Model for the optimal localisation of linear landscape elements based on functional assessment

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Introduction

In the last decades a multitude of assessment methods for landscape functions have been developed (Marks et al. 1989, Bastian and Schreiber 1994). The methods include detailed knowledge from the fields of different sciences and result in maps of landscape risk surfaces. GIS-based models are used to analyse and to asses the landscape functions. New ways are explored by the combination of mathematical methods and spatial data. The assessment of landscape functions is a suitable approach in land uses decision making, especially if a number of different and opposing function assessments are available for the same region. For opposing aims, a method for the integration of land uses in decision making is essential. The authors have developed the framework on multi-criteria landscape assessment and optimisation (MULBO) (Meyer and Grabaum 2003, Meyer 2006, Meyer and Grabaum 2008). MULBO offers a powerful alternative to the common structured aggregation procedures used in landscape planning. The assessment methods integrated as tools in MULBO are validated (Gruehn 2005).

The MULBO-framework focuses on the objectification of the planning process by the integration of multiple assessment results into optimal compromises considering different functions of a landscape and into future land use pattern mosaics or distributions. So far the scenario approach of MULBO for local greenway planning has calculated new spatial distributed land uses. The integration of linear landscape elements into MULBO is now realised. Linear landscape elements are of high impact on cultural landscapes e.g. for water river catchment problems, wind erosion, biodiversity and recreation purposes.

Background/Literature Review

The integration of different landscape assessments in land use decision making is solved in MULBO by multi-criteria optimisation techniques based on linear programming combined with the game theory (Grabaum and Meyer 1998; Grabaum and Kildal 2004). Explicit spatial assessments of landscape functions are used to indicate the carrying capacity of a landscape/territory as subsets of multi-functionality. Details on the seven-step method MULBO can also be found on www.mulbo.de. The most recent optimisation techniques use maximising approaches to solve spatial problems whereas MULBO uses an approach calculating the optimal compromises of land use scenarios to assist decision making (Rossing et al. 2007; Seppelt and Voinov 2003, Holzhämper et al. 2006). Only MULBO realises the stringent orientation on landscape functions (Meyer and Grabaum 2008).

Goals and objectives

Land use optimisation based on Geographical information systems (GIS) uses the existing smallest common geometry as basis of the optimisation problem (raster or vector data). The aim is to find an optimal spatial distribution of linear landscape elements to solve a set of multifunctional problems in rural landscapes. By the way there is an indefinite number of potential solutions for linear landscape elements and a line grid or line net must be generated first to reduce the degree of freedom. By reflecting the idea of optimisation of linear landscape elements the authors developed and coupled different tools to solve the problem.

Methods

The 3 main steps of localisation of linear landscape elements by using multi-criteria optimisation and assessment tools are as follows (Figure 1):

- Generation of the potential line net with the GIS tool "LINE GENERATOR",
- Landscape function assessment of the line net with suitable tools,
- Optimisation of a new line net on the basis of stakeholder goals (scenario settings, weights and rankings) using the compromise optimisation tool "LNOPT 2.0" (land use options).

The generation of a potential line grid should be followed by simple rules. For that reason, only straight lines adjustable in length and heading are discussed. The authors developed the software tool "Line Generator" to produce the grid of potential lines. This software tool is implemented as an ESRI ArcGIS extension.

On the basis of analysed information about the impact of linear landscape elements on landscape functions, assessments are carried out by using the GIS assessment tools available for MULBO (see Meyer and Grabaum 2003; 2008).

This step of the framework results in an attributed line grid and includes the assessment values for each assessment. The output corresponds well to the data structure needed for the landscape optimisation programme LNOPT 2.0 (Grabaum and Meyer 1998; Grabaum and Kildal 2004).

The aim of the multi-criteria optimisation is the localisation of limited new linear landscape elements and to maximise their positive effect on landscape functions. As there could be rivalling goals, the method has to find a compromise. The result is a distribution map showing where different linear landscape elements are to be placed on the line segments. This scenario can be input for further planning steps.

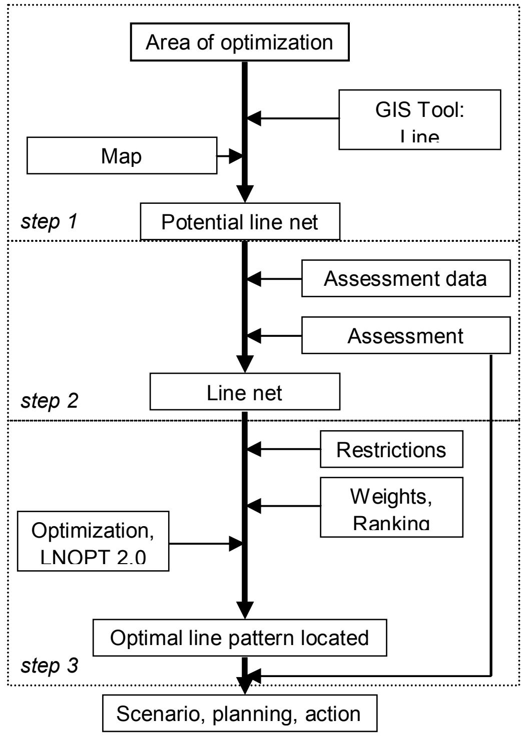

Figure 1. Framework and tools for the optimal spatial location of linear landscape elements using MULBO

Results

The framework was applied on different test sites in the larger Leipzig region. The example of the intensively used agricultural landscape in Barnstaedt (Saxony-Anhalt, Germany) focuses on a solution to solve problems on wind erosion, water erosion (Figure 2) and the habitat qualities for key species (Emberiza calandra, Corn Bunting; Meyer et al. 2007) (Figure 3). By formulation of targets (e.g. the planned length or type of new linear landscape elements, 500 m in Figure 4) multi-criteria optimisation was applied as described by Grabaum and Meyer, 1998, by using LNOPT 2.0. The improvement of the landscape is measured on the basis of the landscape assessments tools for “wind erosion”, “water erosion” and “corn bunting” (Grabaum et al., 2006). The changes in landscape functional risks are demonstrated in Table 1 when comparing the target values optimised with LNOPT 2.0 on the basis of the data set line grid length 500 m for the assessments included.

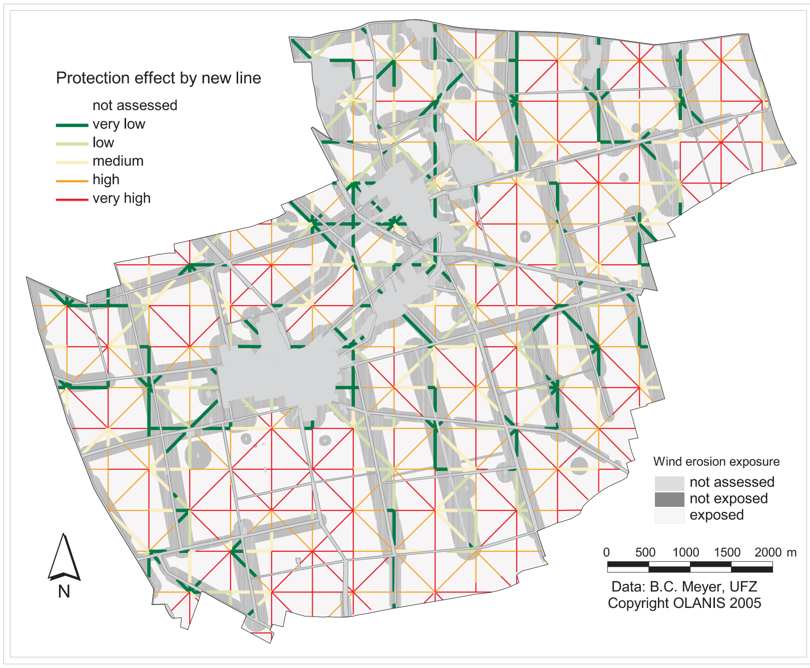

Figure 2. Assessment of the line segments on their impact on the reduction of wind erosion risk

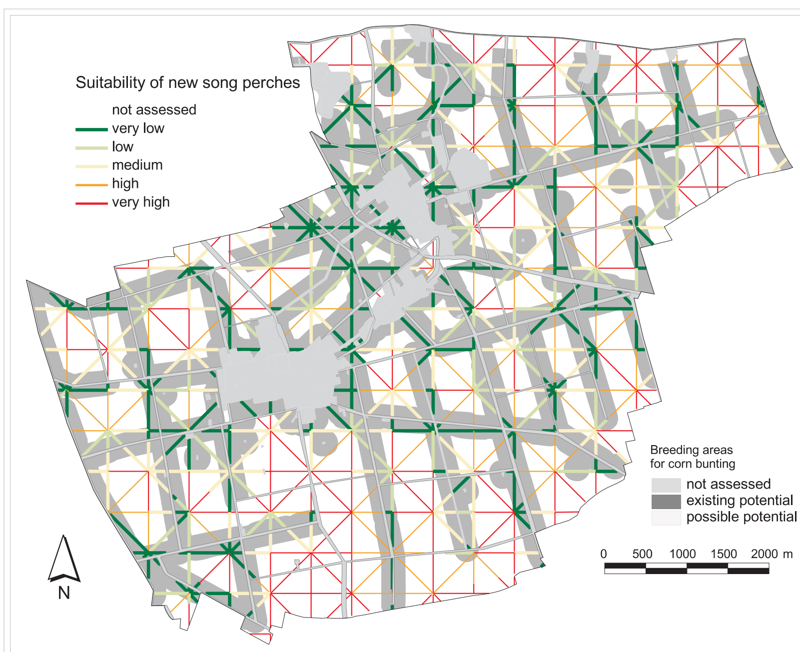

Figure 3. Assessment of the line segments on their impact on the habitat suitability for the Corn Bunting

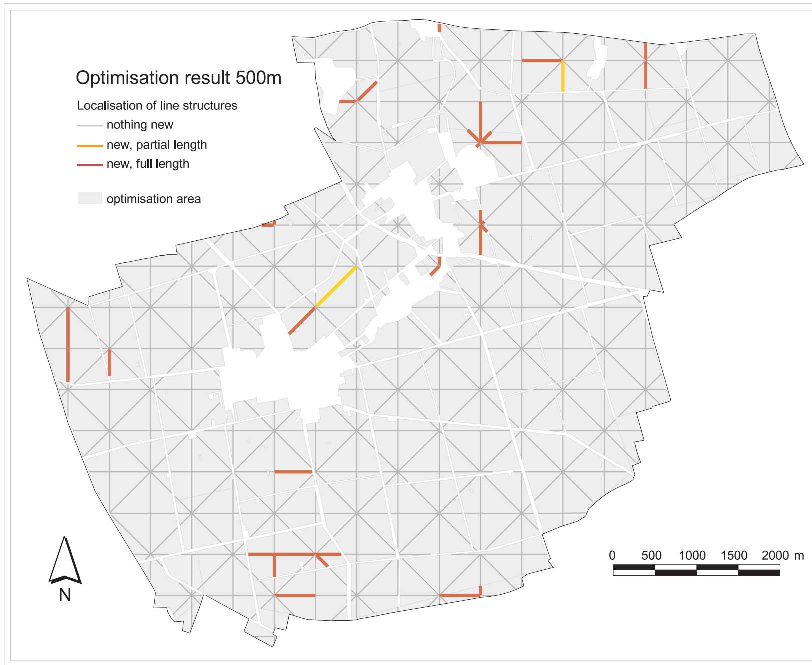

Figure 4. Optimisation result of an even weighted compromise location of linear landscape elements using data set "line grid length 500 m"

Table 1. Comparison of target values optimised with LNOPT 2.0 on the basis on the data set line grid length 500 m

Solution	New distributed line elements (m)	Target value wind erosion risk	Target value water erosion risk	Target value habitat suitability for the Corn Bunting
Actual land use	0	587941	717110	699366
Minimisation wind erosion risk	10000	627941	730088	738046
Minimisation water erosion risk	10000	614347	749532	719889
Maximisation habitat suitability Corn Bunting	10000	620578	727013	739366
Compromise	10000	623580	744291	734196

Discussion and conclusion

An optimal distribution of linear landscape structures has been realised by using the proposed framework. The generation of the potential line grid has been explained. The GIS tool "Line Generator" has been developed by the authors to solve this type of problem by using the geometric concept of the compass rose to produce new line grids. With the technique of line generation, potential problems of application can be seen because of the geometric solution. Some other possible solutions are not achievable with this tool, e.g. double lines, circles or wavy lines.

The discussion of the benefits and disadvantages of our scenario approach by the combination of the tools described relies on the objectification of the planning process, especially when focusing on local greenway planning problems. The calculation of different scenarios for the localisation of linear landscape elements helps to clarify different weights and needs formulated e.g. by stakeholders during the participation process. The usage of the objective results of the landscape analysis on the basis of the landscape functions clarifies the spatial aspects to be solved during the local planning process. The scenario compromises are valuable for the whole area of investigation by integrating the different levels of assessments and land uses/linear landscape elements.

Future aspects of the model development will be (a) the semi-automatic generations of assessments and line net definitions, (b) the focus on trade-offs for better integration on linear element impacts into landscape assessment tools, with the benefit to integrate functional and structural indicator assessments, (c) a more detailed test on the sensitivity of all parts of the tools integrated.

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