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Applying spatial heterogeneity indices in changing landscapes in the Czech Republic

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Abstract

Many very different approaches to landscape patterns are used all over the world in landscape ecology, landscape planning and management. Intensive development of geographical information systems in the last decade has meant increasing interest in analysing landscape changes. GIS has enabled quantification of the spatial changes in large areas, and the provision of much more representative results. However, implementation of the results into landscape planning and management is still not satisfactory. Proposals for analysing changes in land use and the attributes of landscape patterns have been developed and tested in four study areas representing different landscape types. Changes in landscape patterns based on land use are monitored between 1845 and 2000. The results show various rates of simplification of

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land-use patterns in all study areas, taking into consideration natural conditions and human activities. We conclude that spatial heterogeneity is a relevant criterion for landscape planning, design and conservation, and for defining management principles in order to maintain the biodiversity and aesthetic values of the landscapes.
Keywords: landscape planning; landscape management; landscape patterns; land-use changes; GIS

Introduction

The justification of landscape ecology as a science requires that the gap between process studies and spatial planning is bridged (Moss 2000). Effective communication between landscape ecologists, the public and the decision makers is lacking, but will be essential for the future development of the science and for applications of landscape ecology (Wu and Hobbs 2002). It is necessary to develop an approach for generalizing and aggregating ecological knowledge for application in spatial planning (Opdam, Foppen and Vos 2001).

Many of the computer-modelling approaches used in science are based on quite complicated and expensive techniques such as hexagonal-packing models, general neutral models, percolation theory, cellular automata and others (Forman 1995), which would not translate easily into landscape-planning practice. Landscape metrics as a quantitative ecological tool can be very useful for incorporating ecological knowledge into planning and for supporting decision making. Planners and other practitioners would be much more receptive to incorporating ecological knowledge into their activities if they were presented with a single, coherent, consistent methodology (Botequilha Leitão and Ahern 2002). Excessively complicated or abstract approaches are not favoured for practical applications. The use of GIS enables theory to be incorporated into practical planning with the development of applied software.

The electronic revolution in recent decades and the rapid development of geographical information systems (GIS) in the last decade have impacted on progress in landscape-ecological spatial analysis (Forman 1995). Because of its high functionality in terms of processing, analysing and representing spatial and temporal data, GIS has become established as an essential tool in the specific fields of landscape analysis, landscape assessment and landscape planning (Kindler and Banzhaf 2001). Moreover, GIS allows huge ecological data sources to be processed, and much more representative results to be obtained. Its convenience for visualizing the design of the proposed measures supports its application in negotiations with the public and with the authorities in landscape planning and management. Thus GIS can provide a common computer environment for bridging between landscape ecology and landscape planning. Assessment based on landscape ecology has been established in landscape planning since the 1980s (Falero 1986; Miklós 1986). However, in the Czech Republic, despite expansion of the science underlying landscape-ecological assessment, it has not been implemented in planning or management practice.

During the 20th century, the cultural landscape of Europe was progressively intensified, with mechanization leading to increased field sizes, enlarged forest blocks and the removal of small biotopes (Fry and Sarlöv-Herlin 1997; Fjellstad and Dramstad 1999). In some countries, this was strongly influenced by social and political developments. Sklenicka (2002) suggests the political changes after 1948 as a highly significant factor that negatively affected changes in land use and spatial heterogeneity in the Czech Republic. However, these changes, and their impact on the landscape, need to be evaluated objectively.

Spatial heterogeneity is one of the most important characteristics of landscape systems. It strongly influences all movements and flows (Forman 1995) and many authors refer to the importance of landscape heterogeneity for the biotic value of the landscape (e.g. Odum 1971; Hansson 1977; Ringler and Heinzelmann 1986; Noss 1983; Forman 1995). Each of the optional forms of landscape planning also has its potential for managing the spatial structure of the landscape. Therefore, there is an argument for transferring knowledge of, and for promoting the role and value of, measures such as spatial heterogeneity from scientific journals into practical methodologies.

In this paper we apply landscape metrics to illustrate ways of improving the objectivity of decision making in the planning process. Many metrics are used in landscape ecology and some of them could be very useful for practical applications. The metrics should allow interpretation in terms of landscape function, and should also include relations to natural values and biodiversity. A great advantage of having a defined set of metrics for evaluating changes in spatial heterogeneity using GIS is the opportunity to compare the present state of landscape patterns with a historical state or with alternative scenarios. The requirements for a set of metrics that can be used in practical applications are that they should not be too complicated, expensive or time-consuming, and the outcomes should be easy for planners, decision makers and also stakeholders and the general public to understand.

The objective of this paper is to test the ability of a set of metrics to provide an intelligible expression of spatial heterogeneity and its spatial-temporal changes. Special attention was focused on the practical use of these metrics in landscape planning. The principal metric considered is that of spatial heterogeneity, as a measure of landscape diversity. The method is demonstrated in four study areas. The changes in spatial heterogeneity are considered in terms of the development of ecologically stable/unstable land-use types. The results from the study areas are summarized in a GIS environment with graphical outputs and databases.

Methods

Landscape characteristics

The spatial-temporal changes in land use were studied in several study areas, with the focus upon the matrix of the landscape, patches and corridors, and their interactions. The heterogeneity of the landscape was the principal characteristic considered (V) (Mimra 1993), complemented by indices of percentage of ecologically relatively stable land-use types (P_{ES}) (Michal 1994; Lipsky 2000) and edge density (D_E). The calculation of V is based on an equation provided by Mimra (1993), which is used mostly for evaluating ecological values of landscape for bird species. The index is based upon the Shannon-Wiener index of diversity and is supplemented by other variables – whole area, number of all patches. Thus this index enables delineation of study areas, which could be a big issue (Liu, Nishiyama and Kusaka 2003). Then the patches of land use as elements can be used, not only cells with a square shape (Delcourt and Delcourt 1996; O'Neill et al. 1988). The procedure is described in Sklenicka (2002).

The heterogeneity index mainly expresses the diversity in land-use types present in the landscape. Further information about the landscape pattern can be obtained from the size and shape of the patches and the length of the edges, which will be derived from the index of edge density (D_E). The length of the edges can also be used to summarize the size and shape of the patches (Forman 1995). D_E is expressed as the length of the edges per unit area [$km.ha^{-1}$], and only those that separate different land-use types are taken into account.

These two indices are principally used to characterize the spatial arrangement, and in order to complete the tool for landscape evaluation a third index P_{ES} was used to characterize the 'ecological quality' of the landscape elements. P_{ES} is calculated as the percentage of the areas of ecologically relatively stable land-use types [%]. Data for calculating these indices are easily accessible from the GIS databases that were produced when digitizing the basic data.

Study areas

The methods are applied in four study areas (Figure 1). These study areas were selected on the basis of data availability and represent different types of landscape in the Czech Republic. Four studies on land-use changes over the last 150 years reported by Sklenicka et al. (2002) have been processed as parts of broader research projects. Table 1 shows an overview of these areas.

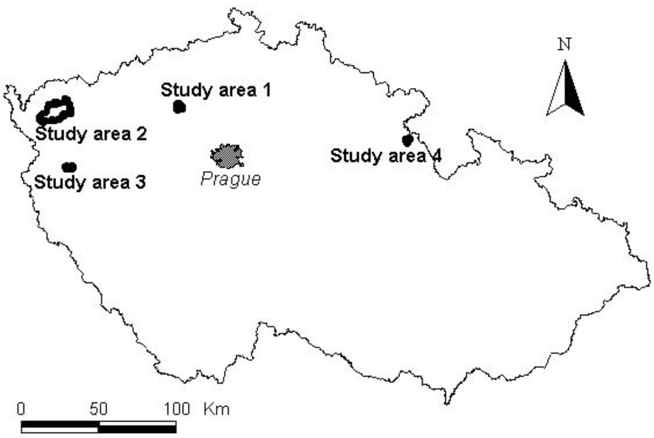

Figure 1. Location of study areas

SA1- Lounsko is an intensively cultivated rural area with large plots of arable land and high soil quality. This area is one with the oldest settlements in the Czech Republic with a long tradition of agriculture. The dominant land-use type is arable land (72%).

SA2 - Sokolovsko is a large area with its landscape structure highly impacted by mining activities: the relief and water system were dramatically changed and the original ecosystems were destroyed in directly affected parts of the area. In parts of Sokolovsko there are only indirect impacts or no impacts. The main land-use types are spoil banks (29%), forest (25%), pasture and meadows (16%) and arable land (13%).

SA3 – Tachovsko is a marginal rural area with large forest plots. This area is influenced by a strong displacement of population in the last 150 years. The dominant land-use types in this area are: forest (50%), pasture and meadows (31%) and arable land (13%).

SA4 - Podorlicko is hillocky landscape of foothills with a fine-grained landscape mosaic. The rugged topography, relatively small plots, rotation of forested parts and pastures are the main characteristic features. The main land-use types in this area are pastures and meadows (39%), forest (27%) and arable land (23%).

Table 1. Essential characteristics of the study areas (AAT is average annual temperature; AASD is average annual precipitation)

Study area	Verbal definition	Location	Total area [km^2]	Altitude [m]	Climate	Average price of farmland [Kč.m^{-2}]
SA1	Intensively cultivated rural landscape	Louny Distr.: Obora, Slavětín, Veltěže	17	about 230	Typically warm and dry, AAT 8.0-9.0 °C, AASD 450-500 mm.	7.24
SA2	Landscape disturbed by open-cast mining	Sokolov brown coal basin	219	400–520	Slightly warm and relatively dry, AAT 6.4-7.3 °C, AASD 640-670 mm.	3.12
SA3	Marginal rural area of alternating agriculture and recreation.	Tachov Distr.: Olbramov, Kořen, Zádub	15	430 – 580	Slightly warm and rainy, AAT 6.0-7.0 °C, AASD 650-750 mm.	2.26
SA4	Hillocky landscape of foothills, mainly used for recreation	Rychnov n. K. District: Bystrá, Janov, Tis, Sněžná	13	520 – 730	From slightly warm to chillier, AAT 5.0-7.0 °C, AASD 650-800 mm.	2.12

Data collection

The geographic information system (GIS) is used for analysing the study areas and for presenting the results, with inputs from aerial photographs, 1:5000 topological maps and 1:2880 historical cadastre maps. The data were scanned, transformed and geographically registered, and the relevant features were digitized in the software package Topol for Windows vs. 5.503. The development of land-use changes was observed over the last 150 years in several time intervals. For this study only the historical results from the period around 1845 and the present-day results from around 2000 are used. Twelve land-use types are recorded; they are grouped into two classes according to estimated ecological stability (Michal 1994; Lipsky 2000; Sklenicka 2003):

- Ecologically relatively stable land-use types: woodlands, water elements, grasslands, wetlands, gardens and orchards.
- Ecologically relatively unstable land-use types: arable lands, hop fields, spoil banks and residual holes, urban areas, roads.

Results

The results from the study comprise the measured characteristics of the landscape. However, in order to transfer the information and knowledge to planning practitioners, the creation of a spatial database for use in GIS was also a significant output. Figure 2 shows an example of graphical outputs from GIS. The characteristics measured for the landscape are summarized in Figures 3 and 4.

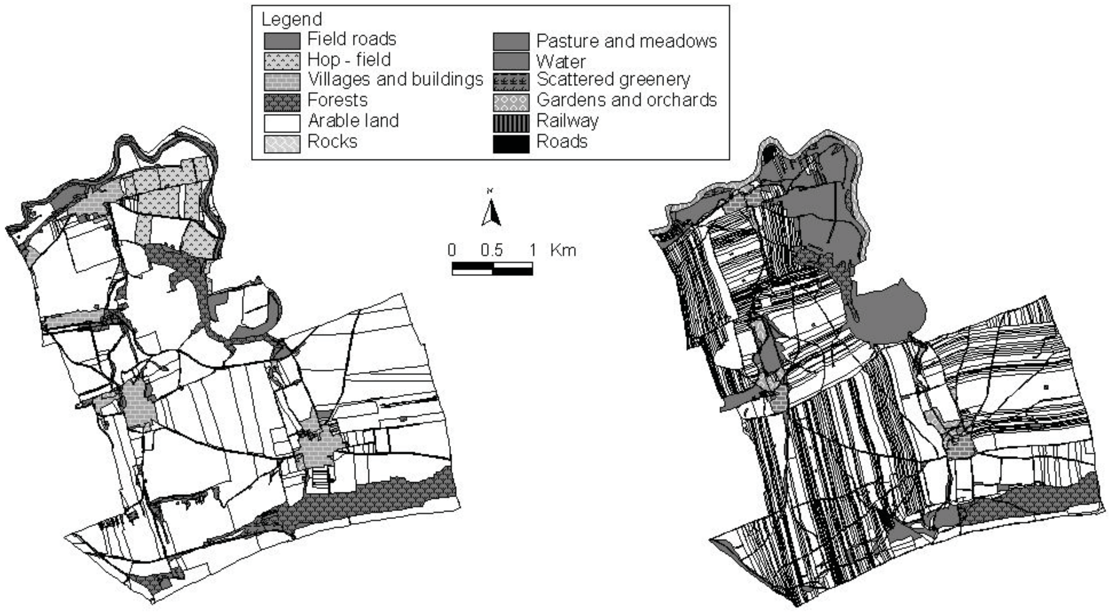

Figure 2. Study area 1 – historical and present state of landscape pattern of land uses

Simplification of the land use patterns was found in all of the study areas. The indices of landscape heterogeneity suggest that there has been a reduction in landscape heterogeneity in all four study areas over the last 150 years. The changes toward a simpler land-use pattern are also supported by the results for the changes in edge-density measurements, with the graph of D_E showing a decrease for all study areas (Figure 3).

In order to interpret these trends, an analysis of P_{ES} was used (Figure 4). A decrease in the percentage of relatively stable ecological land-use types was observed in two study areas – intensive agricultural land (SA1, -7.1%) and mining (SA2, -12.2%). The two other study areas show an increase in relatively stable ecological land-use types (SA3, +31.9% and SA4, +32.8%). This means that in only two cases (SA1 and SA2) the loss of spatial heterogeneity was attended by the loss of wildlife habitats. In the two other study areas (SA3 and SA4), the loss of spatial heterogeneity was accompanied by a reduction in elements of lower ecological quality.

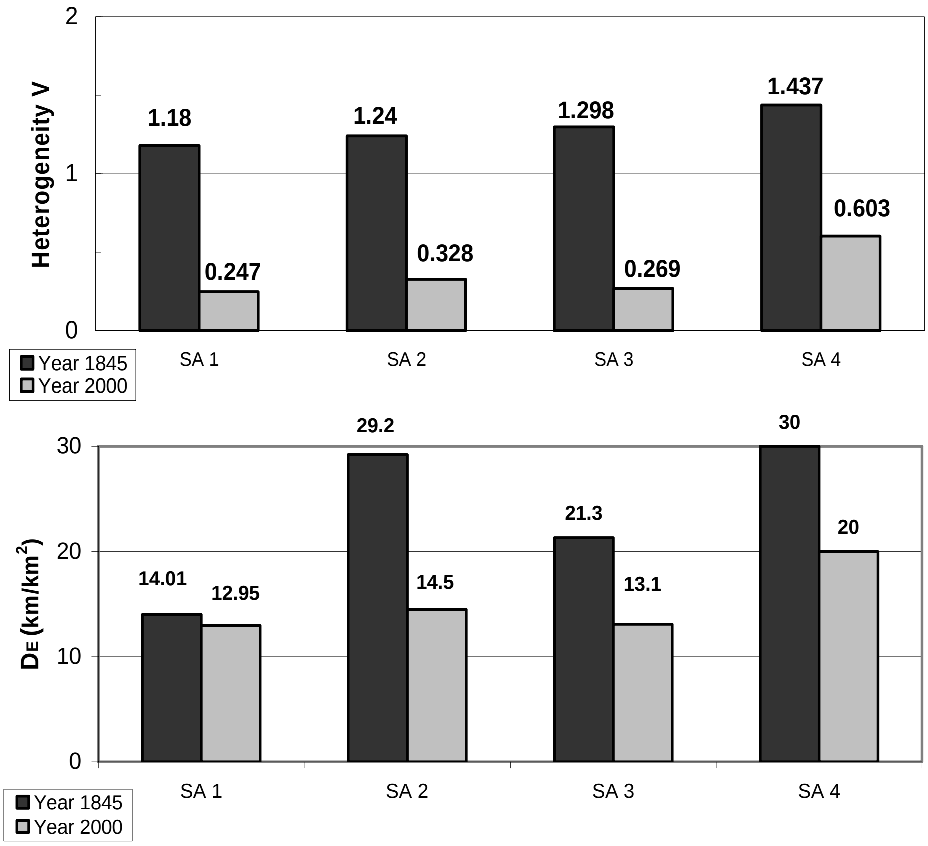

Figure 3. Temporal changes in landscape heterogeneity (V) and edge density (D_E) in the study areas

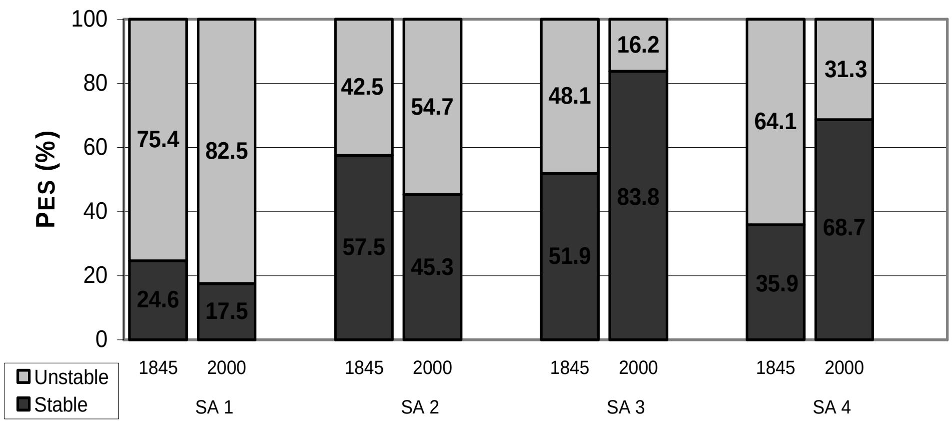

Figure 4. Temporal changes in percentage of ecologically relatively stable land-use types (P_{ES}) in the study areas

Discussion

The process of landscape simplification can be interpreted for many countries and regions from national agricultural statistics (Fjellstad and Dramstad 1999). However, only observations of spatio-temporal changes can explain what has happened to the landscape pattern over a given period of time. Although the index of landscape heterogeneity was originally used for evaluating landscape patterns for bird populations (Mimra 1993), it is also suitable for evaluating whole landscape patterns and can be taken as a quantitative criterion of landscape reconstruction (Sklenicka and Lhota 2002). The only change to the index is in the use of the variables from land use. The index was calculated on the basis of an evaluation of land uses, which makes the results more intelligible and enables easier implementation of the results for recommendations regarding landscape-planning issues.

When applied to data for different years, the changes in the outputs from the index can be interpreted in terms of historical changes in the landscape, and as an input for examining the landscape dynamics. Thus, the spatial characteristics of the landscape can be expressed objectively, and historical maps or photographs are used not only to provide visual inspiration for planners. The response of species to the changes should also be monitored and the metrics should be validated for this purpose.

The results of all four case studies presented here show a decrease in spatial heterogeneity in the course of the last 150 years, as shown by the graphical outputs and expressed by the indices. The three metrics that were used for evaluating the landscape patterns each produced different information for the study areas. The index of landscape heterogeneity provides information about the spatial arrangement of the landscape, as does the edge-density index, which can also be interpreted with respect to special habitats (ecotones), which are often omitted in landscape-planning practice. The third index P_{ES} provides information about the ecological quality of the landscape.

The indices of heterogeneity and edge density are not completely independent, and can in places result in redundant information. August et al. (2002) suggests that, in most cases, land management goals should be to minimize edge-to-core ratios. However, in the context of the significant simplification of landscape patterns in the Czech Republic between 1950 and 1990, when ecotonal habitats were removed in particular, this goal is not adequate. Information about edge density (or length of edges) could make a great contribution to landscape planning, with higher values of edge density suggesting an increase in the ecological and aesthetic values of the landscape. Where appropriate, gradations between classes, rather than an abrupt transition between natural and impacted land uses, should be designed (Kozlowski and Vass-Bowen 1997).

The aims of landscape planning and management mentioned in particular parts of planning legislation are to maximize biodiversity and to provide an opportunity to live in aesthetically pleasing landscapes. Simplification of landscape patterns accompanied by loss of wildlife habitats reduces biodiversity, accessibility to the landscape and the recreational value of the region. However, a process which homogenizes the landscape pattern but increases the percentage of wildlife habitats can counteract the effects of habitat fragmentation. Thus, when a decrease in spatial heterogeneity is accompanied by an increase in ecologically valuable elements, the consequences will probably not be very serious, due, among other factors, to lower habitat fragmentation.

Conclusion

Landscape planning is a transdisciplinary activity that often deals with large datasets, requiring powerful tools in order to be objective and transparent. By using GIS we can produce graphical outputs and figures, which can make communication easier between different types of stakeholders, such as landscape planners and ecologists, and also for other specialist or non-expert audiences and especially for those stakeholders who are viewed as a most important dimension in a sustainable landscape-planning process (Botequilha Leitão and Ahern 2002). Use of the derived databases of measures of landscape characteristics provides an additional source of objective information to be interpreted. The potential to interpret changes in the landscape with the use of a range of metrics, such as those of spatial heterogeneity presented in this paper, argues in favour of their inclusion as common attributes of a planning database rather than as additional extras.

We have not addressed the question whether the proposed metrics encompass all essential information for interpreting landscape change with respect to consequences for biodiversity. Other characteristics of landscape systems (e.g. connectivity, critical thresholds) should also be taken into account in landscape planning (With and King 1999). However, although use might be made of many other metrics for evaluating landscape patterns, how many such metrics lead to duplication of results and thus complicate interpretation rather than adding something new? Political arguments usually prefer a single metric rather than a set of several metrics. So, although it is possible to incorporate the length of edges into an index of landscape heterogeneity, does such an index remain fully comprehensible? It is not likely that a single metric can be produced for all characteristics of a landscape system, while still addressing the complex range of questions posed by different types of stakeholders. Rather, it is probable that a single framework, with a recommended set of metrics and methods, for planning with spatial dimensions in different areas of human activities would lead to greater understanding and more efficiency in the decision-making process.

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