Changes in MII, Leased Ewe Quota and Hill Stocking Rate over Reduced Stocking Rates on the Inbye Area.**

Management Scenario	MII (£)	Change from Base MII per EE left	Ewe Quota Leased In	Hill Stocking Rate
Base	*6738*			*5.43*
1	6406	0.38	390	5.49
2	5977	0.82	379	5.49
3	5512	1.32	349	5.49
4	5036	1.83	360	5.49
5	4971	1.92	389	5.49
6	5509	1.32	360	5.49

In terms of nitrogen fertiliser restrictions under each management scenario, nitrogen applications were constrained through limitations on the average application. This meant that total nitrogen available was limited to provide the correct level of constrained application over the whole 40 hectares as outlined in *Table 10*. For example, under management scenario 2, total nitrogen available was limited to 2000 kg to provide an average application over the whole inbye area of 50 kg/ha. As a result, it was possible that applications for silage production could differ from those for grazing as long as the overall average application matched the requirement of the management scenario.

In the same fashion as for the hill grazing area, *Table 13* summarises the changes in management and investment income (MII) predicted by the model to occur over the decreasing levels of intensity on the inbye land. A value is again given for the change in MII per ewe equivalent left on the entire farm under each scenario, compared to initial MII, representing a possible compensatory payment. The numbers of ewe quotas leased in and any consequent change in stokking rate (EE/ha) on the hill land are also reported. The management scenarios numbered 1 to 6 correspond to the intensities applied in the VEMM Runs 1 to 6, itemised in *Table 10*.

In the case of the first management scenario, the main effect of the changes in management was that the reduction in nitrogen availability meant that the previously optimum nitrogen application for silage (220 kgN/ha) on all silage land was infeasible. Inbye land used for silage under this scenario was therefore split between 10.0 ha at 220 kgN/ha and 6.3 ha at 125 kgN/ha. Since this restriction meant that applications providing lower quantities of herbage were employed, and that the suckler cow enterprise utilised the greater proportion of total silage produced, the marginal value product of the suckler cow enterprise fell relative to alternative sheep enterprises utilising smaller proportions of silage in their diets. The consequence of this change in viability of the suckler cow enterprise meant that the model predicted that the number of suckler cows be reduced and the number of hill ewes increased. Also, because the actual area of land used for silage production actually fell as compared to the base situation from approximately 22 ha to 16 ha, additional inbye land would be available for grazing. As a consequence, the alternative upland sheep enterprise came into the optimal solution. Thus, the suckler cow enterprise became less viable under this scenario as a result of constraints limiting the optimum nitrogen application on silage and also due to potential releases in grassland becoming available to permit expansion of the sheep enterprises.

Expansion of the hill ewe enterprise was permitted by the leasing in of 340 ewe premium entitlements which took the intensity of grazing on the hill land to the maximum attainable level. An additional 50 ewe premium entitlements were leased in for expansion of the upland sheep activity (also at their maximum permitted level due to restrictions on housing capacities) in order to utilise slack grazing herbage provided by the removal of the suckler cow enterprise.

The result of this initial management restriction in financial terms was that MII fell by £332, a fall of only £0.38 per ewe equivalent remaining on the farm. Thus, compared to the financial consequences of the initial management restrictions on the hill grazing area, the model predicted that the restrictions on the inbye land could be almost completely counterbalanced by increased utilisation of the hill grazing area through investment in additional ewe premium entitlement. However, it should be noted that this result is likely to be highly dependant on the price of leased-in quota which has proved be particularly volatile both between and within years (FARMERS WEEKLY, 1996).

The increase in stocking rate on the hill land observed under this first management scenario was sustained under all further changes in management given by scenarios 2 to 6. This was however, more a result of allowing the model to lease-in additional ewe quota rather than a consequence of substitutions in hill and inbye livestock enterprises. However, in scenario 2, the number of hill ewes were reduced slightly to allow a small re-expansion of the suckler herd. This was due to further restrictions in nitrogen application making it viable to buy in additional silage supplies rather than solely producing silage at a below optimum fertiliser application. The overall stokking intensity on the hill grazing area remained unchanged since both enterprises utilised that area. This trend was repeated in scenario 3 where a greater proportion of silage was purchased rather than grown. In scenarios 4 and 5 however, nitrogen applications were constrained to be zero and the restrictions on inbye stocking rates forced suckler cow numbers down again and the hill ewe flock was again slightly expanded. However, again this represented only a slight substitution between the livestock enterprises which had no effect on the intensity of grazing on the hill land.

Under scenario 5, the most severe restriction in management, the suckler cow enterprise is discontinued and the upland sheep activity is limited to a maximum of 40 ewes due to the limitations on inbye stocking rate. This scenario creates the greatest potential fall in farm MII but still only represents a fall of £1.92 per ewe equivalent remaining. These relatively small reductions in income demonstrate the heavy reliance of the farm on the hill ewe activity and the revenue generated through store lamb production and hill ewe subsidies.

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. This value falls somewhat short of the comparative Lake District ESA payment made for such a restriction on inbye land of £55[4] 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). Given that the financial consequence of scenario 6 included a counterbalancing expansion of the hill ewe flock, this is unlikely to be permitted under such a scheme and the losses in MII incurred would be likely to be greater than predicted. 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 inbye area of the case-study farm could also derive positive environmental externalities 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 for scenario 5.

[4] £45/ha for inbye land plus £10/ha flat rate for Tier 1.

Concluding Comments

Changes in farm income brought about by compulsory restrictions in farm management strategy have been assessed and used as guides as to likely payments that a farmer would require in compensation for producing certain environmental goods. However, there is a key issue in this statement; only compulsory changes have been assessed rather than assessing the potential uptake of voluntary changes in management encouraged through offered compensatory payments. Typically, environmental policy in the EU has steered clear of legislative regulation and has depended more on the latter method of assuring the supply of environmental goods (HANLEY et al., 1996). A more realistic approach would be to equip the SEUM with activities which deliver specific environmental goods with a specific financial reward. These rewards to these activities would also be typically more stable than the returns to alternative market oriented enterprises which would be likely to have further significant consequences for the risk averse producer.

However, inclusion of such activities in a MOTAD framework would require large data requirements on previous annual payments which are not yet available due to the limited history of existing policies. Furthermore, these activities could only really be included in the model for retrospective policy analysis where knowledge regarding the site specific requirements needed to attain certain environmental goods would be known. This would lead to the model only being useful for post-policy appraisal, rather than for forecasting the likely effects of policy change before implementation.

An additional problem with this analysis is that it only really deals with the supply of environmental goods. The SEUM is used to assess the costs of supplying environmental goods suggested by ecologists as being of specific ecological interest. However, the implementation of payment schemes designed to enhance the environment are themselves dependant on the supply of public funds and involve expenditure which must be justified to the public exchequer. Thus, a payment level for any such scheme would not only require an estimation of the income likely to be lost by the farmer through such a scheme, but also an estimation of the amount the public would be prepared to pay for the resultant environmental goods. Undoubtedly, many valuations on narrow economic efficiency grounds are available regarding the publics perception of the financial value of certain environmental goods (e.g. WILLIS et al., 1993), however, the specificity of each environmental good will possibly necessitate renewed valuations to be made for each designated area or policy. For example, it may not be applicable to equate the willingness to pay for heather moorland in Scotland with the demand for heather moorland in Northern England nor for woodland regeneration in Scotland. Moreover, the small changes in habitat suitability predicted by these analyses may well be important in ecological terms but may be less apparent to the general public.

With regard to the VEMM, the analysis would undoubtedly benefit from further dynamism being incorporated into the model structure. To this end, the VEMM is currently being extended to allow it to make predictions of the timescale over which vegetation transitions will occur (by accessing a transition matrix of rates of change from one plant community to another) and to take account of the life-history characteristics of the more common species of plants (published information on seed dispersal, viability, etc.).

The analysis presented in this study has, however, 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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