International Congress on Environmental Modelling and Software

1st International Congress on Environmental Modelling and Software - Lugano, Switzerland - June 2002

Jul 1st, 12:00 AM

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Abstract: Agricultural production and its associated land use comprise the most important key factor regarding biodiversity and environmental impact within the wider countryside in Denmark. Currently, a number of land use changes are implemented in environmental action plans, such as afforestation, restoring wetlands and protection of drinking water catchments. Growing attention is put on the potential of GIS (Geographical Information System) as spatial decision support tools in local and regional environmental impact assessment, planning and implementation of governmental policies at local level.

The work presented is part of a multidisciplinary research project, addressing the consequences of changes in agricultural production with respect to ecology, environment and economy. In this paper, focus is put upon linking vegetation ecology and farm economy. Ecological effects are assessed in terms of type, area and fragmentation of biotopes at landscape level. Assessment is based upon the output of a spatial detailed Biotope Landscape Model, describing the distribution of plant communities and nature types in Danish natural and semi-natural terrestrial biotopes. A model, assessing the costs of agricultural land use changes at the farm level, has been implemented. Both models are linked to a GIS, allowing scenario definition and integrated evaluation of model results, including their spatial representation. Three different scenario set-ups of extensified agricultural production are presented here. The scenarios chosen take precedence from ecological as well as economic priorities. Results illustrate possibilities of weighting out objectives against each other by assessing their economic and ecological consequences.

Keywords: GIS, land use, agriculture, scenario modelling, ecological modelling, economic modelling, environmental impact assessment.

1. INTRODUCTION

Over the last century or more, natural and semi-natural biotopes in Denmark have suffered from a quantitative as well as a qualitative decline. Increasing demands for environmental amenities, e.g. biodiversity, recreational areas and non-contaminated groundwater imply a need for regulations of agricultural land use. Restoring wetlands, afforestation and conversion of arable land to extensively grazed grasslands represent examples of land use changes, which are supported by public policies. Accordingly, there is a need for predicting the ecological and economic consequences of changes in land use, such as those arising from shifting Danish or EU agricultural policies.

Since 1997 the multidisciplinary research project *'ARLAS' (ARealanvendelse og Landskabsud-vikling, belyst ved Scenariestudier* = Land use and landscape development, illustrated with scenarios) has been carried out. The project is a co-operation between Danish environmental and agricultural research institutes and the county of Viborg. Research within ARLAS focus upon interaction of land use, agriculture, nature conservation and the environment. The project aims at setting up decision support systems for sustainable management of the Danish agricultural landscapes [ARLAS, 2002].

2. METHOD

The purpose of this paper is to present a modelling framework for assessing the costs of agricultural land use changes together with expected ecological benefits as likely vegetation changes and reduced fragmentation of natural and semi-natural terrestrial biotopes. From a German case, Herrmann and Osinski [1999] found that planning sustainable land use in rural areas require a holistic approach, combining different spatial levels (e.g. federal state, regional and local administrations) to insure coherence between governmental policy and local implementation. Planning is not only a top-down but also a bottom-up approach. Walker and Young [1997] give a number of examples demonstrating the potential of GIS (Geographical Information System) for strategic policy analysis, giving politicians the opportunity of thinking locally while acting nationally. They accentuate the necessity of integrated data sets at a similar scale.

2.1 Economic modelling

When analysing land use related policy measures, the spatial dimension becomes a key factor with respect to appointing relevant areas. The costs and benefits of land use changes may vary considerably even within small regions. Environmental conditions, infrastructure and location of different types of farming differ at regional and local level. The spatial dimension of agri-environmental analysis has been recognised in a large number of economic studies. Agricultural non-point pollution has been analysed in a number of studies [Braden et al., 1989; Moxey & White, 1994; Pan & Hodge, 1994; Vatn et al., 1997]. Opaluch and Segerson [1991] recognised GIS as a useful tool in the environmental and economic analysis of groundwater contamination from agriculture [Schou et al. 2000]. A GIS enables the quantification of economic and environmental effects on a site-specific as well as on an aggregate level. Bateman et al. [1999] utilises a GIS to analyse individual farm costs and revenues and extrapolate predictions from the resulting models to yield agricultural value maps. These maps are suitable for policy appraisals, e.g. to identify the economically optimal areas for conversion of farmland to woodlands.

The possibilities for including spatial aspects in agri-environmental analysis have been improved significantly, as the national authorities administrating the subsidy scheme need information about land use and livestock husbandry on each single farm. The data is stored in a general register (GAR/CHR - General Agricultural Register / General Husbandry Register) and each farm can be geo-coded with the location of stalls and agricultural field.

An economic model is used for estimating the economic output from each farm based on information on land use (crop types), livestock husbandry, and the main soil type of the farm. The information of land use and livestock husbandry on each farm is combined with data of average economic output from each production activity from the Danish Institute of Agricultural and Fisheries Economics (2000), from which coefficients for economic rent per hectare and per animal are calculated. In this way the information on production structure on each farm is utilised in order to reflect as much as possible of the spatial variations.

Thus, the economic rent (π_i) of farm i, is modelled as:

$$\pi_i = \sum_{j=1} a_{ij} \cdot \pi_j^C + \sum_{h=1} h_{ih} \cdot \pi_h^H \qquad (1)$$

where

a_{ij} is the number of hectares on farm i with crop j

π_j^C is the average gross margin per hectare from crop j,

h_{ih} is the number of livestock type h on farm i

π_h^H is the average gross margin per animal from livestock type h estimated by the Danish Institute of Agricultural and Fisheries Economics.

The calculation only includes lines of production, which are sold off the farm. On farms where the production of roughage exceeds the expected need for feeding the livestock husbandry by more than 10 percent excess roughage is expected to be sold off farm at cost prices.

In the present study, the economic output is expressed using two indicators: a) the gross output, which expresses the total economic output of the agricultural activities, and b) the profit which is identical to the economic rent of crop production and of husbandry. The economic rent is what is left when all costs, including labour and capital costs except the capital costs of owning soil, are subtracted. Alternative indicators of economic performance, e.g. gross margins, can also be calculated using the model.

A set of decision rules was introduced for all farms, to represent the farm adjustments implied by the land use changes from cultivated arable land to pasture. Adjustments were determined based upon the percentage of total farmland converted to pastures and the number of livestock units per hectare at the farm. If less than 25 per cent of the farmland is converted to pastures there are no radical changes on the farm, while a change on between 25 and 75 per cent of the farmland result in several adaptations. If more than 75 pct. of the farmland is converted to pasture, the whole farm will be converted to suckler cow production (for details, please see Abildtrup et al. [2001]). This last condition may affect areas outside the marginal lands outlined previously and thus influence landscape structure.

2.2 Ecological modelling

Our aim is to assess ecological consequences for semi-natural terrestrial vegetation on a landscape level. A Biotope Landscape Model has been developed and implemented into a Desktop GIS (ArcView™) for some case areas in Denmark [Münier et al., 2001]. In the UK ecological models have been set up in a GIS environment as part of a computerised Decision Support System (DSS) for rural policy formulation [O'Callaghan, 1996; Rushton et al., 1995]. They use an associative matrix model for predicting distribution of plant communities within 1-km^2 units. Another approach use a multivariate prediction of the occurrence of plant communities by combining results of an ordination analysis with habitat mapping from a spatial database and changes in land use [Watson & Wadsworth, 1996]. In general, approaches fall into two main categories: broad scale, large area models with low spatial resolution and detailed models across minor study areas [van Horssen et al., 1999; Venterink & Wassen, 1997; Cherrill et al., 1995].

The task of our research was directed towards an operational model, working with sufficient detail to assess impact at field level and farm scale, while at the same time covering a larger region. Zonneveld [1989] has inspired our key concept, based upon land units as ecological homogeneous tracts of land at the scale level concerned. Similar approaches are those published by Runhaar and Udo de Haes [1994] and Cherrill et al. [1995]. They consider a landscape as divided into ecotopes, defined as areas of unique combinations of abiotic conditions and land management. Ecotopes can be assumed to support a particular type of vegetation characterised by a specific composition of species as result of vegetation succession over time.

The Biotope Landscape Model was developed upon a floristic classification of plant communities found within natural and semi-natural areas in Denmark, using three hierarchical levels: plant community, sub type and main type [Münier et al., 1998; DANVEG]. Linkage between plant community and landscape was established via a description of plant community's ecology and their dependency on land-use and other human activities in DANVEG.

The landscape properties are reflected through compilation of an ecotope map by combining digital maps on physio-geographical settings (e.g. soil texture, soil moisture, surface geology, slope and aspect) and types of agricultural land use. The ecotopes act as a basis for predicting the spatial distribution of 130 plant communities, aggregated to 31 sub types and 10 main types.

A large project area of 6082 km^2 was chosen for the first implementation of the Biotope Landscape Model, covering a range of characteristic landscapes in Denmark. Testing model predictions against vegetation samples shows satisfying predictions for main types (87% correct) and sub types (59%), while predictions at plant community level was found unreliable (28%). An in-depth description of the Biotope Landscape Model and of evaluation results can be found in a former article [Münier et al., 2001].

3. SCENARIO EXAMPLES

Applications of the modelling frameworks are demonstrated in the study area Bjerringbro/-Hvorslev located in the centre of the peninsula of Jutland (Denmark). The two municipalities cover 425 km2 of which 53% is cultivated arable land and 9% extensively utilised semi-natural areas. All types of agricultural production are found in the area ranging from intensive pig and cash crop production to organic dairy farming. A 10 x 10 km sub-area has been chosen for in depth modelling in the ARLAS project.

In order to demonstrate the potential application of the modelling framework, the models are used to analyse the economic and ecological consequences of policies aiming at conversion of intensive cultivated arable land to extensively grazed grasslands. In the present study, we will analyse costs and benefits of different strategies to increase the area of extensively grazed grasslands in the study area. It is assumed that potential areas for establishment of grassland (pastures) are marginal lands, defined as cultivated arable land on hydrosoils (former wetlands), areas with poor (sandy) soils or slopes with gradients of more than 6 per cent.

To illustrate the effects of different policy strategies, three different scenarios for converting 550 hectares to extensive grasslands have been calculated. All farms having a share of potential grasslands have been ranked according to three different criteria (cf. table 1). In the first scenario, the least costly areas are chosen without setting any ecological restrictions (referred to as *Low cost*). The second scenario has the same condition, but select only farms with more than 20 hectares of marginal lands, presupposing that larger grassland areas may alter the environmental or ecological benefits (*Low cost, > 20 ha*). The third scenario ranks farms according to the largest share of their fields bordering existing semi-natural open areas, regardless of the costs involved (*Close to nature*).

with around 25 per cent by imposing the restriction that the pastures should be at least 20 hectares. An appointment of areas close to existing semi-natural areas, regardless of costs, is much more expensive but still cheaper than a conversion of all potential pastures (*Close to nature*). This may be because areas selected are placed close to other pastures, and thus still are located on less productive soils than the average.

Ecological evaluation has been carried out using two approaches. Predictions by the Biotope Landscape Model give the amount of space occupied by different types of vegetation (cf. Table 2). In some cases, plant communities can not be separated by the information held in the ecotope map. This leads to ambiguous predictions for some areas and is a trade off one has to make for the benefit of a model aiming at nation-wide total area coverage. Most of the new areas will become dry pasture in all scenarios, leaving only little space to other types. The *low cost* and *low cost, > 20 ha* scenarios will lead to more semi-natural areas, mainly dry pastures. Finally, the *close to nature* scenario results in a larger amount of potential 'mire' and 'fen and meadow areas', very likely as it includes more former wetlands.

Table 1. Key economic results (loss of economic rent) for the three grassland scenarios, using different appointment strategies for 550 hectares among all potential grasslands.

Scenario criteria:	Low cost	Low cost, > 20 ha	Close to nature
Extensified land [ha][1)]	547	552	561
Number of farms affected	31	13	30
Average area of grasslands/farm [ha]	17.6	42.5	18.7
Total annual costs [Million DDK]	0.83	1.04	1.90
Average annual costs [DKK/ha]	1500	1900	3400

[1)] The difference in the total area of new extensively grazed grasslands is due to the assumption that the whole area of potential pastures on a farm is converted to grassland, if more than 75% are extensified.

4. RESULTS

First, we find that the average costs of converting 550 hectares under the *low cost* scenario are DKK 1500 per hectare. This is more than DKK 3000 less than the average cost of DKK 4800 for converting all the potential pastures (cf. Table 1 and Abildtrup et al. [2001]). The costs increase

Table 2. Prediction of areas occupied by vegetation sub types for present situation and the three scenarios. The model's predictions are not always ambiguous, leading to prediction of more than one type for some areas. A second column shows the difference to the present situation.

Area - status quo and 3 scenarios [ha]	Present	Low cost		Low cost, > 20 ha		Close to nature	
		Tot.	*Diff.*	Tot.	*Diff.*	Tot.	*Diff.*
Moist pasture	93	99	*6*	100	*7*	99	*6*
Dry pasture	588	813	*225*	861	*273*	889	*301*
Dry pasture / moist pasture / fen and meadow	39	41	*3*	41	*2*	44	*5*
Dry pasture / moist pasture / mire	68	71	*3*	70	*2*	86	*18*
Fen and meadow	23	24	*1*	24	*1*	24	*1*
Fen and meadow / mire	31	32	*1*	33	*2*	32	*1*
Other seminatural	51	55	*4*	54	*3*	56	*5*
Total	**893**	**1135**	***243***	**1182**	***290***	**1228**	***337***

Table 3. Analysis of landscape fragmentation, expressed as proximity of selected vegetation sub types. Model predictions have been used to compute an index for the accumulated inverse distance of areas of one type to all areas of the same type, within a distance of 100 meter.

	Proximity index – status quo and 3 scenarios			
Seminatural areas:	Present	Low cost	Low cost, > 20 ha	Close to nature
Moist pasture	17.3	14.3	17.1	14.3
Dry pasture	101.7	153.3	171.5	223.1
Fen and meadow	7.8	7.6	7.6	7.6
Mire	10.2	10.2	10.0	21.4
All types	**190.8**	**297.0**	**488.4**	**365.6**

The second part of the evaluation addresses the problem of landscape fragmentation. Fragstats, a widely accepted tool for analysing landscape structure has been applied here [McGarigal et al., 2002]. For presentation purposes, an index on proximity has been depicted. The index PROX equals the sum of patch area (m^2) divided by the nearest edge-to-edge distance squared (m^2) between the patch and the focal patch of all patches of the same type. Only patches whose edges are within a specified distance of the focal patch are recognised (in our case 100 meters), as defined by McGarigal et al. [2002] (PROX_AM = Area weighted average proximity). Table 3 shows highest overall proximity for the low cost - 20 ha scenario, as this is the only one with restrictions on minimum size of appointed areas. Anyway, the close to nature scenario gives increased proximity for dry pasture and for the rarely represented mires.

5. CONCLUSIONS

This paper presents a modelling framework for integrated economic and ecological evaluation of governmental agricultural policy at a local level. It demonstrates the potentials of spatial detailed modelling tools in definition and assessment of scenarios, outlining option for extensifying cultivated arable land to grazed pasture. Using a spatial explicit approach helps clarifying and assessing interrelations between physio-geographical conditions, biodiversity, land use and economy. Premises behind scenario set up and the related outcome can be made clearer for users such as decision-makers, farmers or the public.

The models are primarily built upon data set available for the entire country at scale 1:25.000., For the time being, compilation of a nation wide ecotope map is about to be finished. This will allow a transfer to other regions or a nation wide implementation of the modelling framework.

Anyway, some constrains may hinder this for the time being. Crops registered in the General Agricultural Register are not spatially referenced to individual fields, but to blocks of 1 to 12 fields delineated by fixed border in the landscape. Only for the study area, an allocation of fields within the blocks has been done by the Department of Agricultural Systems during the ARLAS project. Lack of this precise allocation weakens the spatial accuracy of the analysis, when porting the approach to parts of Denmark.

Output from the Biotope Landscape Model is in some areas unambiguous, and it still lacks assessments based upon widely accepted biological concepts as a supplement to analysis of landscape structure. Finally, landscape structure measurements and their ecological significance should be elaborated further.

6. ACKNOWLEDGEMENTS

The authors wish to acknowledge for joint funding of the ARLAS project by the Danish Ministry of Environment and the Danish Ministry of Agriculture. Collection and analysis of floristic data, classification of plant communities and description of their ecology were conducted by our colleagues at the Department of Landscape Ecology, National Environmental Research Institute, Denmark. Many thanks to Bettina Nygaard, Rasmus Ejrnæs and Erik Aude for the laborious work done.

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