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Assessing management systems for the conservation of open landscapes using an integrated landscape model approach

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Abstract: The aim of the MOSAIK-project is to test alternative management systems regarding their efficiency in maintaining the characteristic species composition of dry grasslands. We present an integrated landscape model approach to test an alternative management system for applicability in preserving dry grasslands. By rototilling, i.e. cyclic, massive disturbance in the vegetation cover, we established a controlled mosaic cycle comprising a successional series from heavily disturbed areas to grassland and shrubs. The disturbance regime affects the landscape on different temporal and spatial scales. The resulting shifting mosaics determine the habitat qualities for plant and animal species. Changes in habitat quality may reduce the survival of local or regional populations. To predict the local and regional risk of extinction of specific plant and animal functional types, we apply modelling approaches on different scales and levels of hierarchy. We achieve to integrate different modules regarding abiotic and biotic state variables, processes and complex interactions in a spatially explicit way into the MOSAIK landscape model, implementing static as well as dynamic model approaches. The parameters and data necessary for reliable modelling were determined empirically in two study sites in Germany. Subsystems of the overall model are empirically parameterized and validated by means of extensive field surveys. The MOSAIK landscape model is still in development. In this paper we give an overview on the proposed landscape model approach and show the general structure of the MOSAIK landscape model. Preliminary results are exemplified in respect to habitat modelling and economic modelling of two simple management scenarios.

Keywords: Landscape modelling; Cyclic disturbance; Management costs; Shifting mosaic of habitat quality; Integrated modelling

1. INTRODUCTION

The structural change in Central Europe’s agriculture causes a loss of species rich ecosystems that depend on traditional land use [Poschlod and Schumacher, 1998; Waldhardt et al., 2003]. In most regions the agricultural practise has been intensified. Instead traditional (extensive) practise to preserve open landscapes, expensive landscape conservation measures like mowing are currently applied. Consequently, it would be generally desirable to shift from static costly conservation to dynamic, more cost-effective management regimes. To minimise these costs, we examine free grazing as well as infrequent rototilling as alternative management systems characterised by an artificial disturbance regime.

Both systems are characterised by secondary successions which are periodically reset by small scale disturbance events. Therefore, the alternative regimes proposed results in a mosaic of habitat qualities for plant and animal species shifting in space and time. The species’ habitats in this mosaic cycle become dynamic with respect to location and time frame affecting colonisation rate and persistence probability. The alternative systems contrast the classical conservation by cutting that conserves low and closed vegetation cover and does not allow periodical succession.

Before recommending the proposed cyclic disturbance regimes as an alternative to traditional conservation measures, a number of questions concerning regional species persistence and (inter-)relationships between management, abiotic conditions and biotic response have to be answered. Only if the species' requirements and attributes meet the long-term spatio-temporal pattern of habitat quality in this mosaic cycle, the dynamic management regime proposed may serve as a cost-efficient alternative.

We empirically studied rototilled and traditionally managed plots on the landscape scale to analyse these management regimes regarding to their conservational and economical efficiency in preserving the species richness of dry grasslands [Kleyer at al., 2002]. We regionalised our findings by applying modelling approaches on different scales and levels of hierarchy to assess the risk of extinction of plant and animal species. Therefore, we integrate static and dynamic modules regarding abiotic and biotic state variables, processes and interactions into a spatially explicit landscape model. There are several examples of successful applications of landscape models for equivalent tasks, especially in forest ecology and management [e.g. Kurz et al., 2000; Li et al. 2000; Liu and Ashton, 1998]. Other landscape models explicitly evaluate the effect of management scenarios on habitat quality [Gaff et al., 2000; Li et al., 2000] and population persistence [Cousins et al., 2003] of species.

2. MOSAIK LANDSCAPE MODEL

2. 1 Introduction

The MOSAIK landscape model was implemented in Borland Delphi™ and integrates several abiotic and biotic modules (see below and Fig. 1), based on a simple grid-based Geographic Information System (GIS). Hence, the different modules are coupled by a GIS. An interface to ESRI ArcView® enables the import and export of digital maps. Each module was empirically parameterised and validated by means of extensive field surveys. Combining the modules the landscape model allows:

i) scaling and regionalisation, i.e. extrapolating surveys and predicted probabilities of occurrence from plot scale to landscape scale,

ii) spatially explicit modelling of processes, interactions and interdependencies between different abiotic and biotic features, and

iii) assessing the ecological consequences as well as the socio-economic costs of management scenarios regarding rototilling and traditional mowing.

The management regimes consider the frequency, spatial extent and temporal sequence of rototilling measures. It depends on the regime if rototilling can be considered a cost-effective alternative for the conservation of open dry grasslands that helps to preserve the specific species composition.

2.2 Model structure

The MOSAIK landscape model comprises the following modules (see also Fig. 1):

i) Maps

Maps of e.g. elevation, slope, aspect, etc. derived by means of digital terrain analysis on the basis of a digital elevation model.

i) Abiotic models

A soil-landscape model providing information on soil properties that determine soil-water conditions, i.e. statistical analysis of the spatial distribution of soil properties with respect to soil samples and their position in the terrain.

ii) Habitat models

Statistical habitat models predicting the shifting mosaic of habitat qualities for plant and animal species as well as the spatial distribution of these species.

iv) Economic models

Financial models calculating the costs of the management scenarios regarding the time schedule and spatial regime of rototilling and traditional mowing.

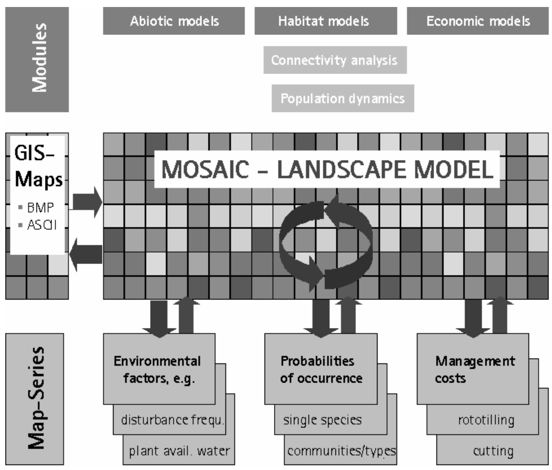


Figure 1. Internal structure of the MOSAIK landscape model.

3. CASE STUDY: LEY LANDSCAPE IN THE NATURE RESERVE “HOHE WANN”, SOUTHERN GERMANY

3.1 Study area and data sources

The empirical studies in order to parameterise the MOSAIK landscape model have been carried out from 2000 to 2003 in the nature reserve “Hohe Wann”. It is located in the Hassberge area in Lower Franconia, Germany (50°03‘ N, 10°35‘ O, see Fig. 2) that belongs to the “Fränkische Schichtstufenlandschaft / franconian escarpment landscape”.

Figure 2. Map of Germany with Hassberge study area.

The area of investigation with an extent of about 7 x 3 km² is characterised by heterogeneous geological substrates, i.e. triassic sand and gypsum keuper as well as the traditional system of inheritance by equal division. South-facing slopes that receive higher-than-average insolation are either used as vineyards or they are fallow land after abandonment. They can be characterised as a mosaic of dry grasslands and shrubs within a matrix of arable land and forestry (see Fig. 3).

The surveys of habitat types, land use and soil characteristics were carried out between 2000 and 2002. Data sets regarding the incidence of plant and animal species as well as habitat features were carried out on 120 plots following a stratified random sampling design. [Hein et al., submitted].

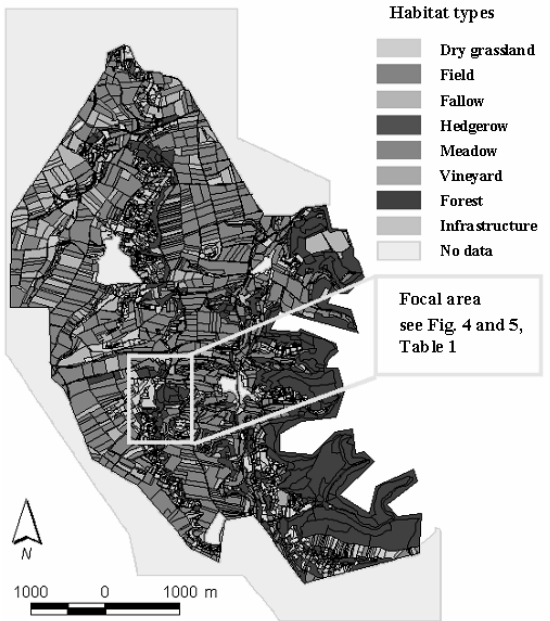


Figure 3. Map of habitat types within the nature reserve “Hohe Wann” in the Hassberge area.

3.2 Scenarios

In order to test the habitat modelling module and the socio-economic module of the proposed landscape model approach we developed two rototilling scenarios (cf. Fig. 6) as examples for more complex scenarios:

i) Scenario **SiLa** (single large): rototilling of a single contiguous patch with an area of ca 7 ha.

ii) Scenario **SeSma** (several small): rototilling of 16 scattered patches with an area of ca 4 ha.

3.3 Preliminary results

3.3.1 Habitat modelling

The landscape model enables the application of habitat models to different disturbance scenarios. Habitat models quantify habitat quality in respect to environment. We used logistic regression [Hosmer & Lemeshow, 2000] to formulate the habitat models [e.g. Hein et al., 2003; Kühner & Kleyer, 2003]. Based on maps of environmental variables (like habitat type, soil properties, land use, slope, aspect, insolation, wetness index, amount of plant available soil water between April to June etc.) we use the habitat models to calculate the probability of occurrence for the entire study area, i.e. we perform a spatial extrapolation from our 120 sample plots. These maps of the probability of occurrence can be calculated for single species, species groups or functional types [Bonn and Schröder, 2001; Kleyer, 2002]. Further, these maps may be transformed to maps showing matrix versus suitable habitat using classification thresholds. These patch maps may be used for the analysis of the effects of spatial configuration (e.g. area, connectivity) on the incidence [e.g. Keitt et al., 1997; Schröder, 2000] or (meta-)population dynamics of species [Biedermann, 2000; Söndgerath and Schröder, 2002].

Although, habitat models assume equilibrium conditions, there are some issues that allow their application in a dynamic context: applying space-for-time substitution [Pickett, 1989] we use time-dependent predictor variables. Predictors directly describing the disturbance regime in terms of frequency as well as depth of disturbance integrate over longer time periods but they directly affect the soil water balance according to their dynamics. Bare soil after rototilling differs in evaporation rate compared to vegetated soil. This aspect is taken into account when calculating time-dependent predictors (e.g. amount of plant available soil water between April and June).

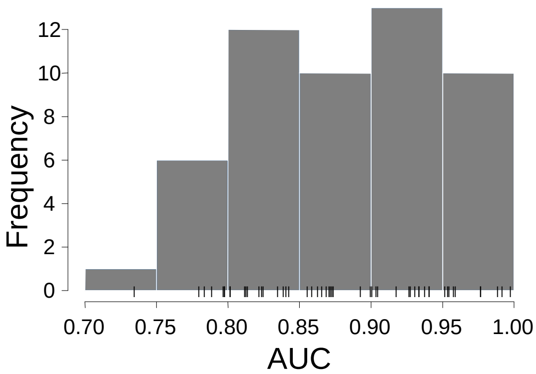


Figure 4. Performance of the habitat models of 52 plants species: frequency distribution of levels of AUC-values.

We modelled the probability of occurrence of 52 plant species and a considerable number of habitat models with good performance (Fig. 4). As a case species the annual plant *Thlaspi perfoliatum* was chosen (Fig. 5 depicts the steps in applying the habitat model). The species' spatial distribution was found to depend on the frequency of disturbance and air capacity of the top soil (maps in Fig. 5) [Kühner and Kleyer, 2003]. The model showed a comparatively good performance (Nagelkerke-R^2 = 0.305 and AUC = 0.780). The species showed an unimodal response regarding the disturbance frequency, meaning that the probability of occurrence reached its maximum for intermediate frequencies (around once per year, what is expected for an annual plant). The response with respect to the second predictor variables is sigmoidal. Since the regression coefficient is negative, the species was found to avoid soils with high air capacity, that dry fast.

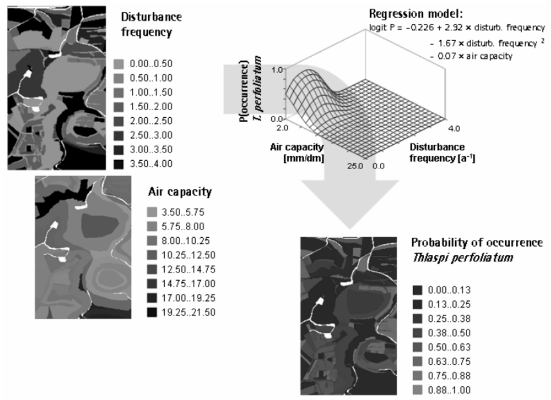
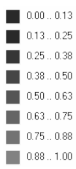
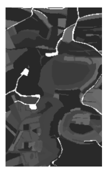
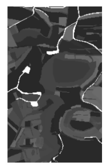


Figure 5. Application of an exemplary habitat model for *Thlaspi perfoliatum*: maps of predictor variables (left), regression equation (top right), response surface and derived map of predicted occurrence probabilities (bottom right).

Table 1. Maps of predicted occurrence probabilities for *Thlaspi perfoliatum* regarding the rototilling scenarios given in Fig. 6 compared to the recent situation (regular mowing).

Probability P (occurrence *Thlaspi perfoliatum*)	**Status quo**	**Scenario SiLa**	**Scenario SeSma**
			
Proportion rototilled (total area = 108 ha)	0%	6.5 %	3.7 %
Habitat units (P × area)	269247 (100 %)	295425 (110 %)	276582 (103 %)

To include the dynamic aspects related to the management applied we used results of frequency analyses conducted on experimental plots (Fritzsch et al., in prep.): if a species revealed significant increase or decrease in the first two years after management, we increased or decreased the probabilties of occurrence estimated by means of the habitat models.

The application of the habitat model onto the two scenarios shown in Fig. 6, the spatial distribution of habitat quality changes. Overall, *Thlaspi per-*

foliatum would benefit from rototilling (Table 1 compares some summary measures and the derived maps of occurrence probabilities). Both scenarios yield higher habitat units.

3.3.2 Modelling of management costs

In two scenarios **SiLa** and **SeSma** the costs of rototilling were modelled in a spatially explicit way. The calculation of the costs of the rototilling is based on parameters like frequency (e.g. each year or every 5 years), effective working time, time for preparation of machines, labour costs, capital costs, costs for farm machines [after Kuratorium für Technik und Bauwesen in der Landwirtschaft, 1998]. The effective working time depends on site parameters like area, slope, soil type, reachability and distance to the next site or farm. As at steep slopes rototilling has to process upwards additionally the orientation of the sites with respect to slope and thus the length of the possible rototilling tracks is relevant. Short tracks require frequent turning of the machines.

Both scenarios imply costs of almost 7000 €/a (see Fig. 6), however, the area-dependent costs are almost twice as large in the second scenario due to higher time budgets (frequent transposing, higher relative amount of fixed costs).

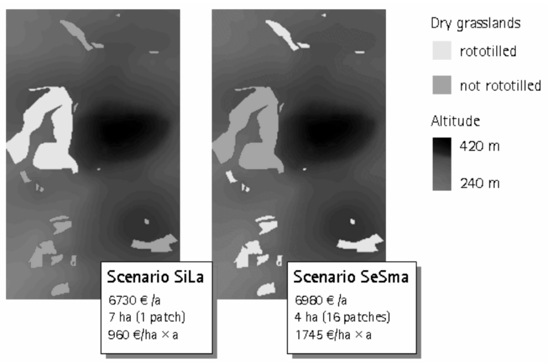


Figure 6. Comparison of two rototilling scenarios: **SiLa** - one contiguous single patch versus **SeSma** - several scattered small patches.

4. CONCLUSION

Based on comprehensive field surveys, the MOSAIK landscape model aims to integrate abiotic models, habitat models and financial models. Using the landscape model, in the study area a number of different management scenarios can be evaluated in respect to nature conservation value and management costs. The results may build the basis of decisions concerning the management of concrete sites, using alternative management systems like rototilling. The application of the landscape model seems especially relevant in situations where the development of sites should be confronted with the costs of the development, as a large number of scenarios can be evaluated in a short time period. Further, the landscape model may be useful for the prediction of future development within environmental planning processes (e.g. impact assessment). However, further developments of the MOSAIK landscape model, like integration of population dynamic models or economic models for pasture management, are necessary in order to achieve valid predictions of the biodiversity of plants and animals as well as management costs.

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