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ECOLOGICAL ECONOMIC MODELLING OF THE CONSERVATION OF THREATENED HABITATS: HEATHER MOORLAND IN THE NORTHERN ISLES OF SCOTLAND

BY NICK HANLEY, HILARY KIRKPATRICK, DAVID OGLETHORPE AND IAN SIMPSON

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ECOLOGICAL-ECONOMIC MODELLING OF THE CONSERVATION OF THREATENED HABITATS: HEATHER MOORLAND IN THE NORTHERN ISLES OF SCOTLAND

by

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ABSTRACT

This paper describes the results of an ecological-economic modelling exercise of the management of a scarce habitat, namely heather moorland. The Orkney Islands of Scotland are used to illustrate a modelling approach which could be easily applied elsewhere, and to other habitats. We describe the evolution and present condition of heather moorland on Orkney, then quantify the extent on over-grazing (leading to ecological damage) on a spatial basis. This is accomplished using a model of heather utilisation and heather productivity. Critical grazing limits are then used as constraints in an economic model of farm production decisions, which enables us to quantify the minimum necessary compensation payments which farmers should be offered to offset income losses due to grazing restrictions. Such a policy is in line with European Union and UK agri-environmental policy, which typically uses payments for income foregone as a means of persuading farmers to protect environmental quality.

INTRODUCTION

Many of the worlds' habitats are theatened by 'development', a change in land use management due to the prospect of increased private returns. Well-known examples include the conversion of tropical moist forest to ranchlands, and the draining of wetlands for property development.This paper is concerned with ecological -economic modelling of certain development threats to a less well-known habitat, namely heather moorland. The development threats here originate in the farm sector. The UK is especially important for the conservation of heather moorland in Europe. Heather-dominated dwarf shrub heath is limited in its geographical extent to North West Europe, and centred on Scotland and the North of England. Here the moorland resource is concentrated in upland and other marginal areas of Scotland. Montane heath is of outstanding nature conservation value since it has been barely touched by human activity (aside from atmospheric pollution effects).

Heather moorland is important ecologically as a habitat for certain bird and plant species, whilst it also has a major impact on landscape quality, being part of the "traditional" ideal of what the Highlands and Islands of Scotland should look like. As we note below, heather moorland has existed on the Orkney Isles since around 3,500 years ago. Historically, the resource has been eroded geographically and in quality terms (since 1945 about 25% of the upland area of the UK has been damaged in some way by human activity [Thompson, MacDonald, Marsden and Galbraith, 1995]). Modelling appropriate management responses to heather moorland degradation requires inputs from both economists and ecologists, since the problem is an interconncted one, depending on biomass growth and removal, and economic incentives regarding grazing pressure. Heather moorland degradation can be argued to result in a loss of economic efficiency in resource use, due to two factors. These are (i) market failure and (ii) policy failure. Since heather moorland conservation generates a stream of public benefits, in terms of wildlife and landscape quality, private agents will have no incentive to take account of these benefits in decisions over land use. Second, farm policy, through creating incentives to farmers to expand at both the intensive and extensive margins, has resulted in a greater privately optimal level of degradation than would be the case in the absence of such policies. This combination of market and policy (or intervention) failure has also been cited with respect to loss of wetlands and loss of tropical moist forests (Sandler, 1993; Barbier and Burgess, 1993; Gren et al, 1994).

This paper proceeds by setting out a brief account of the nature of the heather moorland resource, and then describes ecological modelling of the carrying capacity of the resource for grazing. Next, we describe the construction of an economic model of farming in the Orkneys, and finally results from both models are drawn together to indicate the likely policy requirements of actions to protect the moorland resource.

HEATHER MOORLAND AND FARMING IN THE ORKNEYS: SOME BACKGROUND.

Orkney is an island archipelago lying off the Northern coast of Scotland. Land use in the islands is now dominated by livestock production, with heather moorland being an integral part of grazing management on some farms. Palaeo-ecological evidence suggests that heather moorland developed relatively late in the post-glacial Holocene period. Around 7000 years ago, birch/hazel scrub woodland with some heath understorey covered most of Orkney. A decline in this woodland cover coincided with an increase in wind speeds and a 1-2 degree fall in average temperatures c3000 BC. Decline occurred first in coastal areas. Clearing of trees by Neolithic man for pasture and cereal growing contributed to the loss of tree cover. Further deteriorations in climate occurred around 1500 BC, with still lower temperatures and higher rainfall. These conditions led to the development of heather-dominated peat moorlands.

Over time, gradual arable intensification occurred on Orkney, speeding up after Norse settlement c800 AD. This affected heather moorland by burning and clearing of turves to create arable land. Agricultural improvements in the 1800s (notably the abandonment of the traditional 'runrig' system of cultivation, the introduction of new cultivars such as clover, and drainage programmes) led to more erosion of the moorland resource. The Orkney isles are now practically tree-less, with much improved and relatively-intensively farmed land. Heather moorland is now chiefly confined to upland areas (above 75m) on peats, peaty podzols and peaty gleys, although some low-lying costal sites also exist. Of the total land area of 101,612 ha for the achipelago, some 29,729 ha (29%) is currently covered by heather moorland[1].

Heather moorland can become degraded by overgrazing. This may be defined as occuring when sheep remove an amount of heather which exceeds a certain percentage of the annual productivity of heather on that site. Heather moorland will only survive in good condition if less than 40% of the current season's growth is removed (Thompson et al, op cit). Degradation results in a change in species composition, with heather (*Calluna sp.)* being replaced by rough grasses, such as *Molinia*. When this happens, both wildife and landscape quality suffer, in that birds (such as the merlin) dependent on heather moorland for either food or nesting sites decline. More dramatically, heather moorland may be "re-claimed" by farmers, a process of undersowing and fertilisation which converts moorland into high-productivity grassland. Again, a loss in

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[1] This figure comes from the Laserscan GIS system for the archipelago, constructed at Stirling.

conservation value is the result, although farm profits are incrased at least in the short run by such actions. Overgrazing of heather moorland has also been noted in other parts of the UK.

In Orkney, where moorland was traditionally used as a source of fuel and for low intensity grazing, European and UK agricultural policy has led to a large increase in livestock numbers on moorland (through the subsidization of output prices and payments per head of livestock ("headage payments")), and a reclamation of some moorland areas into pasture. From 1983 to 1992, breeding ewe numbers[2] rose from 37,070 to 54,816, whilst cattle numbers have risen from 92,485 to 100,258. The National Countryside Monitoring Scheme estimates that the total moorland area fell in Orkney from 32% to 28% of the land area between 1940s-1972, but these numbers suffer from aggregation problems leading to an under-estimation of losses, and hide wide regional variations: for example, a 56% decline on Mainland, and a 72% decline on South Ronaldsay (Kirkpatrick and Simpson, 1993). In our farm survey, the area of rough grazing (land used by farmers for livestock grazing, which includes heather moorland) fell from 32,920 ha. in 1983 to 27,395 ha. in 1991. This land has been converted to permanent and temporary grass pastures, with a consequent loss of conservation values.

CALCULATING THE ECOLOGICAL CARRYING CAPACITY OF MOORLAND

In order to determine ecological carrying capacity, data on current growth rates (and hence productivity) of heather, and on grazing pressure must be collected. In order to determine growth rates, detailed botanical surveys were carried out at seven sites in Orkney in 1993. Six of these sites are upland heather moor, one is maritime heath. Given that growth rates are expected to vary

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[2] Breeding ewes correspond to the bulk of total sheep numbers. They are used in this paper as an indicator of grazing pressure.

with exposure and altitude, sites were selected to obtain a representative sample of these variables on Orkney. Table 1 shows estimates of growth rates; as may be seen, these decline with both height and exposure (measured using the Topex method, which allocates a score inversely related to exposure at any site). Given the overall low temperatures on Orkney, and high levels of exposure, these growth rates are low in comparison to the UK as a whole.[3]

Table One Estimates of heather (Calluna Vulgaris) growth rates at different sites on Orkney

SITE	HEIGHT (m)	ASPECT	EXPOSURE (Topex score)	GROWTH RATE (cm/annum)
Hoy 1	150-175	SE	49	3.5
Hoy 2	200-250	SE	25	1.8
Hoy 3	285	SE	9	1.8
Mainland	150-175	SE	26	3.2
Rousay 1	150-175	SE	not recorded	2.5
Rousay 2	150-175	N	27	3.0
Yesnaby	20	flat	8	1.7

Note: The Topex score is inversely proportional to exposure; a lower number therefore means greater exposure. The maritime heath site is Yesnaby.

This information on growth rates had then to be generalised to the whole of Orkney. This was done by first mapping the entire archepelego onto a Geographic Information System (GIS), onto

[3] For example, lowland sites in Scotland record 15cm/year (Bannister, 1978); whilst sites in North East England record between 7-10 cm/ year (Hewson, 1977). Whilst these figures are not necessarily representative of either of these areas, Orkney growth rates still seem relatively low.

which was added land classification data, which represents land cover (such as various types of heather moorland). This enables predictions of growth rates to be made, by relating measured growth rates to land class, exposure and height.

In order to determine the grazing pressure on any given site, the MLURI Hill Grazing Model was used (MLURI, 1993). This computer simulation model allows predictions of heather utilisation rates to be made, and is based on seasonal changes in biomass, and digestability to sheep, of the most common vegetation types found in UK upland areas. Adjustments were made to take account of the effects of altitude and latitude. The inputs to the model required detailed vegetation surveys, and the collection of data on sheep and cattle numbers, movements, types, and fertiliser applications at twenty sites, selected on a stratified random sample basis. Vegetation was classified by type, and entered onto the GIS system. This enabled the extent of grazing utilization (expressed as a % of current season's shoots) to be predicted for any given site.

Table 2 Predicted heather utilization rates, as a % of biomass

LAND CLASS	MEAN	STND DEV
Dry heather moor	10.77	15.66
Undifferentiated heather	8.88	15.98
Heath/grass mosaic	8.42	3.06
Blanket bog	7.39	11.31
Worked peat	5.83	11.33
Wet heather moor	4.36	7.20
Montane	2.95	2.97
Lochans	1.46	0.00

The model demonstrates that heather utilisation peaks in January -April when growth rates are low and alternative forage is also low, so this is the period when most damage can occur. Within the heather community, certain types are favoured by sheep and thus suffer greatest damage (such as pioneer heather). Of the land types found on Orkney, the extrapolations showed that the greatest pressure occurs on dry and undifferentiated heather moorland (Table 2): these are moorlands on drier, lower areas.

Grant and Armstrong (1993) established maximum utilisation levels of different heather types, above which heather would start to diminish as part of the landscape. These are between 40%-5% of current season's shoots, according to heather type. Using this information, we were able to categorise the proportion of the sample which is predicted to be technically overgrazed (Table 3).

Table 3 Predicted overgrazed areas on sample sites in Orkney by heather type

HEATHER TYPE	AREA OVERGRAZED	AS % OF TOTAL AREA
Pioneer	14.547 ha	0.14
Mature	693.015 ha	6.75
Degenerate	21.243 ha	0.21
Blanket bog	87.938 ha	0.86
Suppressed	735.647 ha	7.17
Total	**10263.823 ha**	**15.13**

As may be seen, this amounts to 15% of the land area. Seven of the 11 overgrazed sites in the sample are overgrazed on 100% of their area. Overgrazing is predicted to result in a transition to grassland communities (*Agrostis/Festuca* and *Nardus*). The GIS system enables us to generalise these results to the whole of Orkney, and to predict that overgrazing is most likely to occur on

Eday, moorland fringes on Rousay, and West Mainland. We were also able to identify necessary reductions in grazing pressure (to bring utilisation rates below the maximum tolerable levels for each land class) on individual farms; this provides the principle linkage between the ecological model and the economic model, detailed below.

ECONOMIC MODELLING

Model Construction

As noted above, the system of price incentives and headage payments under the Common Agricultural Policy has encouraged an instensification of agriculture which has resulted in a socially-inefficient level of moorland damage, due to policy failure and the public good nature of conservation benefits (even if over-stocking is privately efficient). From a policy perspective, the UK government is unlikely to force farmers to reduce stocking rates unless they are compensated for income losses. This is due to a reluctance to enforce the polluter pays policy in the agricultural sector, which has been noted world-wide (Parsisson, Hanley and Spash, 1994). Other examples of UK agri-environmental policy indicate a wish to proceed by offering farmers payments for income lost and additional costs incurred, in return for their (voluntary) acceptance of certain restrictions on farming activities: the Environmentally Sensitive Areas scheme, the Nitrate Sensitive Areas scheme (neither of which apply on Orkney), and the Wildlife and Countryside Act all follow this approach.

The economic question here is thus how much compensation society would have to offer farmers to reduce stocking rates to certain ecologically-determined levels. No measure of the benefits of such a state is addressed in this paper, since the policy objective (to preserve heather moorland) is pre-determined (although later work could of course attempt to estimate the benefits of such a policy).The modelling method used must allow farmers to change their enterprise mix in response to policy change: linear programming was chosen as a familiar and widely-accepted tool in agri-environment policy modelling which meets this requirement (Michalek, 1994).

Under LP, the farmer is assumed to maximise net farm income (measured as management and investment income), subject to vectors of input and output prices; resource availability (land, machinery and labour); and ecological constraints, both natural and those imposed by the government. No such government-derived ecological constraints are imposed at present; however, by introducing such constraints to the model (specified as maximum permissible stocking rates, in ewes/hectare), the minimum payment needed to compensate farmers for lost income can be calculated from the change in net farm income. For the LP methodology to be valid, the most important assumption is that farmers are fully-informed, rational profit maximisers . If this is not thought a good description of farmers in Orkney, then the model results should be interpreted as showing how farmers *ought* to respond to a given set of constraints. The models pick the optimal (profit maximising) mix of cropping and livestock subject to these constraints, and to the prices which farmers face for outputs (eg store lambs) and inputs (eg fertilisers). Additional assumptions are that constraints are linear (or capable of linearisation) and that production functions are Leontief-type fixed input combination functions. Farmers are assumed to be risk-neutral in their decision-making, hence the farm plan which maximises profit also maximises expected utility.

Data for the LP model came from questionnaire surveys of 15 farms on Orkney carried out in summer 1993 (total area 18,227 ha.), encompassing a wide range of stocking rates (0.09 - 10.47 ewes/ha.). The dominant production activity was raising store lambs (also suckler cows), and the largest land class was rough grazing. Scottish Agricultural College data was also used for calculation of input-output coefficients and for existing levels of agricultural support. The LP model was constructed and calibrated for all but four of the farms surveyed (where insufficient data was collected to permit calibration). An example calibration (of farm Hoy 2) is shown in Table 4; as may be seen, with respect to the key ecological variable (sheep numbers, and thus by implication stocking rate), the model performs well.

Table 4 Example calibration from farm model

Farm (Hoy 2)	Farm survey data	Model output
LAND		
adjusted moorland	120 ha	nr
permanent pasture	19	nr
temporary pasture	8	nr
total area	177 ha	nr
FODDER ETC		
grass for hay	2	2
grass for silage	0	2
LIVESTOCK		
Sheep:		
Pure-bred hill ewes	107	107
finished lambs	37	5
stores sold	90	122
Cattle		
sucklers	9	9
reared calves	9	8
Total LUs per forage ha.	0.15	0.14
Livestock income	no data	£6452
livestock subsidies	no data	£4676
livestock variable costs	no data	£3951
nitrogen use (kg pure N)	500	514
total fixed costs	no data	£3296
pluricative income	no data	£5000
M/I INCOME BEFORE LAND/PROPERTY CHARGES	no data	£8696

nr = not relevant

Model Results

Having calibrated the farm model, it was then run under a range of increasingly strict (but arbitrarily chosen) stocking rate restrictions, from 1.0 to 0.53 ewes/ha for each farm. This reveals a range of minimum necessary compensations for income foregone; although the actual payments that farmers would recieve depends also on bargaining power of the farm lobby, and the perception of the regulator regarding the likelihood that farmers will accept any given offer (Spash and Simpson, 1994; Fraser, 1995). In addition, it might be noted that since farmers are to an extent exchanging risky income from sheep production for a sure payment, then it is possible that this sure payment could be less than the expected value of income foregone if farmers are risk averse.An example calculation for farm (Hoy 1) is given in Table 5. Since opportunity costs vary across farms we would expect minimum necessary payments associated with a given stocking rate (ecological) restriction to vary also. This is so, with the minimum payment (assuming risk neutrality) varying from £9.1 to £83.6 per ewe removed, for a stocking restriction of 0.53 ewes/ha. In the absence of compensatory payments, some farmers suffer negative incomes under these restrictions.

The level of compensation required to conform to ecological limits will clearly vary with the background level of agricultural support. Ceteris paribus, higher support levels imply greater opportunity costs at the margin for reducing livestock numbers. Falling support should thus imply reduced compensation payments. Under CAP reform, both a reduction in headage payments and in output prices seem likely. We thus estimated the sensitivity of our results to such changes, by measuring predicted farm income losses for the average grazing restriction under both falling output prices and falling headage payments. Results (shown in Tables 6 and 7) confirm the prediction above; as the value of support falls, so does the minimum necessary compensation payment.

Table 5 Compensation payments under a range of ecological limits

Farm (Hoy 1)

RESTRICTION	INCOME (no restriction: £12,913)	EWES REMAINING	COMPENSATION NEEDED PER EWE REMAINING
1 ewe/ha.	£6528	448	£14.25
0.8 ewes/ha	£5250	350	£21.89
0.67 ewes/ha	£4475	305	£27.66
0.53 ewes/ha	£3632	244	£38.03

Table 6 Effects of falling headage payments

	Suggested Compensatory Headage Payment per 0.1 ewe/ha removed			
Livestock Subsidies as % of Base	100%	75%	50%	25%
Moorland Only Restrictions	£2.02	£1.44	£1.03	£0.81
Whole Farm Restrictions	£3.09	£2.16	£1.77	£1.26

Table 7 Effects of falling output prices

	Suggested Compensatory Headage Payment per 0.1 ewe/ha removed			
Livestock Prices as % of Base	100%	90%	80%	70%
Moorland Only Restrictions	£2.02	£1.86	£1.64	£1.43
Whole Farm Restrictions	£3.09	£2.82	£2.45	£2.08

Finally, compensation payments at the individual farm level should reflect not just varying opportunity costs, but varying ecological sensitivity. Upper limits on grazing pressure to prevent further degradation of the heather moorland resource were thus calculated for each farm in the survey. This showed that some of these farms are currently overgrazed, in the sense that the maximum utilisation rate noted above is exceeded given current livestock numbers and movements. Necessary reductions in stock sizes for each of these farms were calculated using the ecological model; this showed some very large necessary reductions on some farms (Table 8).

Table 8 Farm-specific grazing restrictions

FARM	CURRENT STOCK (No.)	ECOLOGICAL LIMIT (No.)	COMPENSATION NEEDED (per ewe removed)
Eday1	1250	350	£10.44
Rousay1	1000	400	£9.05
Rousay4	500	235	£16.18
W Main1	450	40	£12.34
W Main2	130	25	£22.50
W Main3	155	45	£5.51
W Main4	151	50	£12.27
E Main	300	130	£8.67
Hoy 2	467	407	£5.46

Calculations of the necessary compensation per ewe removed show considerable variation, which is principally caused by the extent to which opportunities for diversification vary accross farms. The total compensation payment to each farm will also obviously vary with the absolute number of ewes removed. Farm activities change in response to stocking rate restrictions, with farmers having the ability to diversify increasing arable production, substituting fodder crops for cash crops, and increasing cattle numbers outwith the moorland area[4].

CONCLUSIONS

This paper has shown how ecological modelling can be combined with economic modelling in order to derive policy guidance for the conservation of threatened habitats. A combination of market and policy failure has led on Orkney to grazing levels which are excessive from both an economic and an ecological perspective. Ecological modelling, combined with GIS, can pinpoint the spatial location of overgrazing, and quantify its extent. Economic modelling can then be used to calculate minimum necessary payments to farmers to reduce grazing levels to below these ecological thresh-holds, and can predict the changes in farm activity that occur as a result.

From a policy perspective, the government in the UK is most likely to respond to such ecological problems by offering compensation payments in return for farmers_ voluntarily agreeing to abide by restrictions on stocking rates and fertilization practices. Such a move is in accord with other UK agri-environmental policy, whereby farmers are paid for producing environmental goods in excess of those associated with "good agricultural practice". However, payment rates in such programmes tend to be uniform across a particular area (due to administration costs increasing with the variability of payments; and concerns over the apparent "fairness" of varying compensation rates). This suggests that farm-specific payment rates per ewe removed may be replaced by a fixed subsidy, which would have to be set equal to the oppotunity cost of the marginal farmer, that is the farmer who faces the highest income loss per ewe removed. But this

[4] But not in a way likely to cause significant ecological problems in these areas.

might result in an increase in support costs over the variable payment alternative in excess of the saving in administration costs.

We also note that whilst in schemes such as the Environmentally Sensitive Areas scheme, compensation payments have been calculated in terms of profits foregone (although usually by simple budgeting exercises rather than through LP), 100% take-up rates have not always been achieved, even though payment rates are designed to achieve this. This suggests that some element of farmer decision-making goes uncaptured in such exercises. Farmers may not be the rational profit-maximisers portrayed by LP. In this respect, it may be useful therefore to extend the current work using alternative economic modelling techniques, such as risk-minimisation programming.

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