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From landscape-scale models of forest biodiversity change towards an integrated planning tool
– a GUI for building empirical ecological extrapolation models based on land cover data –

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Abstract: Spatially explicit models linking biological field data with remotely-sensed land cover data have become commonplace for landscape-scale biodiversity assessments, but they usually neither consider time series data nor include future scenarios. Extrapolation models addressing these deficiencies for three keystone species/groups of the Kakamega-Nandi forests in western Kenya proved to be a suitable means for investigating the effects of long-term land change processes on the development of forest biodiversity in space and time. However, the experimental modelling design of the approaches is not considered convenient for a more comprehensive, interlinked assessment including more species/groups and also ecosystem functions and services, nor is it adequate for a strong local stakeholder engagement. Here we introduce a conceptualisation for an integrated forest ecosystem assessment tool to be used as regional spatial decision support system in participatory forest management and planning. The tool is based on ArcEngine technology and composed of two tightly coupled frameworks, land cover change modelling and empirical extrapolation modelling, which use a common visualisation component. The land cover change modelling framework allows creating prospective normative scenarios as well as running future landscape projections and provides an interface for sketch-based modelling, thus enabling freehand drawings from stakeholders to be directly included. The results from the land cover change modelling will directly feed in the extrapolation modelling framework which will provide a tailored suite of GIS functionalities typically needed for establishing spatially explicit procedures (e.g. local and focal functions). All functionalities of the tool will be embedded into a user-friendly GUI.

Keywords: customised GIS; land cover change modelling; empirical extrapolation modelling; biodiversity; spatial decision support system

1. INTRODUCTION

Within the last years, GIS (geographic information systems) and remote sensing-based approaches have been increasingly applied to model forest biodiversity patterns [Gillespie et al., 2008]. Many studies have demonstrated the potential of bringing together biological field data and spatially explicit environmental variables such as e.g. land cover data for deriving species distributions and quantitative estimates of population sizes [e.g. Fuller et al., 2005; Acevedo and Restrepo, 2008]. While these studies have doubtlessly contributed to an improved understanding of species–habitat relationships, they mostly refer to one point in time, i.e. they neither provide information on past changes of biodiversity nor do they incorporate future scenarios. Yet, change information derived from spatio-temporal biodiversity assessments has been considered invaluable for decisions towards a
sustainable tropical forest management [cf. Foody, 2003]. For the Kakamega-Nandi forests in western Kenya, this issue has been addressed by spatially explicit extrapolation modelling procedures linking faunal data from field observations with remote sensing-based land cover time series data and additional future landscape scenarios [Lung et al., submitted]. However, so far future landscape scenarios have not been simulated but have been developed making use of GIS-based land cover allocation procedures. The empirical extrapolation procedures have been established ‘manually’ as processing sequences of GIS functionalities applying the results of statistical analyses. This paper aims to introduce a framework for extending this ‘manual’ work towards simulation and automation. More precisely, we propose an integrated forest ecosystem assessment tool to be used in participatory forest management planning which allows participatory simulations of land cover change scenarios to be directly combined with automated empirical extrapolation modelling. Although developed for our study area in Kenya, the tool is conceptualised to display some generic features that makes it applicable also for other regional case studies aiming at landscape-scale forest ecosystem assessments.

The Kakamega-Nandi forest complex [see Figure 1] is located between longitudes 34°40’00” and 35°9’30” East and latitudes 0°29’30” and 0°3’00” North in western Kenya. The area encompasses three main forest blocks, Kakamega Forest, South Nandi Forest and North Nandi Forest as well as seven smaller forest fragments. The Nandi Escarpment forms a strong contrast in altitude between North Nandi Forest with its highest point at 2,140 m, and Kakamega Forest with its lowest point at 1,420 m. Kakamega Forest is the only tropical lowland rainforest in Kenya and is known for its unique floristic species composition combining the West African influence with Afromontane elements [Althof, 2005]. It is often considered the easternmost relic of the Guineo-Congolian rainforest belt and is renowned for its biodiversity, particularly its birds [488 recorded species, Mitchell et al., 2009]. The forests are surrounded by highly populated agricultural land with a density of 643 people km⁻² in the area around Kakamega Forrest and of 371 people km⁻² around the Nandi Forests in 1999 [Lung and Schaab, 2010]. For the rapidly growing population the forests form an important source for satisfying their daily needs [Mitchell, 2004]. Additionally to the local forest use, various legal logging activities and forest management regimes [ibid] have contributed to the current appearance of Kakamega Forest as a mosaic of near natural forest, secondary forest, plantation forest, bushland/shrubs and natural

Figure 1. Overview map of the Kakamega-Nandi forest complex in western Kenya.
grasslands [Lung and Schaab, 2004]. Together with the various stakeholder groups, currently a participatory forest management plan is developed for Kakamega Forest Ecosystem [Schaab et al., 2009].

2. THE CURRENT STATUS OF LANDSCAPE-SCALE BIODIVERSITY ASSESSMENT FOR THE KAKAMEGA-NANDI FORESTS

2.1 Assessment of long-term land cover change processes and creation of future scenarios

A spatially explicit land cover time series was derived from satellite imagery (eight dates between 2003 and 1972/73) and aerial photography (1965/65 and 1948/(52)) focusing on distinguishing forest formations. In total, two natural forest types, two bushland types and three forest plantation types have been distinguished [for details on data processing see Lung et al., submitted; Lung and Schaab, 2004; and Mitchell et al., 2006]. The forest fill from old topographic map sheets served for extending the time series to 1912/13 (i.e. to the time before commercial logging) and revealed that Kakamega Forest, South Nandi Forest and North Nandi forest then formed a single, U-shaped forest together with the surrounding small forest patches totalling an area of 78,124 ha. This figure has been dramatically reduced by 60% to a total area of 31,179 ha of near natural forest still remaining in the Kakamega-Nandi forest complex in 2003. Simultaneously, the area covered by forest plantations has increased continuously, in particular in Kakamega Forest where plantations account for 14% of the forested area in 2003. A small-scale forest fragmentation index based on a moving-window approach [for details see Lung and Schaab, 2006] emphasised that the three main forest blocks Kakamega Forest, South Nandi Forest and North Nandi Forest have become increasingly fragmented over time, but especially in Kakamega Forest slight signs of improvement are seen for 2003 [Lung and Schaab, 2010]. The results indicated strong correlations between fragmentation and forest management with less fragmentation in the more strictly protected national and nature reserves [Lung and Schaab, 2006, for the reserves’ locations see Figure 1].

Based on assumptions relating to aspects of forest management and protection, different normative landscape scenarios [Nassauer and Corry, 2004] have been developed. Besides a scenario of total deforestation outside the national and nature reserves, five different scenarios of reforestation have been created by means of GIS-based land cover allocation procedures. The range of reforestation scenarios includes a ‘minimal scenario’ assuming the clear-felling of the entire forest and subsequent reforestation with exotic monocultures, a ‘negative scenario’ with strict protection only in the national and nature reserves, a ‘realistic scenario’ which assumes a combination of natural forest re-growth and the reforestation of today’s open areas with either of three plantation types, a ‘positive scenario’ with reforestations only with mixed indigenous plantations, and a ‘maximum scenario’ assuming a strict protection for decades, thus facilitating natural forest re-growth [for details see Farwig et al., submitted].

2.2 Spatially explicit extrapolation modelling of biological field data

Based on the long-term land cover time series data, empirical extrapolation models have been established combining spatially explicit GIS modelling with statistical modelling [Lung et al., submitted]. Using the land cover data of 2003, 1984, 1965/67, 1948/(52) and 1912/13, landscape-scale abundance distributions were modelled for the army ant *Dorylus wilverthi*, the guild of ant-following birds and three habitat guilds of in total 115 birds differing in forest dependency. For each of the three keystone species/groups extensive field abundance data was recorded [Farwig et al, 2009; Peters et al., 2009; Peters and Okalo, 2009]. Whereas data on abundance and species richness of bird habitat guilds was directly extrapolated to five forest types distinguished in the land cover time series, regression models were used for *D. wilverthi* (OLS models) and for ant-following birds (SAR models). For extrapolating the field abundance data in space (i.e. to the entire study area) and time (for the time series and for future landscape scenarios), a procedure of GIS
functionalities (local and focal functions) integrating the results from the regression analyses was ‘manually built’ within the Model Builder of ArcGIS. While for the ants forest cover was employed as the only explanatory variable, for ant-following birds, which are highly susceptible to fragmentation processes, the forest fragmentation index was used as additional variable, thus increasing the overall accuracy of the modelled distributions [Lung et al., submitted].

3. CONCEPTUALISATION FOR AN INTEGRATED FOREST ECOSYSTEM ASSESSMENT TOOL

The extrapolation modelling approaches for the three species/groups have not only demonstrated their suitability for landscape-scale, quantitative assessments on changes in tropical forest biodiversity based on time series data, they also showed the high potential of integrating such approaches with future landscape scenarios for evaluating ecological consequences of forest management decisions and actions. Therefore, for the future an extension of the work towards a more complete assessment of the forests’ diversity (i.e. including field data from more species/groups) and also of ecosystem functions and services would be desirable. A large variety of field data on single species/groups but also ecosystem functions and services have been collected in the study area by the BIOTA East Africa project over the last nine years [see www.biota.de]. These as well as data from other biologists and ecologists working in the Kakamega-Nandi forest area could be used. For each of the datasets, empirical extrapolation models have to be developed, linking the field data to the land cover time series data, to landscape scenarios, and/or to measures deduced from it such as e.g. the forest fragmentation index or ‘distance to forest edge’. As a prerequisite it seems necessary to expand from the current experimental modelling design towards a more mature stage of automation and simulation, thus also facilitating and stimulating the active participation and engagement of local stakeholders from Kenya. Therefore, we propose a framework for an integrated ecosystem assessment tool to be used in participatory forest management planning which employs land cover as prime explanatory variable. The tool will consist of two main frameworks: (1) a framework for land cover change modelling, and (2) a framework for building empirical extrapolation models [see Figure 2]. The land cover change modelling part is meant to provide a basis for defining and developing landscape scenarios to be used as input for the extrapolation modelling which aims at an assessment of the potential ecological impact of past and future changes in land cover. Therefore, the two frameworks should not run separately but be

![Figure 2. The general framework for an integrated forest ecosystem assessment tool combining land cover change modelling, empirical extrapolation modelling and the visualisation of modelling results.](image-url)
tightly coupled with each other, i.e. they should be fully integrated enabling direct function calls [cf. Maguire, 2005]. This would allow landscape scenarios generated within the land cover change modelling framework to be directly used for empirical extrapolation modelling. The two frameworks should employ a common visualisation component tailored to the needs of GIS non-professionals that should provide (1) a visual interface for data exploration, (2) functions for creating animations from the spatio-temporal modelling results, and (3) basic functionalities for map layout (e.g. pre-defined colour ramps, functions for adding and modifying a legend). In order to ensure the use of such a tool in Kenya (or potentially other developing countries) in the long term, financial obstacles in terms of GIS-license costs should be reduced. In this regard, building upon e.g. ArcEngine technology could be a feasible alternative to the more costly ArcGIS package. In the following the desired characteristics and capabilities of the two main frameworks will be further elucidated.

3.1 Land cover change modelling

The land cover change modelling part should provide a framework for constructing alternative futures or contrasting trends that will allow decision makers to anticipate ecological consequences beyond the immediate future and to make balanced choices [Peterson et al., 2003]. Generally, two types of scenarios can be distinguished, projective and prospective scenarios [Nassauer and Corry, 2004]. Prospective scenarios are preferable if uncertainty is great and somehow uncontrollable. Due to a complicated network of different forest-influencing forces coupled with political instability and weaknesses in forest management, uncertainty in the Kakamega-Nandi area is considered high. In particular, forest management decisions and the enforcement of protection policies on the ground do have a major impact on the development of the forests, as all remaining forest areas in the study area are located within legally protected areas [see Figure 1]. Therefore, prospective normative scenarios generated by GIS-based land cover allocation procedures have been given priority so far [see Section 2.1]. However, in order to make the generation of such scenarios more applicable to local stakeholders (which are usually GIS novices), the framework should provide an interface where management decisions or intentions of individual stakeholders or organisations can be incorporated in an interactive manner, e.g. by delineating an area of a planned forest plantation. A promising approach in this regard is to adopt some principles of the concept of sketch-based interfaces of modeling (SBIM) [Olsen et al., 2009] which allows sketches – hasty freehand drawings – to be integrated into existing datasets. This would enhance the legitimacy of such scenarios and thus hopefully lead to an increased acceptance and credibility.

Despite the uncertainties in the study area as outlined above, projective future scenarios could serve as feasible supplements to normative scenarios if such land cover models show a clear internal logic, consistency and coherence [Almaco et al., 2006]. In this regard, a clear documentation and communication of a scenario’s basic assumptions and its underlying input data helps to improve the transparency. Building upon an existing land cover change model would save time and effort. A plethora of differing concepts and approaches to land cover change models have been developed which can be grouped e.g. into micro-level or macro-level models [Verburg et al., 2004]. Since typical agents used as unit of simulation in micro-level models are absent or ambiguous, for the Kakamega-Nandi area a macro-level model seems more suited. More important than its underlying technique (e.g. cellular automata, regression techniques, artificial neural networks) are the capabilities of a potential land cover modelling framework in terms of input data and modelling procedure. A list of criteria specific to the Kakamega-Nandi area has been compiled of which some are considered compulsory while others are regarded desirable but not mandatory [see Table 1].
Of particular importance is that multiple land cover classes can be modelled bi-directionally, especially the different forest formations distinguished in the time series [see Section 2.1]. Although much progress has been made in the development of land cover change modelling approaches within the last decades, one major weakness of most existing landscape scenarios is their limitation to one single class ‘Forest cover’ [Almaco et al., 2006]. A land cover change model capable to model gains and losses of five different forest classes and two bushland classes could significantly contribute to an improvement in this regard. Due to the importance of forest management regimes and decisions for the remaining forest areas in the Kakamega-Nandi area, the possibility to include area restriction data (e.g. different levels of protection due to different forest management types) is also considered obligatory [see Table 1]. It would be advantageous if the SBIM- concept would not only be available for integrating areas of a particular land cover type to a normative scenario, but if decision makers could also make use of this technique for defining the input parameters of a land cover change model, e.g. by adding freehand drawings on area restrictions. Other desirable capabilities are e.g. the possibility of defining land conversion elasticities or that the model should provide routines for calculating both land demand and land allocation [see Table 1].

### Table 1. Desired capabilities of a potential land cover change modelling framework for the area of the Kakamega-Nandi forests related to input data and modelling.

<table>
<thead>
<tr>
<th>Criteria / capability</th>
<th>Input</th>
<th>Modelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of multiple land cover classes (not only binary forest – non-forest) *</td>
<td>Sketch-based user interface (for adding freehand drawings)</td>
<td>Modelling both losses and gains (bi-directional modelling) *</td>
</tr>
<tr>
<td>Use of multiple predictor/explanatory variables *</td>
<td>Continuous predictor variables</td>
<td>Possibility of defining conversion elasticities (related to reversibility of change)</td>
</tr>
<tr>
<td>Sketch-based user interface (for adding freehand drawings)</td>
<td>Dynamic predictor variables (i.e. recalculation before each model iteration)</td>
<td>Calculation of transition rates (land demand)</td>
</tr>
<tr>
<td>Continuous predictor variables</td>
<td>Area restriction parameters (e.g. protection areas/ regimes) *</td>
<td>Calculation of change probabilities (land allocation)</td>
</tr>
<tr>
<td>Dynamic predictor variables (i.e. recalculation before each model iteration)</td>
<td></td>
<td>Flexible number to time steps</td>
</tr>
<tr>
<td>Area restriction parameters (e.g. protection areas/ regimes) *</td>
<td></td>
<td>Soft predictions (maps of vulnerability to change)</td>
</tr>
<tr>
<td>* considered compulsory</td>
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3.2 **Empirical extrapolation modelling**

If biological field data cannot be directly related to remotely-sensed imagery (e.g. for ants and ant-following birds), this both involves statistical analysis (e.g. regression analysis) and spatially explicit modelling procedures within a GIS for implementing the results derived from the statistics. In order to save time and effort, for the statistical part we propose an external software package (e.g. the open source software ‘R’). For the GIS part, a framework customized and tailored to functionalities for building spatially explicit extrapolation procedures would enable an active decision making process allowing local stakeholders to be directly engaged in the model development. Although the requirements in terms of GIS functions might vary depending on the characteristics of the field data used, a library of generic functionalities typically needed for empirical extrapolation models should be included. Buffering operators to calculate the proportions of different land cover classes within certain distances around a field point count station or transect is an example of such a typical function. Moreover, a set of focal neighbourhood functions (i.e. a moving window algorithm) and local functions (e.g. mathematical operators) should also be available. All identified functions should be embedded into an intuitive, self-explaining graphical user interface (GUI). This means that the user is prompted to select among pre-defined values for the different modelling parameters (e.g. the size of a moving window) and each function is accompanied with a comprehensive, self-explaining help
system. The framework should also provide an interface for running zonal statistics on the modelling results (i.e. on the derived landscape-level distributions of single species/groups or ecosystem functions/services). The user should be able to define one or multiple areas for which the spatially explicit modeling results are totalled to a single figure and displayed in a chart. Again, the SBIM- concept could be applied to enable local stakeholders to easily delineate their areas of interest.

4. CONCLUSIONS AND RECOMMENDATIONS

In order to facilitate participatory land use planning and a more comprehensive, systematic landscape-scale biodiversity assessment, advancement from the existing experimental modelling design towards an easy-to-use tool tailored to the needs of local decision makers is necessary. In this context we propose an integrated forest ecosystem assessment tool combining two major frameworks, land cover change modelling and empirical extrapolation modelling. The land cover change modelling framework should facilitate to create prospective normative landscape scenarios and to run projective land cover simulations. For both types of scenarios, local stakeholder involvement should be triggered by providing a sketch-based interface of modelling, thus enhancing the usability of the tool. The framework for empirical extrapolation modelling should provide a library of typically needed GIS functionalities embedded into an intuitive GUI. For the Kakamega-Nandi forests the integrated forest ecosystem assessment tool would not only allow to hindcast spatially explicit distributions of species and ecosystem functions / services back to the beginning of the 20th century. It would also enable to anticipate possible effects of land cover scenarios developed in a participatory manner on forest biodiversity patterns. Designed to the specific needs of GIS novices (e.g. local decision makers and others engaged in forest management), it could therefore serve as regional Spatial Decision Support System (SDSS) for a more holistic, truly participatory assessment of the forest resources of the Kakamega-Nandi forests. However, as the tool displays generic functionalities it is not limited to Kenya but re-usable in other regional case study areas of tropical rainforest.

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