LITERATURE REVIEW OF BIO-ECONOMIC MODELLING ETC

There have been a number of modelling exercises for the British uplands that have focussed on biological issues (see earlier Sarah G section or e.g. Armstrong *et al*., 1997a, 1997b, Sibbald *et al.* 2000, Sanderson and Rushton 1995). There are, however, relatively few examples of combining biological and economic data within the same modelling programme, or of truly bio-economic computer models, for the UK. There are however, a number of examples of work in bio-economic modelling in other countries and other contexts.

In a recent review of bio-economic modelling, Brown (2000), reviewed some 21 models. He stated that these ranged from firstly, models that were biological process models to secondly, those for which a limited economic component had been added to economic optimisation models to which various bio-physical components are added as choices in the optimisation process. Thirdly, in between biological process models and economic optimisation models are models which seek to integrate both biological and economic processes. He cites SAVANNA (Coughenour *et al*., 2000) as an example of the biological process model, whilst the GRAZPLAN (Donnelly *et al*.,1997, Freer *et al*., 1997) suite of models are considered to be integrated. Both these two models are relevant because they relate to herbivore/pasture models in different continents and contexts to the heather moorland context of the present study.

Interestingly as a model targeted for the UK uplands, Brown (2000) lists HILLPLAN (Sibbald *et al.* 2000) as one of the first types. This is on the basis that certain elements of socio-economic data are included (farm size, number of animals in flock) in this Macaulay Institute model. Whilst a number of papers (Sibbald *et al.,* 2000, Milne and Sibbald,1998) aspire to the inclusion of economic performance and data in the working model, as yet results of this part of the model have not been published.

The Australian GRAZPLAN model (Donnelly *et al*.,1997, Clark *et al.,* 2000, Freer et al., 1997) and its constituent models (GrassGro and GrazFeed**)** are good examples where pasture resources, plant growth, animal production and economic consequences are all integrated. These model is targeted at field and pasture systems, where there is good knowledge of forage availability and utilisation.

Of direct relevance to the UK context there have been a number of attempts to model biological relationships in practical settings. Numerous models have been produced which simulate the grazing of domestic livestock (Gordon and Hutchings, 1993), predicting animal energy requirements (reviewed in Wallach *et al*., 1984), intake (e.g. Demment and Laca, 1993; Finlayson *et al*., 1995), and foraging behaviour (e.g. Illius, 1986; Focardi and Marcellini, 1995; Newman *et al*., 1995), as well as herbage growth (e.g. Johnson and Parsons, 1985; Lauenroth *et al*., 1986; Rice, 1986; Hutchings, 1991) and vegetation dynamics (e.g. Parsons *et* *al*., 1991; Sanderson and Rushton, 1995; Birch *et al*., 1997; 2000; Palmer and Hester, 2000). By combining a range of these models, computer based decision support systems have been created, which are designed to assist farmers and land managers in their practical management and decision making (e.g. Hill Grazing Management Model (Armstrong *et al*., 1997a; 1997b), GRAZPLAN (which includes the GrassGro and GrazFeed decision support systems) (Donnelly *et al*., 1997; Freer *et al*., 1997; Moore *et al*., 1997; Clarke *et al*., 2000), HillDeer (Partridge *et al*., 1999), HILLPLAN (Milne and Sibbald, 1998), STOKPOL (McCall *et al*., 1991), LADSS (Sibbald *et al*., 2000)).

Most of the above are not truly bio-economic models. In the UK context of heather moorlands there are a number of problems and issues. In a workshop a decade or more ago on 'Modelling Heather Management' (Whitby and Grant (eds),1990), there was a gap linking the biological papers and the economic papers. White and Whitby (1990) were concerned with examining profit trade-offs between grouse and sheep on heather moorland. They used profit curves for sheep numbers per hectare related to bag numbers for grouse, but there was little biological interaction. White and Wadsworth (1994) took this one stage further by including a significant biological component, different heather states, to combine grouse and sheep economic output in relation to heather moorland state and to predict optimum shoots of grouse. However, the linkage between the biological state of the heather and sheep numbers and particularly sheep economics used was empirical only, using gross margin data for sheep from actual moors at different static stocking rates for the sheep component of the model runs.

There are a number of problems with linking biological factors with economic factors in upland livestock systems. Whilst the quantity of offtake has been predicted by a number of models (Armstrong et al.,1997a and b), the economic value of this offtake is difficult to estimate. Firstly, unlike, for example, sown grasslands where a direct economic value in terms of hay or silage cropped from the grass can be used to value quantities of grass grazed, hill vegetation has no direct value. Secondly, relationships between actual offtake and animal performance are difficult to predict in upland situations and has been shown for a number of studies, these relationships differ over time, both in term of season and acros years (references here to Redesdale and Pwllpeiran studies). Thus after predicting offtake there is no easy way to convert to animal performance and thence to economic value for output nor to changes in costs. Thirdly, the complexity and relative inflexibility of hill livestock systems add other constraints in the modelling process. Whilst theoretically it is easy to understand that reduced total offtake (by for example increasing total number of livestock) would reduce individual animal performance, it is less easy to convert increased availability of offtake into increased animal performance because much of this will depend upon the animals presence to convert into performance by either extra animal numbers or increased performance and growth. Extra ewes and extra lambs cannot be provided easily into practical system with the restrictions of the breeding system and of headage limits created by grazing rights and by SAP quotas. Fourthly, given the complex nature of breeding livestock systems, there are a number of ways that changing availability of offtake and the quality of offtake might be expressed, number of lambs produced, weight of lambs, changes in costs (particularly of supplementary feed and of inbye fertiliser requirements). These different biological pathways will have different economic outcomes. Yet there is a need to understand how changing different parts of the biological system will impact upon other biological factors and then in combination on economics and to make this information accessible to farmers, conservation land managers and policy makers.

Away for the moment from upland livestock systems, in animal breeding, such issues are particularly keenly felt where small, but cumulative, benefits in animal performance have impacts on resource use and net financial margins. Bio-economic modelling is thus a key part of a number of animal breeding studies (Roghsedge *et al.* 2002, Wang and Dickerson 1991, Amer *et al*.,1997). Such as approach is used in models used as a basis for this study (Conington *et al*.,2000, insert Conington et al., 2004). Here the key bioological/economic linkages are made by modifying supplementary feed costs for single bearing ewes (which has a readily accessible economic value) by marginal changes in energy offtake requirement. Thus even small reductions in offtake, such as with reduced animal numbers, with reduced weight loss by ewes, or lower body mass, lead to reductions in costs, which have a direct impact upon gross margins per ewe and per hectare. Similarly, feed and forage costs for ewes fed or grazed off the hill (fror example , modified by different twinning rates) can be estimated in terms of the amount of fertiliser needed to increase grass production, or to rent more grass fields, exactly as farmers do in practice.

Other direct costs of animal production (e.g. animal health products, wintering costs for hoggs and marketing costs) are much easier to include associated with animal location and performance data and pose no particular modelling or calculation problem. Similarly, direct costs of any vegetation management pose no difficulties, except in relation to livestock exclusion which requires evaluation of three basic options. Temporary disposal and then replacement of animals once restoration complete; adding more animals to the residual system (which creates problems of measuring the economic impacts on the whole flock, as described above); or temporarily renting extra land for the displaced flock need to be simulated and added into the final financial evaluation.

Scaling up from component, through plot scale to whole system is a key use for models, where only partial system data is available. This is a major value in the present study both to undertake postdictive calculations or evaluate prescriptive targets. Scaling data up to farm level is a major benefit, using some elements of the physical data measured, linked to interpolative or simulated data sets at larger scale.

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