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Indicators to monitor the structural diversity of landscapes

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ABSTRACT

An important level of biodiversity, alongside the diversity of genes and species, is the diversity of ecosystems and landscapes. In this contribution an indicator system is proposed to measure natural diversity (relief, soils, waters), cultural diversity (main land use classes, diversity of land use, ecotones, connectivity) and anthropogenic impacts (fragmentation, hemeroby, protection). The contribution gives an overview of various indicators on landscape diversity and heterogeneity currently used in Germany and Europe. Based on these indicators a complementary system, is presented. The indicators introduced here are derived from regular evaluations of the digital basis landscape model (Basic DLM) of the Authoritative Topographic-Cartographic Information System (ATKIS), the digital land cover model for Germany (LBM-DE) as well as other supplementary data such as the mapping of potential natural vegetation. With the proposed indicators it is possible to estimate cumulative land-use change and its impact on the environmental status and biodiversity, so that existing indicator systems are supplemented with meaningful additional information. Investigations have shown that indicators on forest fragmentation, hemeroby or ecotones can be derived from official geodata. As such geodata is regularly updated, trends in indicator values can be quickly identified. Large regional differences in the distribution of the proposed indicators have been confirmed, thereby revealing deficits and identifying those regions with a high potential for biodiversity. The indicators will be successively integrated into the web-based land-use monitor (http://www.ioer-monitor.de), which is freely available for public use.

1. Introduction

A highly diverse landscape fulfils many vital natural functions such as the maintenance of species diversity. The diversity of ecosystems and landscapes is an important level of biodiversity (Noss, 1990). At the same time it helps to maintain functions required by humans to secure their quality of life. Thus parameters which capture the diversity of landscape structures are of interest both to environmental monitoring schemes as well as spatial planners and developers. Such indicators can serve not only to capture biological diversity but may also have application in other ecological fields dealing with the topic of landscape. Some examples are the suitability of the landscape for recreation (Fry et al., 2009), aspects of the local climate (Oke, 2001) or the prevention of agricultural erosion (Siyuan et al., 2007). The diversity of landscape structure must also be considered when investigating ecosystem services and corresponding indicators (Syrbe and Walz, 2012). Regional and landscape planners can make use of indicators on landscape structure to analyse the current state of the landscape and associated natural resources. Such evaluations can be used to derive goals for future development (Botequilha Leitão et al., 2006; Lang et al., 2009).

Here we understand landscape and landscape diversity as a patchwork of cultural and natural elements typical for central Europe, arising through man's activities through the ages. Landscape diversity is considered here as the diversity of land uses but also the diversity of structures and forms (Haber, 2008, p. 92). In this sense, the terms *diversity* and *heterogeneity* in regard to landscape describe the non-uniform distribution of a wide range of forms of land use as well as linear and point-like structural elements (cf. Turner et al., 2003). Waters' edges or extensive semi-natural regions have particular functional characteristics, for example acting as connecting corridors between biotopes. Furthermore, the diversity of ecosystems or the degree of naturalness (hemeroby) (Walz and Stein, 2014) are both pertinent to the issue of landscape diversity.

Diversity in the forms of use across a landscape can be captured numerically on the basis of land-use information. "Landscape metrics" offer a way to precisely capture the composition and configuration of landscape elements. Such metrics describe the size, shape, number, type and configuration of landscape elements. Spatial analysis by means of such mathematical indices enables the

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quantitative analysis of landscape structure (Turner, 1989, p. 173; Turner and Gardner, 1991; McGarigal and Marks, 1995).

Theories and methods of geo-ecological structural analysis have been developed in German-speaking countries since the earliest days of landscape ecology (Schmithüsen, 1948; Troll, 1968; Haase, 1976). The approach was taken up and further refined by researchers in North America in the second half of the previous century (Burrough, 1981; Gardner et al., 1987; Turner and Gardner, 1991; Forman, 1995). North American scientists frequently make use of the so-called patch-corridor-matrix-model, which describes the structure of a landscape as a matrix of some dominant land-use form into which other landscape elements are embedded (patches). In addition to extended landscape elements there are also linear connecting elements of natural original (e.g. rivers and streams) as well those created by man (e.g. road networks), both of which can be designated as corridors. In the case of the typical European landscape with their long history of use and diverse forms of anthropogenic intervention, it is often difficult to clearly specify a dominant matrix structure. Rather the landscape is assumed to resemble a mosaic of areal and linear elements that interact closely with one another.

Over the past two decades the concept of landscape structure analysis has been widely adopted in Europe (Blaschke, 2000; Lang and Blaschke, 2007). Measures of landscape structure are no longer of interest only to scientific researchers but are also finding application in spatial plans and in the field of nature protection (Johnson and Patil, 2006; Walz, 2006; Botequilha Leitão et al., 2006; Uuemaa et al., 2009). Certainly the availability of the free software FRAGSTATS has contributed to this wider usage (McGarigal, 2002). Calculation of these metrics is frequently a useful complement to current methods. At the same time there still exist many obstacles or uncertainties regarding the selection and significance of individual indices (Li and Wu, 2004; Corry and Nassauer, 2005; Schindler et al., 2014). Overviews of the huge number of metrics that have been proposed to describe landscape structure can be found in O'Neill et al. (1988), McGarigal et al. (2002) and Walz (2001).

To monitor the natural and cultural landscape, indicators are required to assess "primary" (natural) diversity as well as to capture "secondary" diversity (Walz and Syrbe, 2013, p. 3), namely that associated with human activity. Although there exists a large range of indicators and systems to capture and monitor diversity at the level of landscapes, these are not consistently or comprehensively applied.

Against this background, the main aims of the study are:

- to give an overview of indicator systems in Europe and Germany
- to elaborate the methodological background of indicators on landscape structure and diversity
- to develop, conduct and discuss a model for a nationwide landscape assessment based on landscape indicators.

As a result this paper proposes a set of indicators on structural landscape diversity which can be regularly updated on the basis of official geodata. These indicators can be used to assess the condition of the landscape and identify any significant change.

2. Methods

2.1. Theoretical considerations on indicators and landscape monitoring

Indicators should allow the measurement of characteristics that are otherwise difficult to capture, such as changes in the landscape and repercussions on biodiversity. They must simplify and clarify complex interactions and developments, while permitting visualisation on the basis of concrete spatial units (Bollmann and Koch, 2001, p. 395). "Indicators are methodological constructs which make use of various measurable forms of information in order to provide a quantifiable statement in regard to a selected phenomenon" (Barkmann, 2004, p. 582). A set of landscape indicators can be regarded as a model of reality, providing simplified but significant information on the state and development of the landscape system. The individual indicators are themselves based on models of landscape and species ecology, e.g. on habitat models.

The necessary base data should be already available or easily gathered with a reasonable degree of effort. It is also important that such base data are regularly updated and are exhaustive for the area of investigation. Indicators must fulfil three main functions (based on León, 2005, pp. 4–7):

1. *Function of communication and information:* Indicators can contribute to the practical implementation of measures by illustrating the status quo as well as areas where action is required. In order to influence target groups and actors such as politicians and citizens, it is necessary that indicators give a highly objective and easily comprehensible picture of the current situation.
2. *Function of analysis and evaluation:* In order to monitor activities as well as the impact of political strategies and funding programmes, it is necessary that indicators can provide comparable findings on any topic of interest over a long time period. This enables the identification of development trends as well as progress made or indeed setbacks.
3. *Planning function:* Indicators can reveal where action is required by describing the general state of affairs (see points 1 and 2) as well as providing more detailed spatial information to permit the identification of problem sites within any planning region.

The primary focus of this paper is on landscape monitoring, defined by Blaschke as "the planned investigation of a landscape at regular intervals", serving to "capture and analyse changes and developments in its structure, function and human use." (Blaschke, 2002, p. 116). Such landscape monitoring is indispensible for the protection of natural resources. Legal and political goals in nature protection at the regional, national or European level can only be maintained and assessed by means of a permanent system to monitor landscape diversity and changes in land use. Article 7 of the Convention on Biological Diversity provides legal backing for such monitoring (Blaschke, 2002, p. 119).

A system of extensive landscape monitoring, such as for the entire territory of Germany, must have the following features (Blaschke, 2002):

- regular data capture at defined intervals,
- the use of GIS and remote sensing data,
- individual landscape elements are not the primary interest but rather changes to the mosaic of individual landscape patches,
- a focus on key indicators that are easy to capture over long time periods and which represent critical factors of landscape development,
- a high degree of abstraction and a strict focus on land use.

The underlying notion is that patterns of land use reflect basic functions and process, so that changes to these patterns (the disruption of landscape structures by intensive farming, construction, fragmentation, etc.) indicate that landscape functions have been transformed (Blaschke, 2002, p. 119).

Furthermore, in regard to species diversity, this indicator system implies that (Hoffmann and Greef, 2003):