Chances and limits of using landscape metrics within the interactive planning tool Pimp Your Landscape

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Abstract: Landscape metrics provide valuable information for the interpretation of landscape patterns. With regard to the implementation of structural landscape parameters into the evaluation system of the planning tool Pimp Your Landscape, we studied values of landscape metrics at different spatial resolutions. A literature review and a case study led to a choice of metrics that might be suitable for the assessment of several landscape functions and services. We tested this set of landscape metrics for a test area in Saxony, Germany. Except for diversity indices which gave consistent responses, landscape metrics varied significantly with changing resolution. Considering these results, we selected few easily applicable, unambiguous landscape metrics. With respect to the spatial resolution, these indices might be useful to quantify processes, functions and services on landscape level within Pimp Your Landscape. Using class-level indices, a specific aggregation of land use types might be helpful for an exact description of land use pattern changes caused e.g. by landscape fragmentation.

Keywords: Pimp Your Landscape; landscape metrics; scale problem; biodiversity; landscape aesthetics

Introduction

A major challenge in landscape management is the permanent consideration of ongoing changes, such as shifts in the climatic frame conditions or altered demands on environmental services. Legal restrictions limit the degree of freedom to react flexibly on such changes and to avoid undesirable trade-offs. Therefore, planners often demand for an easily adaptable and usable planning tool that also considers planning restrictions (Fürst et al., 2008). The interactive planning tool Pimp Your Landscape (PYL) was developed to correspond to this need (Fürst et al., 2009). It allows both evaluation and visualization of land use scenarios. PYL is a web-based tool for supporting multi-criteria decision making and participatory processes in land use management at landscape level. Furthermore, the tool enables even the inexperienced user to design his landscape by mouse click. As basis, the European wide available maps and classification of land use Corine Landcover 2000 (CLC 2000) are used.

PYL was designed to support the understanding of complex interactions between various land use types on landscape level and to provide a basis to evaluate the impact of user-made land use pattern changes on most important land use services. Therefore, the continuous spatial problem "landscape" must have been divided into spatially distinct units, which can interact and communicate with each other and to which different attributes can be assigned.

The mathematical approach, which has been chosen to reflect complex spatial interactions, was a cellular automaton with Moore-neighbourhood ship. Cellular automata were first introduced by Ulam (1952) and their potential to support the understanding of the origin and role of spatial complexity was highlightened by Tobler (1979). The approach was e.g. used to model urban structures and land use dynamics (Barredo et al., 2003; White et al., 1996; White & Engelen, 1994, 1993), regional spatial dynamics (White & Engelen, 1997), or the development of strategies for landscape ecology in metropolitan planning (Silva et al., 2008). Nowadays, cellular automata are broadly used to simulate the impact of land use (pattern) changes and landscape dynamics (e.g. Moreno, et al., 2009; Wickramasuriya et al., 2009; Yang et al., 2008; Holzkämper & Seppelt, 2007; Soares-Filho et al., 2002).

A major shortcoming of the approach "cellular automaton" is that ecological or aesthetical aspects on a landscape level cannot be appraised by counting cells, because this would ignore e.g. the spatial connectivity of land use types or landscape fragmentation. LMs might contribute to PYL by providing a landscape related evaluation procedure.

The core of PYL is a hierarchical approach to evaluate the impact of land use pattern changes on environmental services (cf. Koschke et al., this volume; Fürst et al., 2009). The evaluation starts by selecting the land use types (biotope types / ecosystem types), which are of regional relevance and by defining the land use services and functions of regional interest. The land use classification standards of CLC 2000 and the land use services and functions set described by Perez-Soba et al. (2008) are available as initial settings. The user can modify these initial settings or adopt completely different settings according to the regional application targets.

In a next step indicator sets are identified, which provide information on the impact of the land use types on land use services and functions. This step requires several feed-back loops with regional experts: a major problem in the holistic evaluation on landscape level consists (a) in the different scales and dimensions of indicator sets at the different land use types (Fürst et al., 2009) and (b) in the regional availability of respective knowledge sources. Therefore, a meaningful selection and weighting of the indicators is requested, which respects also regional expert knowledge and experiences to compensate existing knowledge gaps.

Based on the indicator sets, the impact of each land use type on each land use service or function is evaluated on a relative scale from 0 (worst case) to 100 (best case). The introduction of this relative scale enables (a) to compare the impact of different land use types on an individual land use service or function. (b) The setting of a relative scale as reference supports also a multifunctional evaluation, which faces the challenge to make comparable reactions of different land use services and functions on land use pattern changes.

The resulting (regional) value table represents initial impact values of the land use types on the services and functions. These must be regionalized to consider (a) the cell specific environmental frame conditions (e.g. height above sea level, mean annual precipitation and temperature, soil type and exposition) and (b) the neighbourhood of different land use types. This step is supported by rule-sets, which offer the user the possibility to specify a possible increase or decrease of the initial value in dependence from neighbourhood type (homogeneous land use types vs. different land use types, edge to edge vs. corner to corner) and in dependence from the (available) environmental attributes.

Building upon the regionalized evaluation basis, landscape structure indices (LMs) are introduced to adopt the evaluation of "soft" land use services and functions referring to biodiversity or services related to the aesthetical value of a landscape. The indices help to integrate the heterogeneity of the land use pattern, the size and connectivity of patches and the form of patches from the holistic landscape view (e.g Uuemaa et al., 2009).

The aim of our contribution is to facilitate the quantification of environmental services that are influenced by complex human-environment interactions (Parker et al., 2008) by choosing adequate LMs. Furthermore, the applicability of LMs as valuation tool especially for landscape diversity and landscape aesthetics was tested.

1. Methods

The here used version of PYL enables users to evaluate the impact of land use pattern changes on four environmental services, namely economy, ecology, aesthetic value and water quality. These were chosen in a very first attempt to develop a representative approach of how to use LM, to improve the evaluation within PYL. Suitable attributes to quantify ecological state and tourism potential of landscape are biodiversity and landscape aesthetics. These are based on landscape properties such as heterogeneity of land use, size, form and connectivity of patches, etc. LMs are frequently used to describe these properties using numeric parameters. The methodical procedure is shown in Figure 1. Based on natural compartments and cultural influences that generate a specific patch mosaic-, geometry- and topology- describing LMs can be assessed. These indices help to quantify ecological processes that serve as parameters for the evaluation of landscape functions.

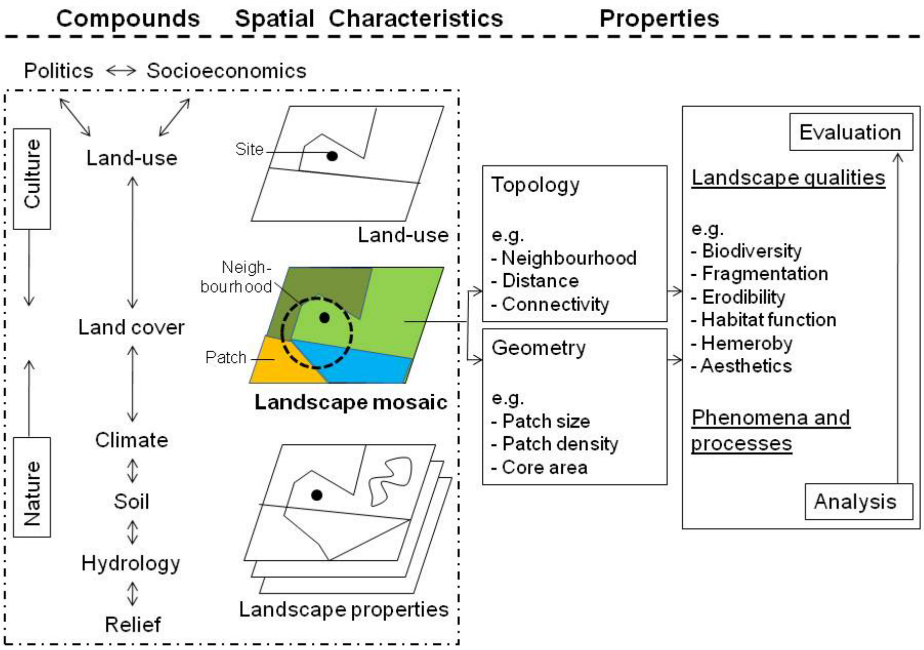

Figure 1. Landscape at the interface between nature and culture (Zebisch, 2004 –modified)

For selecting suitable LMs we carried out a literature review with particular regard to most recent papers (e.g. Fry et al., 2009; Billeter et al. 2008; Sang et al., 2008; Uuemaa et al., 2008). Our aim was to select widely used, thoroughly described, and successfully tested LMs. Furthermore, we selected LMs, which are easy to use, replicable and not redundant.

Not only landscape-level indices are of interest. We also considered class-level indices, computed for pattern of single LUTs. Indices reflecting quantity and spatial configuration of certain classes are useful to investigate properties of LUTs. Therefore, we selected different types of widely used LMs, which allow concluding on diversity and aesthetics. To calculate LMs we used FRAGSTATS 3.3 investigating a test-area in Saxony, Germany. The test area has a quadratic shape with an area of 900 km². Our aim was on the one hand to identify suitable LMs and to point out possible difficulties on the other hand. In this preliminary study we used the FRAGSTATS software to test LMs. The final implementation of LMs will be realized independently from other software than PYL.

Since it is likely that users of PYL might possess maps of variable spatial and thematic resolution, the area of investigation was analyzed regarding three different resolutions. The edge length of each cell ranged from 100 m to 1000 m including one intermediate step of 500 m (Figure 2).

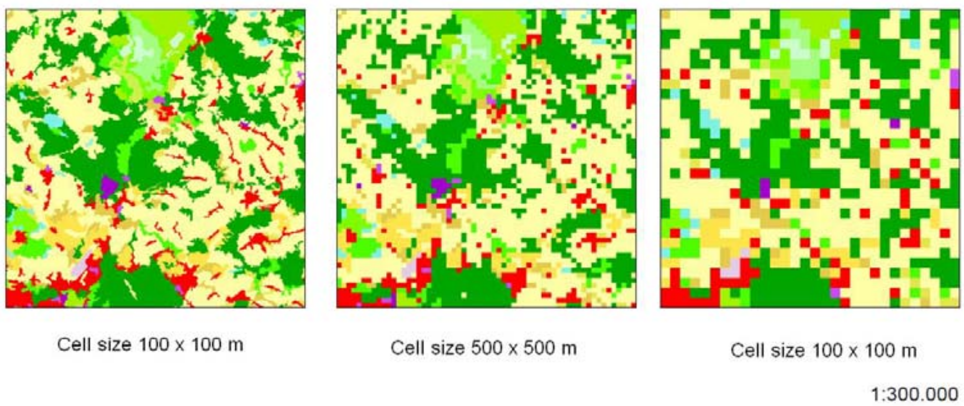

Figure 2. Test-area in three different resolutions (edge length 100 m, 500 m and 1000 m).

The implementation of LMs into PYL is not completed, yet. Nevertheless, first results of this preliminary study allow some conclusions that will be discussed below.

2. Results and discussion

3.1. Testing LMs

For the test area we calculated several LMs. We found a lack of consistency of evaluation results for different scale levels. That might cause problems in the use of PYL at different scales. LMs show different behaviour with changing scales. Some changes are linear to scale, others give a more or less consistent response and others again react with an inconsistent response (Diaz-Varela et al., 2009, Table 1).

Table 1. Selected LMs at landscape level and different resolutions

decrease with decreasing resolution

Resolution	NP [-]	PD [ha-1]	TE [m]	ED [m*ha-1]	LSI [-]
100 m	311	0,346	1.977.200	22	17
500 m	266	0,296	1.265.000	14	12
1000 m	150	0,167	883.000	10	8

	decrease with decreasing resolution			increase with decreasing resolution	
Resolution	SHAPE_MN [-]	NDCA [-]	AI [-]	AREA_MN [ha]	CORE_MN [ha]
100 m	1,932	588	90	289	202
500 m	1,285	266	66	338	338
1000 m	1,199	150	52	600	600

consistent response

Resolution	DIVISION [-]	SHDI [-]	SIDI [-]	MSIDI [-]	SIEI [-]	MSIEI [-]
100 m	0,93	1,73	0,72	1,29	0,77	0,46
500 m	0,88	1,72	0,72	1,27	0,77	0,46
1000 m	0,88	1,76	0,73	1,31	0,78	0,47

(NP.. Number of Patches; PD.. Patch Density; TE.. Total Edge; ED...Edge Density; LSI...Landscape Shape Index; SHAPE_MN...Mean Shape Index; NDCA...Number of Disjunct Core Areas; AI...Aggregation Index; AREA_MN...Mean Patch Area; CORE_MN...Mean Core Area; DIVISION...Landscape Division Index; SHDI...Shannon's Diversity Index; SIDI...Simpson's Diversity Index; MSIDI...Modified Simpson's Diversity Index; SIEI...Simpson's Evenness Index; MSIEI...Modified Simpson's Evenness Index)

The modifiable areal unit problem (MAUP) can be subdivided into three groups. Considerable efforts were made to solve these problems in the past. A major aspect is how grain size, zoning and areal extent of investigation influence results (Buyantuyev & Wu, 2007; Diaz Varela et al., 2009; Kendall & Miller, 2008; Saura, 2002; Uuemaa et al., 2005; Wickham and Riitters, 1995; Wu et al., 2002; Wu, 2004). Also size and degree of aggregation of the patches in one class influence the values of LMs (Neel, 2004). Additionally, the determination of optimal values for each case represents a further complication of working with LMs.

The scale-problem is exemplarily shown for the Shape Index in Figure 3. Less spatial resolution entails an aggregation of raster cells. That implicates the SHAPE-value of patches converge to 1, which means shape approaches a square, the optimal shape in a raster map. This effect distorts the complexity of the landscape.

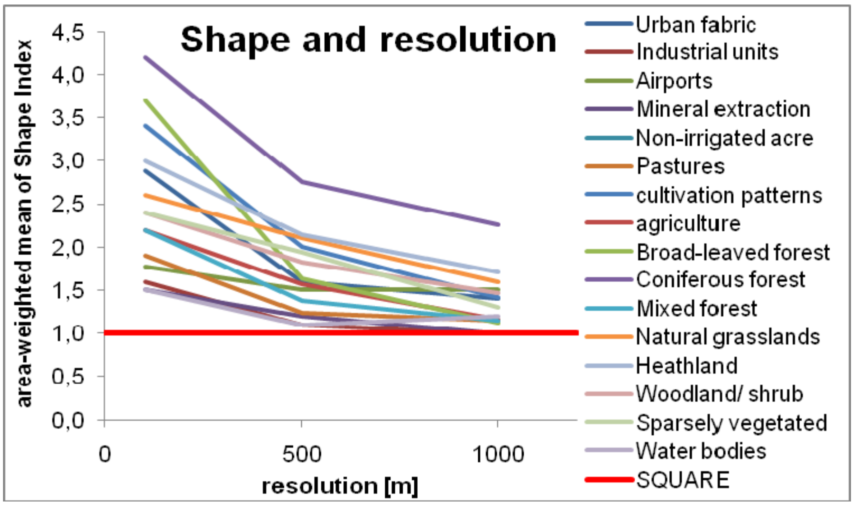

Figure 3. reaction of the area-weighted Shape Index to the change of resolution (edge length of one raster cell 100 m, 500 m and 1000 m): Patches seem to be more compact by decreasing resolution.

Changing grain size affects other LMs as well. The normalized Shape Index (nLSI) for example changes its meaning with changing resolution. nLSI is a measure of aggregation, which ranges from 0 to 1. If a landscape would consist of one single square, it is 0. In case of complete disaggregation (like a checkerboard), nLSI has the value 1 (McGarigal & Marks, 1995). With less spatial resolution the patches seem to be more evenly distributed as shown in Figure 4. Another effect of changes in the resolution is the loss of small patches and whole land use types (here “sport facilities”, Figure 4).

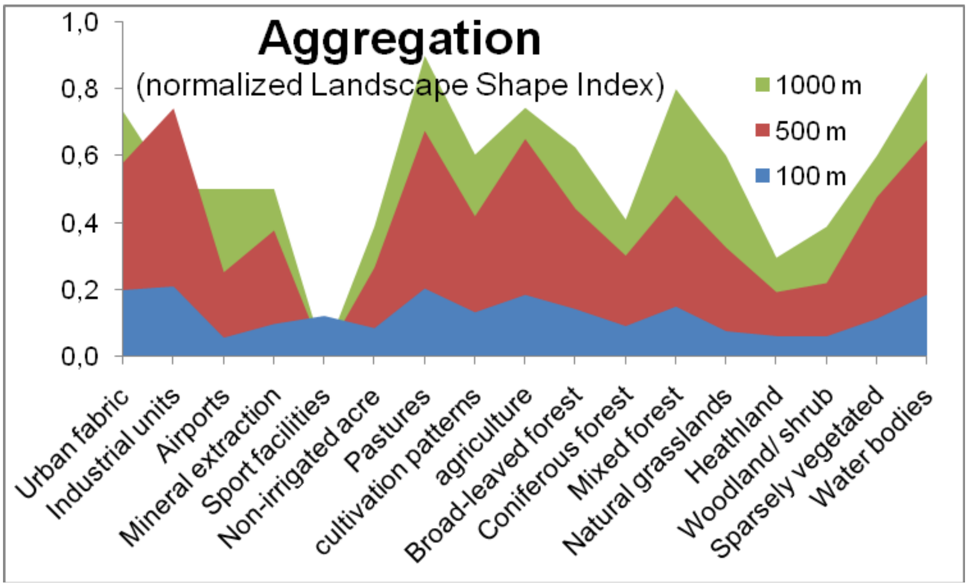

Figure 4. Loss of validity of the normalized Landscape Shape Index (nLSI) through loss of spatial resolution: Patches are strongly aggregated at a resolution of 100 m. At a resolution of 1000 m patches seem to be nearly uniformly distributed.

We realized that these difficulties may complicate the use of LMs within PYL. Obviously LMs of different resolution are not comparable and consequently should not be evaluated at the same ranking scale.

The only consistent LMs to the change of scale are diversity-metrics like Shannon's or Simpson's Diversity Index (SHDI / SIDI) (Table 1). The problem of these diversity indices is that each type of land use is taken into account. Hence, a great variety of urban classes would suggest high spatial diversity. As diversity in the context of PYL is used to indicate ecological and aesthetical value, these diversity indices are not appropriate for our purposes.

3.2. Choice of LMs

Our calculations indicate that LMs recording structural richness are useful for the description of landscape aesthetics. Several studies also showed that residents are most satisfied with their environment when it contains large connected tree patches with a high degree of complexity in shape and with a high variability in size (e.g. Lee et al., 2008). Thus, LMs like the Effective Mesh Size (m_{eff}) might be considered for implementation in PYL. While the Edge density (ED) indicates the complexity of a landscape, m_{eff} is also sensitive to the fragmentation of the focal LUT and represents an index for the ecological value. The Aggregation Index (AI) shows the degree of dispersion of the patches of each class and their compactness, respectively.

It has been widely accepted that less fragmented and more heterogeneous landscapes show a better ecological functionality than homogenous and fragmented landscapes (Lee et al., 2008). Hence, also for this assessment criterion m_{eff} might be taken into account. An alternative might be the Shape Index (SHAPE) that operates on the basis of the perimeter-area ratio and represents one of the most straightforward measures of entire shape complexity.

To characterize connectivity of patch classes or to quantify patch isolation, a widely used and simple LM is the Euclidian Nearest Neighbour Distance (ENN), which is defined using simple Euclidean geometry as the shortest straight-line distance between the focal patch and its nearest neighbour of the same class (McGarigal & Marks, 1995). With the purpose of evaluating biodiversity, several diversity-indices were developed that give consistent response to the change of extent (Diaz-Varela et al., 2009) and scale (Table 1).

To avoid redundancies, only few indices were chosen from the large number of LMs for future implementation in PYL (Table 2). Main Selection criteria were adequate reflection of the environmental services of interest and robustness against varying thematic and spatial resolution. Water quality and economic value might be addressed best by class-level indices (Table 2). For an evaluation of ecological aspects at landscape level, an aggregation of LUTs is necessary. Therefore, we decided to aggregate the LUTs into:

- Natural and anthropogenic influenced/artificial LUTs according to the degree of hemeroby.
- Sealed and unsealed areas.

Table 2. Review of environmental services that will be described by specific LMs

Evaluation criterion Environmental service	**Evaluation parameter**	**Landscape metrics** (Aggregation level)
Ecology		
Biodiversity	Effective habitat area	Core Are Index (natural areas)
	Connectivity of habitats	Nearest Neighbour Distance (natural areas)
	Heterogeneity	Patch Density (natural areas)
	Degree of Hemeroby	Hemeroby Index (degree of hemeroby)
	Richness of natural habitats	Patch Richness (natural areas)
Erodibility	Vulnerable areas of wind erosion	Core Are Index (class level)
	Areas where fast runoff components determine runoff	Core Are Index (class level)
Fragmentation	Mean size of not fragmented areas	Effective Mesh Size (unsealed areas)
Aesthetic value		
Structural richness	Heterogeneity	Patch Density (natural areas)
	Mean size of not fragmented areas	Effective Mesh Size (unsealed areas)
	Distribution of patches	Aggregation Index (class level)
Economic value		
Efficiency	Compactness	Aggregation Index (class level)
Water quality		
Mass fluxes	Analysis of buffer strips	Riparian buffer zones (class level)
	Fractal dimension	Perimeter-Area Fractal Dimension (class level)

Conclusions

According to Mander et al. (2005) the usage of LMs as landscape indicators at different scales is one of the major challenges in landscape modelling. Li and Wu (2004) claimed that "interpreting indices remains difficult because the merits and caveats of LMs remain poorly understood". The study presented here intended to test the applicability of LMs for different environmental services as basis for an integrative evaluation of land use pattern changes within PYL. It provides an assignment of environmental services and associated LMs.

Diversity metrics like Shannon's Diversity Index (SHDI) or Shannon's Evenness Index (SHEI) are not useful for our purpose of evaluating not only spatial diversity but also biodiversity. Most useful LMs for evaluation of landscape aesthetics are the Patch Density (PD) of natural areas and the Effective Mesh Size (m_{eff}). The latter can be used to evaluate structural diversity and degree of fragmentation as indicator of biodiversity as well. Moreover, the Core Area Index (CAI) and the Nearest Neighbour Distance (ENN) might be useful regarding connectivity of habitats.

With respect to scale problem, there are two basic approaches to deal with this in the future. Either all input maps will be obliged to have identical spatial resolution and extent or different approaches of evaluation have to be developed.

The final integration of LMs into PYL is a future task. The conceptual planning aims at the most efficient way of integrating LMs on the one hand and the highest user friendliness of Pimp Your Landscape on the other hand.

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