Geoinformation Technologies for Geocultural Landscapes: European Perspectives

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Landscape metrics – A toolbox for assessing past, present and future landscape structures

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ABSTRACT

This chapter provides an overview of the development, the potential and some limitations of landscape metrics in the context of historical landscape analysis and landscape planning. Starting with a review of the background and motivation of landscape structure assessment, followed by a brief overview of major concepts of this approach, the chapter discusses the major components of landscape structure to be quantified in a comprehensive way: the analysis of area, density, edge, form, core area, proximity, diversity, and subdivision. It then gives insights into some practical experiences from the use of landscape metrics for assessing historical landscapes, and points out specific implications such as the stepwise backward editing and the most suitable metrics. In a complementary way, the potential and usability of landscape metrics for planning purposes and for the comparison of different future is examined. The chapter closes with a short statement on the achievements thus far, followed by a look at future tasks and provides a link to a discussion of sustainable landscapes and the question of whether a specific landscape structure may be of relevance to it. One of the most important challenges is to find and publish standardised and widely agreed measures for planners and authorities.

1 MEASURING LANDSCAPE PATTERN

1.1 Spatial context matters

The quantitative assessment of landscape structure is of increasing importance for a wide range of landscape ecological applications (Blaschke 2006, McGarigal 2002, Turner 1990). As one of the primary research questions, landscape ecology investigates the relationships between pattern and process, i.e., how ecological processes are influenced or even

Landscape structure: spatial characteristics of a landscape or a portion of a landscape as being attributed to the spatial arrangement of landscape elements or units.
driven by the spatial configuration of ecological units (Turner et al. 2001). Landscapes exhibit specific patterns or mosaics of constituting elements, commonly referred to as patches, and this heterogeneity is measurable and can be quantified. As Forman (1995) and others point out, ecological processes and functions are strongly interlinked with the structural properties of the landscape. Analysis of the landscape pattern gives insight into underlying processes, potentials, and functions (see below). It has been widely argued that the arrangement of ecological units (i.e. patch mosaic) rather than the mere quality of patches is crucial for the integrity of e.g. protected areas (see Blaschke 2006 for an overview). A decade ago or so, findings in the assessment of habitat integrity and the suitability of habitat arrangements convinced ecologists that the spatial context is crucial (Wiens 1997). Originating from the quantitative branch of North American landscape ecology, these ideas have since settled in European landscape applications and spatial ecological research (Blaschke 2000, Walz 1999 and 2001). A broad set of quantitative measures, called landscape metrics, has been elaborated within this approach. Structural indicators, based on landscape metrics, describe landscapes in terms of size, shape, and neighbourhood relations (Lang & Klug 2006). They express in mathematical terms the arrangement and configuration of landscape

*Figure 1. Facets of landscape structure analysis (Lang & Blaschke 2007, modified).*
elements in a specific area of interest. They characterise different spatial properties of landscape units (cf. figure 1) by specific measures or in an aggregated manner using basic statistical values (mean, standard deviation, etc.).

1.2 Landscape structure and scale

Earth neither exhibits a uniform coverage nor an unstructured, chaotic surface. Views from above, captured on aerial photographs or satellite imagery, reveal regular structures and patterns. Such structures are perceived as an arrangement of homogenous units, but appear in different scales. Landscape ecologists relate the genesis of landscape structures to, first, the spatial variability of supplied resources (e.g. water, different soil types, micro-climate, topography, etc.) and, second, to systemic processes that lead to spatial organisation. “Patch context matters” – this short and comprehensive formula represents an emerging paradigm in spatial ecology. Investigating spatially explicit characteristics of a given landscape portion draws from the notion that observed patterns and underlying processes are closely interlinked. This notion is by no means new (Lang et al. 2004): traditionally, landscape ecological research has been strongly influenced by airphoto interpretation methodologies developed in the early decades of the 20th century (Troll 1966). The bird’s eye perspective opened ecologists the way to characterise and compare the spatial arrangements of landscape patterns, on a broader, an overview scale. This has enabled, and still does, complementing ground investigations and in situ measurements. When Troll (1939) coined the term ‘landscape ecology’, specific patterns and arrangements of landscape units (German: ‘Verbreitungsbild’) were related to respective processes. A complex cause-effect network was considered interlinked with these observable patterns (Leser 1997). Later, Troll proposed the term ‘ecotope’, including functional relationships between organisms and their environment (a kind of spatial manifestation of ‘ecosystem’ as defined by Tansley in 1935).

The ecotope concept was revised and adapted to incorporate hierarchical concepts, meaning that units reflect multiple scales of process and pattern in the landscape (Carol 1956). The idea of geographical dimensions was born at the same time by defining specific cause-effect feedbacks on several scales of investigation (Neef 1967). The dimension in which uniform processes take place (and can be measured locally at one specific site) was since called the topological dimension. Above that, the chorological dimension refers to various heterogeneous aggregates in broader scales. Whereas this idea implies a hierarchical concept, it is less flexible than recent multiscale approaches. Wu (1999) has introduced the hierarchical patch dynamics paradigm (HPDP), which rests upon two principles: (1) patches (as landscape units) are hierarchically structured and ‘homogenous’ under specific aspects only; and (2) within a hierarchical set of patches, at least three levels should be taken into consideration, i.e., the focal level (level under investigation), Level +1 which controls the focal level, and Level −1 which is controlled by it. In other words,
level –1 provides explanatory variables for the focal level, and Level +1 constraints (Burnett & Blaschke 2003).

1.3 Landscape elements: patches, corridors, matrix

The smallest, homogenous landscape unit (according to scale) is referred to as ecotope, patch, or cell (Zonneveld 1989), or more general as landscape element (Forman & Godron 1986), or as land unit (ibid., Lavers & Haines-Young 1993, Wiens 1989). Within landscape structure analysis, the most commonly used (and straightforward) term is ‘patch’ which is defined as a “relatively homogeneous area that differs from its surroundings” (Forman 1995). In a morphogenetic view we differentiate between several types of patches: disturbance patches, remnant patches, environmental resource patches, introduced patches, ephemeral patches (Forman & Godron 1986). The term ‘patchiness’ describes the spatial arrangement of patches reflecting the way patches are distributed in space. Patchiness is a scale-dependent phenomenon meaning that scaled representations lead to different kinds of patchiness. Patches considered homogenous in a given scale, may be composed by a set of patches in a finer scale (‘within-patch-heterogeneity’, Blaschke 1995, see HPDP above).

According to the conceptualisation of Forman & Godron (1986) and Turner (1989), there are – next to patches – other, complementary types of landscape elements, namely corridors and the (landscape) matrix. Both types are scale-dependent. The matrix is defined as the dominant surface type, either in terms of area coverage (at least 50% of a given landscape under investigation), or in terms of its connectivity or the degree of control-over dynamic. The concept becomes clear, when looking at the type of landscapes in Northern America which functioned as prototypes for this concept: Large, extended forested areas (matrix) intermingled with small clear cut islands (patches). However, in highly managed cultural landscapes in Central Europe with their small structures, the landscape matrix is often not clearly definable (Lang & Blaschke 2007). Corridors, instead, are abundant here or there. The term ‘corridor’ comprises all elongated structural elements, which appear as linear elements, caused by their specific length/width ratio. Usually, corridors play important roles as conduits of matter and organisms to allow for functional and physical connectivity (Forman 1995, Noss 1993), but could similarly function as barriers. All patch edges may be considered barriers (boundaries) to a certain degree. Knauer (2001) for example highlights the ecological importance of hedges in otherwise agrarian landscapes.

1.4 Structure, function and change

The ‘landscape structural approach’ (Dollinger 2002) investigates the specific arrangement of landscape units, and the resulting landscape mosaic as a whole. It characterises status and temporal changes of prevailing
spatial structures in the landscape. As mentioned earlier, these structures are considered spatio-temporal manifestations of processes that occur in various scale domains (Forman 1995, Levin 1992, McGarigal & Marks 1995, Meentemeyer & Box 1987, Turner 1989 and 1990, Wiens 1989). These processes include fluxes of substances, matter and energy, as well as interactions among organisms. Pattern and related processes are encapsulated in a cause-and-consequence relation, which is non-linear and, to a certain degree, bi-directional. In other words, the observable pattern is often a product of spatially constrained processes (e.g. a groundwater influenced bog area); vice versa do prevailing structures influence processes (e.g. a new road may be a barrier for former animal dispersal routes).

Structure, function and change (or development) are three profound aspects of landscape research, already highlighted by Neef (1967). These aspects are central in recent literature as well (Forman 1995, Forman & Godron 1986, Risser 1987, Turner et al. 2001, Volk & Steinhardt 2002). The landscape structure results from a cluster of interrelations (synchorical occurrence, Neef 1967) between different landscape compartments (e.g. soil, water, climate/air, relief) at specific local sites (vertical structure of the landscape). Structure is measurable by investigating the specific configuration and arrangement of landscape elements, with respect to their size, form, spatial distribution. These arrangements are indicative of fluxes of substances, energy and matter, as well as organisms and information.

Landscapes fulfill a range of different functions, directed towards specific ecological and societal purposes; according to Marks et al. (1992) there are several landscape functions including habitation function, protection function, control and other abiotic process functions (like buffer function, filter function, or transformation of matter and energy), development and regeneration. Costanza et al. (1997), Costanza et al. (1998), de Groot et al. (2002) and Steinhardt et al. (2005) add several other functions from a human-centered perspective, such as information function, production and recreational function. Further functions include social and economic values such as aesthetic values, which reflect the subjective sensing of landscapes by humans. The production functions are confined by the respective capacity of landscapes to meet the demand of humans (and other organisms). Natural capital is a recent approach looking specifically at the potential of landscapes to fulfill the demand for a set of functions (Potschin & Haines-Young 2003).

In reality, we often face a plurality of functions, i.e., landscapes exhibit a multifunctional character (Brandt et al. 2000, Klug & Zeil 2006). This applies under four aspects: (1) integrated (vertical) multifunctionality meaning there is a spatial overlap of different functions on the same land unit simultaneously; (2) spatial/scale dependent (horizontal) multifunctionality, which can be considered as a mixture of different land use types in one spatial layer; (3) temporal/sequential multifunctionality which is a spatial overlap of functions on the same land unit at successive periods (dynamic). Here, we consider the changing expression of system
qualities caused by e.g. crop rotation. (4) The temporal-integrated multifunctionality, where the priority function is changing without restricting other functions at the same land unit and time.

Cultural landscapes are highly integrated, multifunctional landscapes, with a complicated pattern of combined functions, visible as the prevailing land use pattern. The intensity of the cultural (i.e., human) influence has been measured by so-called stages of hemeroby (Blume & Sukopp 1976), ranging from a-hemerob (near-natural) to meta-hemerob (highly modified or degraded). From a perspective of landscape structures, one often assumes that with increasing human influence the structures become less convoluted, less ‘natural’. Measures like rectification of river runs (e.g. Klug & Blaschke 2003), land consolidation, road alignments, tunnels, etc. all provide simpler structures, it seems. On the other hand, first impacts in otherwise natural landscapes (e.g. clear cuts) may produce more complex structures as before. So, the transition from ‘historic’ to ‘modern’ landscapes does not necessarily imply a trend to simpler, more monotonous structures.

Finally, landscapes are dynamic: they undergo development and are subject to change. There are different qualities of changes, ranging from seasonal, cyclic changes (phenological course, crop rotation systems), through episodic, but still repetitive changes (e.g. forest fires, avalanches, floods and the like), to more pertinent changes, often directed by a trend. This trend may be caused by changing land use patterns due to changing climatic regime (e.g. desertification, decreasing average temperature) or especially economic-political changes such as for instance changes

Figure 2. Present state, historic states, and future states. Structure assessment for investigating landscapes from different perspectives (see text for explanation).
caused due to declining subsidy payments in agriculture. Changing landscape structures can be identified and quantified; they offer valuable hints for changing processes in the background. For instance, habitat fragmentation may lead to loss in biodiversity due to decline in dispersal space and limited possibilities for foraging or mating.

As figure 2 portrays in a schematic way, characterising structural characteristics of landscapes under present state conditions ($t_0$, see 1) is only one possible focus of landscape structure assessment. Present state conditions may be compared against historic conditions (2) and likely future states (4) of landscapes. By applying time series reflecting past landscape conditions, the historic development of landscapes may be analysed, trends and drivers identified (3). Different future scenarios may be evaluated (5) in order to identify a most favourable one. Previous time slices may be compared among each other. Irrespective of the given state at present, a future state may be oriented towards a previous state requiring restoration measures and management (6).

2 LANDSCAPE METRICS – THE TOOLBOX FOR QUANTIFYING LANDSCAPE STRUCTURE

2.1 The rationale of landscape structure assessment

The landscape structural approach has been influenced through and supported by tools, methods and concepts from geographical information science and digital image analysis. Today, the toolbox of ‘landscape metrics’ provides a set of formulae for the quantitative spatial analysis of landscape structure. Since the development of landscape metrics in the 1980s and 1990s, in which conceptual considerations were of primary concern (Blaschke 2000, Gustafson 1998, O’Neill et al. 1988, Turner 1990), today the approach is established in various workflows and utilised in decision making and planning (Botequilha Leitão & Ahern 2002). Recent works (e.g. Banko et al. 2000, Blaschke 2000, Bock et al. 2004, Joos et al. 2005, Klug & Blaschke 2003, Lang et al. 2002, Langanke et al. 2005, Langanke & Lang 2004, Perkmann & Lang 2007, Schöpfer & Lang 2004, Walz 2006, Walz et al. 2001, Weiers et al. 2004) show off the potential of the approach for a variety of applications, including studies on

- biodiversity, habitat integrity, fragmentation;
- landscape planning and environmental assessments;
- landscape modelling and change analysis of land use patterns;
- catchment management;
- planning and landscape design.

Clearly, the objective of applying landscape metrics goes beyond describing and measuring patterns: its aim is to “[...] explain and understand the processes that occur. Thus the description of landscape pattern as an end in itself is limited” (Haines-Young 1999). In other words, the potential of the approach resides in its complementary use with other, more field-based investigations (Dollinger 2002).

Time series:
a technique to sequentially observe the development of a specific area by standardised data sets and analysis.

Scenario:
a specific future state of a landscape according to defined conditions.
Measures taken from the toolbox of landscape metrics describe spatial properties of a certain portion of a landscape. This 'portion' is often defined pragmatically (for example represented by an administrative unit boundaries or sometimes simply a rectangle; see figures 3b and 3c). Consequently, landscape limits representing ecological boundaries are often missing. Consequently, talking about 'the landscape' is often misleading when simply referring to an area of investigation. On the level of single patches, so-called patch metrics calculate basic geometric properties, e.g. area, edge length or shape (see figure 3, left). As patches are usually categorised according to a certain classification key, other metrics address the level of unique classes and their instances (i.e., patches assigned to these classes). On the level of classes any patch metric can be statistically aggregated (mean, standard deviation, etc.). We call these metrics class-aggregated. Furthermore, there are class-specific metrics, e.g. the summation of area-weighted distances (proximity). On the landscape level, we have landscape-aggregated metrics and landscape-specific ones. The latter comprise measures for assessing the overall spatial distribution of patches, either spatially implicit (composition, i.e., based on area percentages of classes) or spatially explicit (configuration).

For a concise overview of the levels of landscape structure assessment see Lang & Blaschke (2007) or McGarigal (2002).

In many cases, neighbouring patches of the same category are separated by border lines. These lines may have important landscape functions and represent ecological boundaries (e.g. barriers, corridors, etc.). Such boundaries, due to their specific length-width ratio are often not represented as polygons but as line features. For practical reasons, neighbouring patches may be combined, the boundaries between them 'dissolved'. As shown in figure 3 (middle and right), this has implications for the application of landscape metrics. In order to avoid this effect the line features can be buffered, transferring them into disjunctive polygons.

Figure 3. (a) Form metrics (radius of gyration). Note that patch A and B have the same size, i.e. 1.5 ha. (b) Original land use mapping with three classes for a 16 ha subset of a landscape. NP (number of patches): 1299. (c) Neighbouring patches of the same class are dissolved, NP drops to 200. Shape index for coniferous forest patches for the same landscape clipping. Shape index (SI) was calculated for a dissolved forest patch (right, SI = 4.9), and the 27 corresponding, non-dissolved patches (middle, SI ranges between 1.1 and 2.3).
2.2 Categories of structural characteristics

The exact number of potentially available metrics is difficult to estimate, as with any metric there are statistical derivatives attached to it. Statistically, many metrics are correlated and there have been attempts to de-correlate them and identify factors through e.g. principal component analysis (Lausch & Herzog 2002, Ritters et al. 1995, Walz 2001). Other approaches try to semantically narrow down the sheer number of metrics according to ecological (or other) aspects (Klug et al. 2003, Lang et al. 2002). Under the following subheadings six categories of landscape metrics are portrayed in a condensed form corresponding to main structural aspects. A selection of established metrics is given as representatives of particular sub-aspects (for a detailed overview see Lang & Blaschke 2007).

2.2.1 Area, density and edge metrics

Basic measures of patch size, perimeter, class, area in total or as a share are used for the calculation of most other landscape metrics. Particularly, patch area is often used in more complex metrics in order to enhance the effect of larger patches against the smallest. Concerning edges, the difference between adjacent patches can also be evaluated. Several metrics exist to measure heterogeneity under this aspect via edge length and edge density. Edges may be valuable transition zones between patches (ecotones, see below) and highly favourable, or function as barriers or borders. Thus, when not explicitly considering the quality of the linear elements, misleading results can be easily obtained. For example, when edges mainly consist of little roads or other barriers, the landscape needs to be considered as being highly fragmented instead of highly structured.

2.2.2 Form analysis

Patch size does not provide explicit information about the particular shape of a patch, but the latter can be measured in various ways. A categorisation of patch shape and the respective ecological implications is given by Forman (1995). The most common and intuitive measures are based on area-to-edge relations according the formula of circular area. ‘Shape Index’ (SI, cf. figure 3) values close to 1 indicate rather compact patches (close to a circle), whereas elongated patches yield higher values. More advanced metrics detect, for instance, the proportion of medial axis, the dissection of body or edge, and the curvature of the borderline (Moser et al. 2002).

2.2.3 Core area analysis

Boundaries between patches are often transition zones (ecotones) with a particular species mix (Forman 1995) or of any other abiotic buffer function. We can consider the interior of a patch as being ‘protected’ against influences from outside. For example, when looking at edge sensitive species that avoid boundaries, the effective area of a patch differs from its actual size by a specified core area distance. Methodologically, core areas are constructed

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**PCA (Principal Component Analysis):**

A multivariate statistical method to identify and extract principal components in correlated datasets.
Buffer:
a GIS technique to construct a corridor around an outline or line with a specific distance.

Disjunct:
spatially non-adjacent.

Least cost path:
a technique to calculate an optimised path based on cost minimising, whereas ‘cost’ is taken as a generic concept (e.g. distance, altitude, etc.).

Thematic resolution:
the degree of detail of a given classification scheme.

by negative buffers. In cases where the initial patch is very small, no core area may be left over by this procedure. On the other hand, elongated and complex shaped patches like alluvial forests along a river may be split up in a larger number of small, disjunct core areas.

2.2.4 Proximity and neighbourhood analysis
The proximity of patches may be influential to any processes depending on distance. For instance, proximity among neighbouring habitat patches may have a strong ecological influence on the viability of metapopulations (Hanski & Simberloff 1997, Wiens 1997). The metapopulation may be no longer viable, when functional exchange between suitable habitats through animal dispersal is not guaranteed. The ‘Proximity Index’ measures “both the degree of patch isolation and the degree of fragmentation” (McGarigal & Marks 1995). It is implemented as distance-weighted area in several variations (Lang & Blaschke 2007). A specific search distance (proximity buffer) reflects the potential dispersal range of the respective species or the range of any other abiotic process. It is assumed that larger neighbouring patches are more influential to smaller patches than vice versa. This results in higher values for smaller nearest-neighbour patches sharing the same distance. A zero (0) value is assigned to patches, which are situated outside the buffer distance. Alternatively, the least cost path edge to edge distance can be analysed, as well as other neighbourhood measures evaluating the co-action of adjacent or distant patches.

2.2.5 Diversity analysis
Still, another aspect of landscape heterogeneity is addressed by the group of Diversity metrics. For instance, based on information theory (Shannon & Weaver 1949), the ‘Shannon Index’ quantifies landscape composition. The basic element of the formula is area percentage of classes. Diversity metrics should be taken with care when interpreting absolute values; they prove more suitable for comparative studies. Due to the fact that the number of classes (increasing potential richness) influences diversity, this group of metrics strongly depends on the number of potential categories provided by the classification scheme (thematic resolution). Evenness metrics detect the share of class proportions, excluding the thematic resolution.

2.2.6 Subdivision analysis
The group of subdivision metrics measure landscape dissection and fragmentation on the level of specified classes (Jaeger 2000). Landscape dissection (e.g. by roads) does not imply significant loss of area, as the portion of land covered by the dissecting lineaments is comparatively small. Still, every dissecting element has an effect on the coherence of the (remaining) landscape, and the influence of the subdivision effect is measurable by the so-called effective mesh size and related measures.
2.3 Landscape metrics as structural indicators

Indicators can be of different temporal and spatial scale, but even local level indicators are very often not spatially explicit. But many applications on the local scale require decisions to be supported by spatial explicit indicators (Blaschke 2001) as, for instance, landscape metrics. In many cases a certain metric is difficult to interpret, simply because we know little about the links between measured structure and underlying processes. This in particular applies to the complexity of culturally grown, small-scaled landscapes within Europe. In terms of a non-ambiguous interpretation, there are at least three aspects to be considered:

- Firstly, there may be certain cases, in which increasing or decreasing values do not unambiguously indicate the improvement (or deterioration) of a certain status. For example, when determining Edge density at $t_0$ and then looking at respective values at $t_1$, higher values may indicate a richer and more complex structure, which from an ecological point of view may be considered more valuable than a poorer, more uniform structure. On the other hand, higher values may also be triggered by an increase of dissecting linear structures (roads, transmission lines, etc.), which leads to an unfavourable status as compared to $t_0$.

- Secondly, results often cannot be interpreted by looking at absolute values alone, but need to be seen in relation to specific requirements, such as the needs of a species with respect to its habitats. Using Area as an indicator may reveal critical values for some particular species with given minimum habitat requirements, whereas the same values may prove insignificant to other species which react invariant to a certain patch size. Related to this, additional parameterisation may be needed in order to calculate certain metrics (e.g. specific distances when assessing proximity or isolation).

- Thirdly, results may be dependent on the interpretation key and the number of classes being used when a spatial representation of a certain landscape is established. For example, the comparison of two landscape portions with significant differences in forest cover may reveal inverted results if diversity is calculated on land use classifications of different details.

There are few structural measures used in operational monitoring of ecosystems in the European Union, but suggestions by the Joint Research Centre of the EU promote the use of landscape metrics at a landscape level based on remote sensing images (JRC 1999). Lausch & Herzog (2002) review existing land use indicators and see potential for indicators that quantify landscape pattern in this context. However, they stress the need for harmonisation of landscape metrics regarding input data, data processing and the selection of landscape metrics in order to make standard applications of those metrics in land use monitoring effective (Langanke et al. 2005).

Being aware of the shortcomings and interpretational problems of some landscape metrics, a carefully selected set of spatially explicit landscape metrics may be used as target-oriented structural indicators. For
IDEFIX (Indicator Database for Scientific Exchange):
www.geo.sbg.ac.at/large/idefix.htm

SPIN (Spatial Indicators for European Nature Conservation) project:
www.spin-project.org

ArcGIS:
a GIS and Mapping Software provided by the company ESRI. ArcGIS is a complete system and integrated collection of GIS software products.
www.esri.com

V-LATE (Vector-based Landscape Analysis Tools Extension):
provides a selected set of the most common metrics to cover basic ecological and structure-related investigations.
www.geo.sbg.ac.at/large/vlate.htm

selection criteria of metrics see for example Syrbe (1999). Based on a comprehensive literature study, metrics have been identified and transferred to a database named IDEFIX (Indicator Database for Scientific Exchange) within the SPIN project (EVG1-CT-2000–00019) (Klug et al. 2003). The database facilitates research and provides assistance in interpreting structural indicators. IDEFIX users get familiar with the metrics available, their behaviour, biases, and limitations. The focus is set on semantic content and the relationship to specific ecological issues rather than on mathematical discourse. The database allows for an appropriate choice of a delimited and sound set of metrics. The IDEFIX database has been designed for pan-European issues related to the Natura 2000 concept, especially in the context of monitoring and change detection tasks, but can be utilised in any other context. For the calculation of selected measures, the database has been linked to the ArcGIS extension V-LATE (vector-based landscape analysis tools extension, Lang & Tieke 2003).

3 IMPLICATIONS FOR CHARACTERISING HISTORIC LANDSCAPES

Changes of land use often take place as small-scale measures with local impact, and maybe insignificant if taken in isolation and assessed independently. However, by cumulative effects under both spatial (neighbourhood) and temporal (accumulation) aspects they can lead to significant changes of regional structures and environmental conditions. Therefore, important tasks of landscape ecological research at present are to monitor and assess natural resources, to examine impacts and effects of human intervention and, last but not least, to observe the state of the environment over long time periods.

Current main processes of landscape change result in alteration of landscape structure. One of these processes in central Europe is the suburbanisation around urban areas, while another process affects the rural areas by increasing fragmentation through infrastructure and communication lines. In addition, in many European regions the actual trend in agriculture leads to intensively used large field plots. Structural changes have consequences for landscape functions, like biodiversity, potential for food production or human recreation. Therefore, investigating changes of landscape structure aims at the following questions:

- How have land use and the landscape structure changed over historical time periods?
- How have these changes affected the ecosystem pattern and biophysical processes?
- Can general trends be deduced on structural land use changes over the next few decades?

Against this background, it is important to use landscape metrics for the evaluation of the effects of structural changes on selected environmental protection goods.
3.1 Historical maps and other data sources

Digital preparation and analysis of historical maps and subsequent digital land use mapping using GIS techniques are the basis for such evaluations of historic landscape structure. This enables the spatial and statistical appraisal of large time series and allows connecting them with natural-spatial data.

Since the 18th century land surveys in Europe have provided suitable cartographic bases for historical landscape analysis. Examples are the Swedish Register Maps (1692–1709), the “Topographic maps” of the Prussian land survey since 1830, the “Saxon Milestones” since 1780 or the First Austrian land survey (1764–87), the latter covering large parts of Eastern and Central Europe. Similar map series are also available for other parts of Europe. These maps have sufficient resolution in terms of geometry and content for medium-scale studies and allows landscape development over more than 200 years to be investigated. Older maps are rarely accurate enough and should at most be used for supplementary information.

It is important to consider the specific quality when comparing map contents from different times. Special attention should be paid to geometrical accuracy (measurement errors), the differing information content and the scale dependency of the spatial accuracy. The study of land use change at national level can serve for statistical purpose and the determination of overall trends only. At the regional scale, general trends of land use classes may vary due to the specific bio-physical settings. Furthermore, especially for the calculation of landscape metrics the accuracy of the data is important. The generalisation on larger cartographic scales can bias the results.

Studying landscape change in periods of recent centuries should also be supported by means of other sources and materials documenting land use and the reasons why it changed. For example, additional useful information is contained in historical landscape descriptions, local chronicles, street maps, register maps, and increasingly remotely sensed data as well as landscape paintings and special lawsuit map sections. In addition, geomorphologic and stratigraphic-pedologic studies can contribute to the analysis of previous landscape changes.

3.2 Notes on data preparation for analysis of landscape structure

As a first step, the historic maps need to be georeferenced. The second step is the digitising or vectorisation of the land use information taken from the historical maps. This can be done by “backward editing”. For this method, the present (existing) land use vector-layer on the screen is underlain by the historical map while only the changes in the geometry have to be edited. This process is repeated for all historical maps used, beginning with the newest and incrementally proceeding to prior maps. For the further analysis of land use and its development over time, a combined dataset consisting of cartographic linear and polygon features is essential. This is important because polygon features are often divided by linear objects, like roads, streams, hedges that exhibit a certain width and thus area. Also for the analysis of ecological processes,
for example soil erosion, it is necessary to combine lines and polygons for instance, to delineate such important erosion barriers as field boundary ridges or hedges within the polygons (Neubert et al. 2008).

3.3 Problems of comparability

When processing and comparing available maps, it must be borne in mind that they vary in terms of survey techniques, map contents and given details depending on the time when they were produced. Moreover, old maps often do not include legends or any other form of explanation. The introduction of the Prussian legend in the new edition of the survey maps around 1870 was the first time that clear, uniform map symbols were used (in fact a modified set of the same symbols is still employed nowadays). Other difficulties result from the different areas covered owing to the changing borders of the several states. Any analysis of historical maps must therefore start with an examination to determine congruence and comparability between modern and historical maps. For the analysis a unified legend should be compiled (Neubert & Walz 2002, Walz et al. 2001).

3.4 Metrics as indicators for land use change

The results of an investigation into historical landscape development primarily consist of quantitative statistical information on historical states. Only by standardisation, it is possible to assure the comparability and reproducibility in different investigation areas. The difficulty is the selection of metrics which provide universally valid results, independent from the specific situation of the test site.

In most cases relatively simple, straightforward landscape metrics are used (table 1), because they are easy to interpret and comprehensible for presentations in the public.

3.5 Examples of investigations

Studies on land cover change can be found at very different levels of scale, from European across nationwide over to very local for single communities. For example, in a research project on cultural landscape in Austria, landscape metrics were used for an appraisal of the whole state (Wrba et al. 2002). At the European scale, landscape metrics were mainly used for the description of biological diversity (European Commission 2000) and as indicators for changes in agricultural landscapes (European Environmental Agency 2001). Different research studies in Germany evaluated the effects of land use changes on landscape function on the medium scale (Haase et al. 2007, Neubert et al. 2008). At the local scale, there are investigations of Bender et al. (2005), who assessed landscape change on the basis of land register maps for different communities in Bavaria. Cousins (2001) conducted a study on change of agriculture in Sweden also on basis of cadastral maps and on additional aerial photos. The development of the National park region “Saxon Switzerland”
Table 1. Landscape metrics as indicators for landscape change (cf. Neubert & Walz 2006).

<table>
<thead>
<tr>
<th>Information</th>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Division of landscape into small patches</td>
<td>Measurement of areas: Mean Patch Size</td>
</tr>
<tr>
<td></td>
<td>Measurement of edges: Edge Density</td>
</tr>
<tr>
<td>Heterogeneity of patch areas</td>
<td>Variation of patch area: Patch Size</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation, Patch Size</td>
</tr>
<tr>
<td></td>
<td>Coefficient of Variation</td>
</tr>
<tr>
<td>Fragmentation (e.g. by infrastructure)</td>
<td>Measurement of edges: e.g. Mean Patch Edge</td>
</tr>
<tr>
<td></td>
<td>Measurement of areas: Effective mesh size, area of unfragmented spaces</td>
</tr>
<tr>
<td>Shape and complexity of land use patches</td>
<td>Shape indices: Mean Perimeter-Area Ratio,</td>
</tr>
<tr>
<td></td>
<td>Mean Shape Index, Mean Fractal Dimension, Double Log Fractal Dimension</td>
</tr>
<tr>
<td>Richness of a landscape</td>
<td>Dominating land use class</td>
</tr>
<tr>
<td>Distribution/regularity of arrangement and alteration of land use patches</td>
<td>Interspersion and Juxtaposition Index</td>
</tr>
<tr>
<td></td>
<td>Diversity- and evenness indices: Shannons’ Diversity/Evenness</td>
</tr>
<tr>
<td>Degree of isolation of patches within same land use classes</td>
<td>Mean Proximity Index</td>
</tr>
</tbody>
</table>

(figure 4) showed the ‘loss’ not only of land in terms of total area but also of resources and landscape functionality even in such a nature protected area (Walz 2005a).

3.6 Further work

Further works need to focus on the development of complex evaluation methods for the impact of land use changes on the functionality of landscapes. Considering the landscape structure is one important issue, but a lot of other information is necessary for its assessment. The actual trend in the field of landscape metrics shows the direction. Landscape metrics are often part of complex ecological models, however it can hardly be expected that landscape metrics themselves can deliver information as an assessment indicator.

4 LOOKING INTO THE FUTURE – LANDSCAPE METRICS AND LANDSCAPE PLANNING

4.1 Integration of landscape metrics in landscape planning

As technological progress and ever growing human demands make the world change rapidly, time periods of significant change seem to be occurring more rapidly than in previous decades (Bastian & Bernhardt 1993). Consequently, people permanently try to adapt themselves to their local environment to make life easier or even more profitable. Adaptation
to new situations means shaping the landscape and thus having an impact on the landscape structure. From a spatial perspective landscape planning is similar to the adaptation to new situations. The important tasks in landscape planning exercises are to examine the cumulative spatial impacts and the effects of human intervention on processes and functions with consequences in their substance, matter and energy exchange mentioned above. Considering landscape planning as a means to provide scenarios of how the future may be, an upcoming challenge in future applications using landscape metrics will be to structurally describe, analyse and evaluate planning results. Comparing them with the present status will enable forecasting and prediction of the question: “What planning option may result in which positive or negative effect?”

4.2 Strength and weaknesses of landscape metrics in planning studies

Given the rapid rate of change and the decreasing time horizon for reaction, understanding the complexity of landscapes and their pattern is an essential requirement to devise pro-active rather than re-active strategies for landscape development and future scenarios. Therefore, landscape planning – as an endeavour to design best suited spatial arrangements of landscape elements – is strongly coupled with landscape development. Landscape development relies on modelling outcomes supported by empirical evidence. It is based on decisions made within a landscape planning procedure with the aim to predict long-term social, economic and ecological effects of landscape alteration to maintain future demands to multifunctional landscape resources.

In order to structure the complex system of landscape planning for an achievable future state (German: ‘Leitbild’), landscape metrics can be used to support decisions between alternative planning solutions. In
response to this challenge, this section briefly highlights some major obstacles and potentials the landscape metrics approach holds for describing, classifying and planning landscape visions embedded in a trans-disciplinary, holistic concept.

For assessing future planning states of landscapes, landscape metrics are supportive in comparing present states and conditions with aspired future land use allocations. They are useful for deriving potential process-based scenarios and showing the functional consequences of changes being diagnosed. As Tischendorf (2001) noted, landscape metrics are able to effectively predict ecological consequences resulting from land use changes and changes in landscape pattern. Furthermore, landscape metrics may be a useful toolbox for characterising differences among planned alternative development strategies (Jongman 1999). As an example, Pernkopf & Lang (2007) analysed alternative road infrastructure developments using the effective mesh size (Jaeger 2000) to find a suitable route with less impact on landscape fragmentation (figure 5).

However, the quantification and unique characterisation of present and future states, or the comparison between alternative futures are the main challenge of using landscape metrics. A comprehensive understanding of landscape processes and functions as well as their interconnections are necessary to give qualitative value to the spatial characteristics derived from the given landscape pattern (Klug et al. 2003). The linkage between ecological processes and landscape metrics has been paid too little attention in many studies (Thompson & McGarigal 2002). Nevertheless, a range of publications have demonstrated the applicability of landscape pattern indices for characterising landscapes (Corry & Nassauer 2005, O’Neill et al. 1988), but limited knowledge has been derived from the quantifications in various case study areas (Botequilha Leitao & Ahern 2002). Accordingly, there is a certain lack of evidence that pattern-based indices are directly interlinked with ecological processes. In addition, the transfer

![Figure 5. Comparison of the impact three scenarios for road construction using the indicator Effective Mesh Size ($m_{en}$) under three different options: (1) roads taken as linear feature only (black bars), (2) considering direct space requirement of road construction (dashed bars), (3) considering indirect space requirement due to noise and other ecological disturbances (white bars) (Pernkopf & Lang 2007, modified).](image)
of knowledge about the behaviour of landscape metrics to different case
study areas is still limited, as is the scalability of landscape metrics in dif-
ferent scale domains (upscaling, downscaling) (Corry & Nassauer 2005,

example using landscape metrics for catchment-level planning and catch-
ment management. They examine relationships between land use alloca-
tions and water pollution distribution and discuss how different kinds of
metrics can contribute to answer different questions from the European
Water Framework Directive (Directive 2000/60/EG). Buffer stripe imple-
mentation as a contribution for preventing surface waters from eutrophi-
cation, and retention area for water to minimise high water impact on
downstream villages and cities were analysed. They conclude that despite
the fact that a common ecological interpretation of the metrics used is
lacking, the usability of landscape metrics for tracking the consequences
and impacts of the measures being planned is high.

But there are more challenges to tackle. Many applications of land-
scape metrics focus on habitat models, dealing with the quality and con-
nectivity of habitats with special attention to certain species. In many
such studies habitat structures and process-based behaviours of single
species have been analysed without considering the impact on other spe-
cies and habitats nearby or at the same place, or on other compartments
such as water, soil, relief or climate. The multifunctional character of
cause-and-consequence relationships requires a more pronounced focus
on pattern and process.

As a conclusion, landscape metrics serve landscape planning pur-
poses to contribute to the evaluation of future scenarios and compare
them with present situations, but cautious use in making inferences from
landscape patterns to alternative landscape scenarios is recommended.
On the other hand, landscape metrics are not supposed to fulfil the objec-
tives of landscape planning when used in isolation. Landscape planning
has many disciplinary and organisational facets. According to the latest
standards, landscape planning should involve the public in a transdis-
ciplinary planning process to consider social, economic and ecological
perspectives in equal parts. Spatial planning concepts should be enriched
with socio-cultural and financial aspects which cannot be assessed by
landscape metrics alone. Hence, landscape metrics can only play an
important, but not exclusive role in measuring the spatial distribution and
arrangement of land use or land cover. They may help drawing better
conclusions for the better steering of the processes and functions that
depend on the change of landscape pattern.

4.3 Further research requirements

Further research in applying landscape metrics need to go beyond a
mere experimental stage to equip alternative future plans with quantita-
tive values that can be evaluated and compared. What is required is a
shared knowledge stock with evidence-based explanations and hints on
the interpretation of results having been achieved and metrics successfully applied as indicators. There are tools available (e.g. Fragsstats 2.0, V-LATE, Landscape Analyst, see Lang et al. 2004), but to make them fully available and operable for designers and planners is still a challenge (Botequilha Leitao & Ahern 2002). What is needed is more assistance in evaluating alternative plans to give decision makers support to effect informed decisions. We need to elaborate knowledge on how landscape metrics are related to landscape quality objectives. These aggregated objectives should be tracked by landscape metrics as indicators to predict future scenarios consistently.

5 CONCLUSION & OUTLOOK

We can conclude that landscape metrics are “doable” by any GIS-literate person. But the existence of a satisfactory amount of methods and tools does not guarantee any improvement of the investigations carried out. We may compare it to statistics: figures about distributions of numbers or instances alone may only partially, or in certain cases, help explain or solve a problem. A trivial but sometimes overlooked fact is that the computer will always generate numerical results or – more specifically – landscape metrics. Only if we find standardised and widely agreed “measures” with the reality, then landscape metrics may become operational part of landscape planning processes. Like the accuracy assessment in remote sensing every set of metrics may then be accompanied by standardised and widely known accuracy measures. Since there is no “right” or “wrong” we may aim for “relevant” or “irrelevant” as major categories of such a metrics. In figure 6 the two landscapes represent roughly the same landscape metrics. Researchers may want to find out whether or not either of the two particular distributions may be relevant to the problem under investigation.

Especially when it comes to the concept of “sustainable landscapes” (Antrop 2006, Blaschke 2006, Potschin & Haines-Young 2006) the particular realisations of similar statistical pattern as shown in figure 6 may make a difference. The term ‘spatial quality’ has been introduced to underline this phenomenon. Antrop (2006) states that the notion of sustainable landscapes involves a contradiction. Landscapes because of their unpredictable and evolutionary nature, may contribute to sustainability, but they are not sustainable in themselves. Therefore sustainability is positioned in the character of change, and not in terms of any optimal state (Vanautgaerden 2005). As landscape changes, also its meaning and significance changes and consequently its management should be adapted.

As methods for habitat patch delineation have improved significantly over the last 20+ years to better inform our understanding of landscape metrics, we witness now an increasing amount of empirical studies investigating organism-specific use of habitat patches (Girvetz & Greko 2007). Similarly, measures are needed at a landscape-level which are “ecosystem
Neutral landscapes: landscapes generated (mostly randomly) by special algorithms varying the portions of contributing classes for testing landscape metrics.

Figure 6. Two artificial landscapes (so called “Neutral landscapes”) with similar landscape metrics generated randomly using the same distribution and spatial clumping functions.

function sensitive”. This observation goes hand in hand with the recognised need for a parsimonious core set of metrics, a requirement stated from the ‘early days’ of landscape metrics (Blaschke & Petch 1999, Cain et al. 1997, Griffith et al. 2000, Lausch & Herzog 2002, McGarigal & McComb 1995, Neel et al. 2004, Rütters et al. 1995, Scanes & Bunce 1997, Tinker et al. 1998). These studies and many others suggested that patterns can be characterised by relatively few components. But a brief review of these studies does not reveal a concordance in the identification of important landscape structure components. These facts lead to the conclusion that there may be no fundamentally important aspects of landscape structure per se. With some caution we may conclude instead that structure patterns are discriminatory to specific landscapes. Some of the authors cited above argue that the problems of comparability are more likely a consequence of the fact that the different studies did not use the same pool of metrics, the same data types and accuracies, and that they used different methods to identify components. But if our skepticism holds true, comparisons between landscapes based on landscape metrics stay difficult.

The authors believe that we do need less severe restrictions for comparisons within the same landscape or region. This is a positive message to the readers: rather reducing comparative assessments of landscapes across Europe to mere quantitative measures, we may concentrate on the concept of “sustainable landscapes”. Given the complexity of real landscapes and real world communities a future research need is to develop alternative solutions in the planning cycle serving the needs for multiple uses and – consequently – multiple scales. Conceptually and in accordance with Blaschke (2006), the authors believe that a key issue will be the ability to take into account the multiplicity of (spatial) scales of study so that each phenomenon studied at its specific level can be integrated through hierarchically organised spatial concepts.
REFERENCES


Geoinformation technologies offer many new perspectives for geocultural landscape research in a huge variety of scientific disciplines such as archaeology, geography, geology, geomorphology, history, spatial planning, and cultural resource management. The main objective of this book is to constitute a link between landscape related research problems, geoinformation methods and corresponding applications in a wide multi and interdisciplinary perspective. Thus, it bridges the gap between theoretically addressed research issues, methodology used for analysis and practical cases. Its main value is that it addresses innovative geospatial technologies that can support different workflows needed for such analysis. It provides descriptions of a variety of research issues and technological approaches that may be used to support processes of data capturing, mapping, and analysis. These techniques and concepts are illustrated in selected case studies and numerous practical examples.