Transboundary landscape structure to determine the environmental situation of traditional land-use activities in Austria and Czech Republic

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ABSTRACT

This investigation was carried out to demontrate the usefulness of landscape metrics as information source to inform in a quantified way on the diverse shaped landscape of Waldviertel's (A) and Trebon Basin's (CZ) transboundary EUROREGION Silva Nortica (German: Nordwald). Landscape has been shaped over centuries by different political systems with respective landscape management policies and agricultural practices, implemented by using different technological tools, what at the end lead to the diverse face of the landscape what we are looking at today. The landscape metrics were calculated on vector maps derived from a pixel-based classification, based on a Landsat scene from year 2002. A semantical approach was used instead of correlation and factor analysis to select a set of structural indices suitable for the quantitative assessment. The study area was devided into subregions using the formerly tightly closed border to divide the Czech from the Austrian part. The landscape analysis were conducted for both regions individually and later compared to each other. The resulting numbers quantify significant differences in the values and indicate the visually graspabale non-similar pattern for both sides of the border. These findings indicate that anthropogenic influences based on different political framworks and rules, create landscapes of different behaviour, processes and functions.

1 INTRODUCTION

The (political) factors influencing landscape management in this Czech-Austrian cross-border environment have changed dramatically during the last decades of political transformation. In this context it is claimed by several authors (Herzog et al. 2001; OECD 1997) that methods to properly monitor the effects of these changes in land use and land cover are necessary. For this purpose, common agreements on core sets of indicators are currently to be aspired from international initiatives for landscape change evaluation (e.g. EU Natura 2000 Directive based on the Fauna-Flora-Habitat-Directive (92/43/EEC)). However, to finally arrive at an expressive, understandable and publicly acceptable set of landscape metrics, there are still several obstacles to overcome. First, the existing state of the landscape to be examined is not investigated in sufficient detail, that is to provides information about the absolut condition currently existent. Yet, it is strongly necessary to correlate the derived metrics values with the existent underlying condition. Secondly, different landscapes with their distinct environmental conditions still poses high hurdles to the spatial transferability of metrics. Therefore, comparing two landscapes with different prerequisites still causes problems to the landscape analyst. Thirdly, the focus of the studies can often vary and therefore a unique statement on the quality of the landscape as a combination of the individual interpretation of the resulting values remain difficult. Despite these facts, landscape metrics are in scientific discussion and their importance for landscape management is stated higher and higher (Forman 1995, Blaschke 2000).

The faces of the landscape are determined by various types of land cover patches representing different types of anthropogenic land-use and natural systems, forming ecological relations (networks) and thus create biodiversity. Over decades the landscape mosaic is regularly subject to change with patches continously experiencing change in their size and shape. Meaningful interpreted with sufficient knowledge on the local spatial structure and environmental conditions, landscape metrics can thus provide helpful indications on the inter-patch relationships, turned out by processes and as a result can tell us something on the integrity of the ecosystem within the continually alternating landscape (Klug, Langanke, Lang 2003). However, understanding and describing the contemporary local (environmental) conditions not just base on the gradual monitored changes of different states of the landscape in the past, as it has been done in most prior applications. On the contrary, it seems to be important to describe the landscape's condition individually by applying and interpreting landscape metrics just to one representative point in time.

The task to promote cross-border sustainable development in the region Silva Nortica, poses today equally a challenge and an opportunity to bring new tools and methods into practice. This is, among others, to perform a problem-adequate structural analysis of the landscape under consideration. The transboundary region Silva Nortica is a place where traditional land-use activities are still fostered, in particular agriculture development, carp cultivation, and forestry. Nevertheless, since the fall of the former Iron Curtain it is to assume, that the structural reforms in agriculture, the risen transnational traffic and the related constructional upgradings in this once remote area will have a substantial influence on the fragile network of the local ecosystems, like e.g. the valuable wetlands of the Luznice water catchment area. These developments are asking for reactions by landscape planners and -policies, whom themselves for their work have to rely on solid quantifiable statements and informations regarding current and expectable trends of land use. Landscape metrics are foreseen to provide information regarding the configuration and composition of the landscape (Farina 2000). Thereby the measured values describe spatial elements by unfolding the overall structure of the landscape, referring to underlying processes and functions (Klug and Zeil 2004). This is performed by the description of single landscape elements (patches) and their class aggregates with special attention to their problem-specific interrelations.

2 METHODOLOGY

Landscape metrics are beeing used in several disciplines since the 1950`s by Paffen (1953), Haase (1964), Neumeister (1972), Haggett (1973), Garten (1976) and Stöcker and Bergmann (1978) as well as several american landscape ecologists (Forman and Godron 1986, Riiters et al. 1995, Tuner et al. 2001), but software, able to reasonably exploit the expressivness of the metrics became first possible with the arrival of powerful GIS environments in the late 1970's. Since that time, geographers and landscape ecologists promote landscape metrics as a tool for landscape structure analysis. Landscape ecology as a discipline is based on the premise of strong interrelations between ecological functions, processes and change, taking into account the underlying pattern of spatial elements and ecosystems and their relative distribution. To these belongs the flow of energy, material and species in relation to size, shape, number and condition of the unique components of the landscape (after Walz et al. 2001). To analyse these complex relationships between structure and processes, new methodologies and concepts came up using landscape metrics to monitor and evaluate changes (Forman and Godron 1986, Blaschke 2000). The structure of the landscape is the expression of local diversity from which we derive conclusions to functions of nested ecosystems. In that sense, functions refer to the importance of system components as storage and modulator of processes, where processes are the summarizing term of relations and dependencies between compartments in representation of energy and matter flows. In the 'natural landscape' (German: Naturlandschaft) abiotical elements predefine the representation of land cover and land use elements. Following this concept, landscape metrics are problem-adequate as indicators to characterize anthropogenic influences on the landscape level. Thus, relations between the natural area and the cultural landscape can be analysed and deficits be shaped.

2.1 Shape and location of the study area

To describe the systems on both side of the border we need a spatial representation. For this purpose, appropriate delineation of a problem adaequate study area can be defined in several ways. One way is to take administrative units whereas other types, according to Simpson et al.(1994), Knick and Rothenbuerry (1997), Mladenoff et al. (1997) include e.g. watershed zones (catchments) or 'natural landscape units' as described by Herzog et al. (2001). Regarding this survey it was our intention to give a comparing view on this heterougenous landscape on a rather coarse (regional) scale. Therefore, a representative subset was choosen, located directly at the border line in form of a boundingbox with a total area of 70.000 ha and having its geographical extremes at 48°80`N - 49°20`N and 14°60`E – 15°00`E (figure 1). The study area is subdivided into two pieces and covers parts of Southern Bohemia's Trebon Basin in Czech Republik (CZ) in its northwestern and parts of Austria's (A) Northern Waldviertel in its southeast extend, located in the geographical center of the recently (2002) established cross-border region EUREGIO Silva Nortica The vegetation consists mainly of a mix of coniferous forest, water and grassland. Principal ecosystems to find here are fish ponds, forest, xerotrophic sand societies, grassland and intensively used agro(eco)systems. The industrialized agro-production, aimed at maximizing yields became the prime agricultural policy objective for years on both sides of the border, with the consequential implementation of this policy leading to the creation of large field units, in particular in the communistic planned economies. "This large size was at least in part due to standard reclamation practices, which were in fact designed to create landscapes with optimal conditions for industrialized farming" (Herzog et al. 2001). However, one of the side effects of the enlargement of the field sizes was, that most of the ecological infrastructure were removed as well, leading to a reduction in ecotones, ecotopes, hedgerows, single trees and therewith a simplification of the landscape matrix.

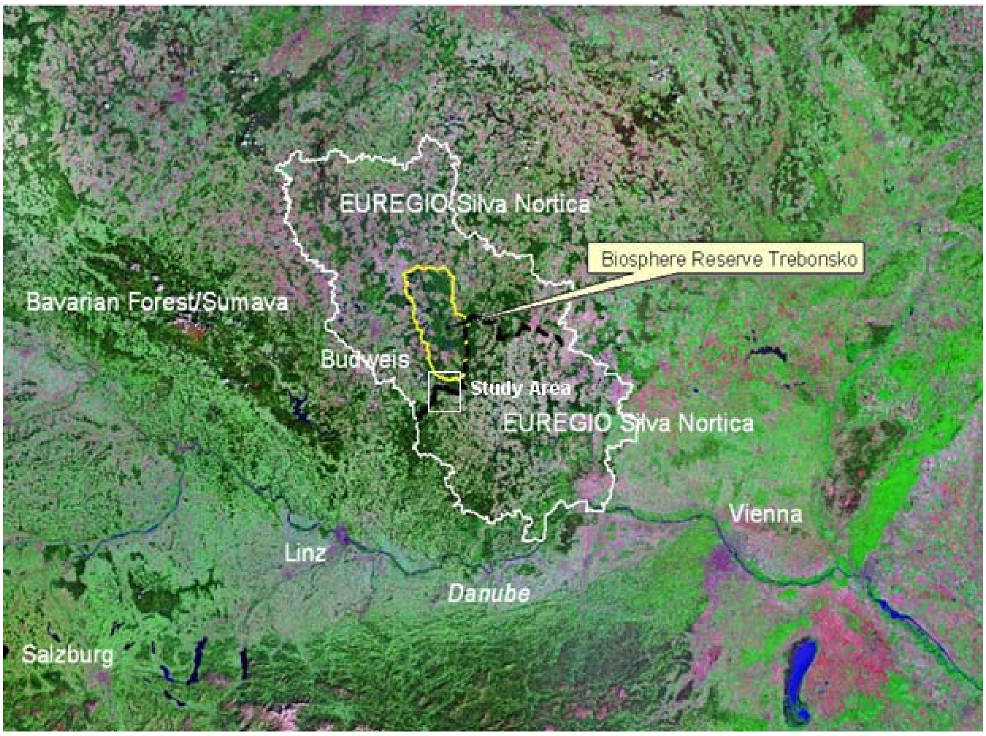

Fig.1: Transboundary region Silva Nortica – Red line, Biosphere Reserve Trebonsko – Yellow line, Boundary CZ-A – dashed black

2.2 Goals and objectives (why, for what, purpose)

The description of the landscape and its characteristics by means of landscape metrics will contribute to develop an understanding on the things, which have had a shaping effect on the region under consideration over the last decades. Here, along the former Iron Curtain border the landscape is still structured very heterougenously, already detectable by the human eye. Thus, referencing each state on both side of this *divided* entity will provide us with a wide range of de facto values each metric can exhibit. Therewith we are able to calibrate the ranges to relative minimum maximum of values and derive conclusions about the meaning of these differences. Having identified the meaning of the differences by applying a proper interpretation, the attained knowledge about these effects and (driving) factors can thus later be introduced into regional cross-border development efforts. The awareness and recognition of ongoing processes hereby serve as a base to enable stakeholder and expert rounds, to guide the landscape toward a sustainable future.

2.3 Data used

A five class (forest, arable land, grasland, settlements and water) deep pixel-based classification of the Landsat ETM 2002 scene (21st of July) was produced using Erdas Imagine 8.7 software. This classification was taken over from a change detection study from 1991 to 2002 carried out by Stroebel et al. (2004) in the Iron Curtain project (http://www.geo.sbg.ac.at/projects/ironcurtainweb/). The classification was first converted from ESRI Grid file to ESRI Shapefile and finally exported to ArcGIS 9.0, where the indicator calculation was performed by using the Arc GIS extension vLate (Vector-based Landscape Analysis Tools Extension, http://www.geo.sbg.ac.at/larg/vlate.htm) developed by Lang and Tiede (2003) in the EU funded project SPIN (EEVG 1-CT-2000-019, www.spin-project.org).

Prior to the calculation process with vLATE, a critical pre-processing step had to be carried out. The underlying data needed to be processed by a dissolve procedure to harmonise the polygons showing a size smaller or equal than 1000 m². This reduction of the total number of patches was essential to eliminate the so called "salt and pepper effect". The reduction of polygons lead to a higher performance of the calculation algorithm in vLATE, fully aware of the content based influences of these pre-processing steps. Due to the reduction of polygons the real small scaled landscape structure with the numerous small sized lakes and the characteristic agricultural plots on the austrian side was generalised. Nonetheless, the represented general states of the landscape structure on both sides could be remained and kept directly distinguishable. Another argument for this pre-processing is the focus on the aspired meso-scale dimension with a cartographic representation of 1:50.000, which allowed for generalization. Moreover, it must be considered, that one pixel of the Landsat ETM 2002 scene was 900 m^2 (30 by 30 km), with the consequence, that one area at least must have comprised two pixels.

2.4 Selection process

To reduce the numerous metrics available to a manageable set, we applied a semantical approach after Klug et al. (2003), where purposefull small sets of indices where identified, that nevertheless adequately reflects the major landscape properties taking into account the underlying (management) question to be answered. This statistical method not urgently avoids redundant information or doubling-up of similar information due to correlations (Riiters et al. 1995, Herzog et al. 2001) but contribute to the progress of knowledge due to the remaining carrying capacity of the potential indicator information. The selection of the metrics therewith is not an arbitrary task, but instead should be transparent and pursuable. The preferation of indices remain from the recommendations stated in the database IDEFIX (Indicator Database for Scientific Exchange) developed by Klug et al. (2003). These recommendations are revealed from literature reviews, previous projects and experiences with landscape metrics. Thereby one main goal was to avoid ambiguous interpretation of one and the same representation of a metrics value. The indices used here follow the groupings proposed by Lang and Klug (2003), limited to the categories of size and shape, since they found suitable to answer the here posed questions in the most comprehensive manner.

2.5 Calculating, mapping and interpreting landscape metrics

As Lang, Klug and Blaschke (2004) and Gustafson (1998) figured out, several open GIS-based software solutions exist, that can be used to perform a quantified landscape structure analysis, but less solutions exist to do so on vector datasets. In this study, the indices were calculated using the ArcGIS 9.0 extension vLate 1.0 (Lang and Tiede 2003). As most of the calculation procedures are based on class level and the results are presented as tables, charts and graphs (see chapter 3), the spatial representations in form of thematical maps is generally found not meaningful for this sort of analysis.

3 RESULTS

Size metrics

The landscape metrics values are reflecting the trends identified from the visual interpretation of the satellite scenes and from the areal statistics. At first sight, the metrics show, that forest dominates the land cover in the overall study area (see Table 1). In contrast, Built-up areas have exhibits the lowest quantity. However, with regard to the total Number of Patches (NP), grassland (Grld) dominates in both regions clearly in front of forest (CZ = 33.98 %; A = 45.00 %) whereas the share of arable land in the landscape is more dominant. Both indices indicates a rural setting of the study area with a focus on small patched grassland distribution and greater agricultural farming plots. The third important landscape structuring cover type is built, though here occupying just about 2-3 % of the the total area.

Tab 1: Total area (TA) and Number of Patches (NP) of SA, Silva Nortica

CLASS	Area CZ (km²)	%	Area A (km²)	%	NP CZ	NP CZ (%)	NP A	NP A (%)
Forest	261285.16	56.24	135500.76	53.64	548	16.58	383	13.67
Arab	129095.66	27.79	83353.83	33.00	781	23.63	560	19.99
Grld	57441.27	12.36	26035.74	10.31	1123	33.98	1265	45.15
Built	10630.41	2.29	7460.11	2.95	763	23.09	581	20.74
Water	6144.85	1.32	244.90	0.10	90	2.72	13	0.46
TOTAL	464597.36	100.00	252595.33	100.00	3305	100.00	2802	100.00

Mean Patch Size (MPS) is an indicator for the grain of the landscape (McGarigal 2002), together shown on class level with the Patch Size Standard Deviation (PSSD in Table 2. Comparing the MPS shows considerable differences between the two areas for the classes forest, grassland and water. In general it could be figured out, that MPS of the landscape classes on the Czech side is significantly larger than on the Austrian side. This observation is confirmed by the Coefficient of Variation (CV). This indicates on one hand, that the general fragmentation of landscape on the Czech side is not very much proceeded, what on the other hand, does not wonder, still taking into account the former large scale planned agriculture and pond cultivation practice on Czech side. In contrast, the rather small scale agriculture and pond cultivation practice in Austria got again underlined by these numbers.

Table 2 Mean Patch Size and Patch Size Standard Deviation for study area Silva Nortica

CLASS	MPS CZ (km²)	MPS A (km²)	PSSD CZ	PSSD A	CV CZ (%)	CV A (%)
Forest	476.80	353.79	7172.47	3751.47	1504.30	1060.37
Arab	165.30	148.85	1125.59	1285.56	680.96	863.69
Grld	51.15	20.58	202.60	52.64	396.10	255.76
Built	13.93	12.84	61.40	69.85	440.71	543.97
Water	68.28	18.84	115.82	25.25	169.63	134.06

Further landscape metrics as Total Edge (TE) and (MPE) are calculated to provide information on the heterogeneity in the landscape by calculating the length of perimeter and edges of adjacent class-patches. The results are presented as average values for each class. Arable land has the highest TE expressed as share of percent of the Austrian resp. Czech area (A = 38.79 %; CZ = 32.70 %). That is, that the total class of arable land on Austrian side is more fragmented and interspersed than the one on the Czech side. In distinction to this, the class forest has the largest Total Area (TA) on both sides (Table 1). The MPE represents minimal differences in classes characteristics. As a consequence of the industrialized farming on the Czech side, the MPS of arable land increased and the shape of the plots got a more geometrical order. Additionally, the forests were arranged to comparatively larger areas, whereas smaller pieces and ecotopes has been removed.

Table 3: Total Edge (TE) and Mean Patch Edge (MPE) metrics for study area Silva Nortica

CLASS	TE CZ (km)	TE CZ (%)	TE A (km)	TE A (%)	MPE CZ (km)	MPE A (km)
Forest	1524.34	30.33	1085.88	28.00	2.78	2.84
Arab	1643.15	32.70	1504.31	38.79	2.10	2.69
Grld	1364.40	27.15	985.51	25.41	1.21	0.78
Built	395.90	7.88	296.06	7.63	0.52	0.51
Water	97.45	1.94	6.60	0.17	1.08	0.51
TOTAL	5025.24	100.00	3878.36	100.00	1.54	1.46

Shape Metrics

Two important measures describing the complexity of a single patch are the Mean Shape Index (MSI) and the Mean Perimeter Area Ratio (MPAR). MSI is 1 when the patch is circular and tends to 2 with the patch getting a more narrow and rectangular form. The MSI calculated for the study area shows similar values on both sides of the border (Table 3). This is due to the more or less equal aggregation or clumpiness of the patches of the classes compared. Convoluted patches are rare and the shape of the agricultural plots are more or less rectangular. The MPAR non-standardized index additionally describes the shape complexity of a patch. This means, the smaller the MPAR the more compact is the patch.

Table 4: Shape Metrics for study area of Silva Nortica

CLASS	MSI CZ	MPAR CZ	MSI A	MPAR A
Forest	1.604	0.067	1.667	0.063
Arab	1.635	0.069	1.733	0.067
Grld	1.644	0.062	1.588	0.067
Built	1.447	0.081	1.451	0.08
Water	1.403	0.04	1.279	0.067

Diversity Metrics

To measure and monitor landscape diversity, landscape metrics can contribute to the understanding how processes of (human) interferences affects the landscape`s richness over time. Shannon`s Diversity Index (SHDI) is a popular measure of diversity and somewhat more sensitive to rare patch types than Simpson`s Diversity Index (SDI). SHDI = 0 when the landscape contains only 1 patch, which is equal to the meaning of no diversity. SHDI increases as the number of different patch types (e.g. Patch Richness) increases and/or the proportional distribution of area among patch types becomes more equitable. However, SHDI is recommendet to use only with a Patch Richtness (PR) greater than 100 (Yue et al. 1998).

Shannon`s diversity index is more sensitive to richness than evenness. "Thus, rare patch types have a disproportionately large influence on the magnitude of the index" (McGarigal 2002). Simpson`s diversity index on the other hand is relatively less sensitive to richness and thus place more weight on the common patch types. Simpson`s Diversity Index (SDI) is a dominance index weighted towards the abundance of the most common land use / land cover type rather than richness (Magurran 1988). Therefore it should be less dependant on the number auf land cover types than SHDI. Both indices have been applied by several landscape ecologists to measure the aspect of landscape composition within landscape structure (e.g. O'Neill et al. 1988). Calculating Shannon's Diversity measure here, the index shows almost the same values for both sides in the study area. The same is with Shannon's Evenness Index, measuring the distribution of patches (Table 4). That means for Shannon's Evenness Index neither a dominating nor an even distribution of area among patch types. However, there is no area with a primarily dominating allocation of a specific land cover type.

Table 5: Diversity metrics for study area of Silva Nortica

Index / Side	CZ	A
Number of Class	5	5
Shannon's Diversity	1.082	1.045
Shannon's Evenness	0.672	0.649

4 CONCLUSION

Landscape metrics have been proved useful in assessing the current conditions in this Czech - Austrian transboundary landscape and allowed to link assumed historical landscape shaping reasons to index numbers. Thereby the subdivision of the test area into subthemes of border regions proved helpful, especially on class- and landscape scale. In contrast to other delineated study areas, which are chosen on a more or less arbitrary basis, the subregions allow specific consideration to be linked to system characteristics and enable us to distinguish between the effects of major driving forces which have taken place over time on the respective side. The configuration of a landscape is represented by landscape metrics through mapping polygons and their describing features, such as number, size, and shape. In our case, the metrics used indicate on a comparable diversity on class level for both sides. However, more significant differences appear when the Number of Patches (NP) is taken into account. It indicates a major fragmentation on the Austrian side, although its Total Area (TA) is smaller than on Czech side. The size metrics report that the Total Area of each class does not depend on Number Of Patches (NP) (Table 1), which means that the grade of patchiness on the Austrian side is higher.

The detailed characteristics of the landscape on both sides of the border could be described more clearly with the Mean Patch Size (MPS) and the Patch Size Standard Deviation (PSSD). Applying these indices, continuously higher values describing the main classes (forest, grassland and water) are to be observed on the Czech side. As the MPS and the PSSD can be used to describe the grade of (anthropogenic) segmentation of the landscape, the higher values of MPS and PSSD on Czech side in view of forest and grassland may be the result (and the affirmation) of the taken conservation measures (as part of the study area is piece of the RAMSAR wetland zone and the Biosphere Reserve Trebonsko) and therefore an absences of large sized industrial activities. Moreover, the remaining larger agriculture plots in this fertile area on the Czech side (Table 2) can be interpreted as a cultural heritage of communist times, resulting as a special process-value-indication. The industrialized agricultural production aimed at maximizing yields became the prime agricultural policy objective, while the implementation of this policy led to the creation of large field units.

The absence of excessive human development in this transboundary area in general can be represented by the Coefficient of Variation (CV), which is concerning the classes Built and Arab higher on Austrian side. The assumed driving force behind the landscape change was the fact, that the border region was not settled for years but instead was intensivly agriculturally used. In contrast, the higher grade of urbanization and more economical activities on the Waldviertel`s side is to be taken cautiously (and is obviously wrong, taking the full EUREGIO area into consideration) as in communist times border areas were generally limited to military purposes and the Biosphere Reserve Trebonsko with its core zone has a mayor share of the study area.

Variations in the values of the shape metrics (MSI and MPAR) could be observed. The MSI for the class Water on Austrian side is lower than all other classes. This is owed to the fact, that the commonly small sized ponds on Waldviertel side were represented in the original landcover classification (Landsat scene = 900 m² resolution per pixel) just by 1 - 2 pixels with the consequence, that they could not develop more complex shapes when converted into polygons (scaling and generalization effect).

The Mean Perimeter Area Ratio (MPAR) informs how the landscape mosaic is structured by describing the complexity of patch shape. On both sides, the class Built has almost the same value (Table 3), and as such indicates that the size of the urban areas are smaller and less compact compared to other classes. This observation is confirmed by the values of Mean Patch Shape (MPS). For class Built there is to notice, that although size and shape of the patches are almost the same on both sides, they do not exhibit the same intensity of fragmentation.

The elaboration of indicators describing landscape structure by means of landscape metrics is an important contribution to a comprehensive description and understanding of the fragile network of adjacent ecosystems forming the face of a landscape. In this sense, the indices have the ability to relate structure and functionality in different landscape types. Thus, the combination of remote sensing, GIS and landscape ecology as innovative tools can be very supportive in decision making processes with respect to sustainability of landscapes and their resources as well as future planning strategies. However, there is a large potential for pitfalls and misinterpretations arising with easy to use software products developed (Lang et al. 2004). Therefore, the analysis of spatial structure is only useful when applied meaningful to the ecological phenomenon under consideration; to avoid taking place of unwanted future development dynamics (Klug et al. 2003).

Especially after the accession of Czech Republik to the European Union it seems to be obvious, that due to the dynamically altering political processes this transboundary region was and still will be subject to manifold changes in the near future. It is therefore planned to cover these changing processes in a follow-up analysis with regard to the beaviour of the metrics to the (expected) alteration of the landscape on both sides of the border.

5 REFERENCES

Blaschke, T. (2000): Landscape Metrics: Konzepte eines jungen Ansatzes der Landschaftsökologie und Anwendungen in Naturschutz und Landschaftsforschung. In: Arch. für Nat.- Lands., Vol. 39, S. 267-299

EU-Gesetzgeber (1992): Richtlinie 92/43/EWG Des Rates zur Erhaltung der natürlichen Lebensräume sowie der wildlebenden Tiere und Pflanzen.

Farina, A. (2000): Principles and Methods in Landscape Ecology; Kluwer Academic Publishers. First Edition

Forman, R. (1995): Land mosaics: the ecology of landscapes and regions. 632 S., Cambridge

Forman, R., Godron, M. (1986): Landscape Ecology. 619 S., New York.

Garten, G. (1976): Die Anwendung quantitativer Untersuchungsmethoden zur Abbildung und Kennzeichnung von Gefügestrukturen - dargestellt am Beispiel einer landschaftsanalytischen Untersuchung im Südteil der Lausitzer Platte. Dissertation. Pädagogische Hochschule, Dresden.

Gustafson, E. (1998): Quantifying Landscape Spatial Pattern: What is the state of the art? In: Ecosystems, Vol. 1, S. 143-156

Haase, G. (1964): Landschaftsökologische Detailuntersuchung und naturräumliche Gliederung. *Petermanns Geographische Mitteilungen* 108(1/2):8–30.

Haggett, P. (1973): Einführung in die kultur- und sozialgeographische Regionalanalyse. Berlin.

Herzog, F., Lausch, A. (1999): Prospects and limitations of the application of landscape metrics for landscape monitoring. In: Maudsley, M. und Marshall, J.: Heterogeneity in Landscape Ecology: Pattern and Scale, S. 41-50.

Herzog, F., Lausch, A., Müller, E., Thullke, H.-H. ; Steinhardt, U. und Lehmann, S. (2001): Landscape Metrics for Assessment of Landscape Destruction and Rehabilitation. In: Environmental Management, Vol. 27, H. 1, S. 91-107

Klug, H., Langanke, T., Lang, S. (2003): IDEFIX - Integration einer Indikatorendatenbank für landscape metrics in ArcGIS 8.x. - In: S. Strobl, T. Blaschke, G. Griesebner (Hrsg.), Angewandte Geografische Informationsverarbeitung XV, S. 224-233. Salzburg

Klug, H., Zeil, P. (2004): The choice and use of landscape metrics for catchment characterization. Proceedings of the Eco-Geowater Conference "GI for International River Basin Management", p. 73-82, 3.-5. June 2004, Budapest

Knick, S.T., Rotenberry, J.T. (1997): Landscape characteristics of disturbed shrubsteppe habitats in southwestern Idaho (USA). *Landscape Ecology* 12:287–297.

Lang, S. (1999): Aspekte und Spezifika der nordamerikanischen Landscape metrics innerhalb der Landschaftökologie und experimentelle Untersuchungen zum Proximity Index. Diplomarbeit. Naturwissenschaftliche Fakultät. Universität Salzburg

Lang, S., Klug, H. (2003): Interactive Metrics Tool (IMT) - a didactical suite for teaching and applying landscape metrics. Nitra Conference, Slowakia

Lang, S., Klug, H., Blaschke, T. (2004): Software zur Analyse der Landschaftsstruktur.. IÖR-Schriften, Band 43, S. 29-36, Dresden

Lang, S., Tiede, D. (2003): vLATE Extension für ArcGIS – vektorbasiertes Tool zur quantitativen Landschaftsstrukturanalyse, ESRI Anwenderkonferenz 2003 Innsbruck.

Magurran, A.E. (1988): Ecologcial Diversity and its Measurement. Cambridge

McGarigal, K. (2002): FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure. Vers. 3.3 (from Help File)

Mladenoff, D.J., Niemi, G.J., White, M.A. (1997): Effects of changing landscape pattern and USGS land cover data variability on ecoregion discrimination across a forest–agriculture gradient. *Landscape Ecology* 12:379 –396.

Neumeister, H. (1972): Probleme der Anwendung und Auswertung der Faktorenanalyse bei geographischen Untersuchungen. Halle, Dissertation B.

OECD (1997): OECD environmental data - compendium 1997. Organisation for Economic Co-operation and Development, Paris.

O'Neill , R.V., Krummel, J.R., Gardner, R.H., Sugihara, G., Jackson, B., DeAngelis, D.L., Milne, B.T., Turner, M.G., Zygmunt, B., Christensen, S.W., Dale, V.H., Graham, R.L. (1988): Indices of landscape pattern. Landscape Ecology 1:153-162

Paffen, K. (1953): Die natürliche Landschaft und ihre räumliche Gliederung. Forschungen zur Deutschen Landeskunde 68.

Riiters, K., O`Neill, C., Hunsaker, C., Wickham, J., Yankee, D., Timmins, S. (1995): A factor analysis of landscape pattern and structure metrics. In: Landscape Ecology, Vol. 10, H. 1, S. 23-39

Simpson, J. W., Boerner, R.E.J., DeMers, M.N., Berns, L.A. (1994): Forty-eight years of landscape change on two contiguous Ohio landscapes. *Landscape Ecology* 9:261–270.

Stöcker, G., Bergmann, A. (1978): Zwei einfache Modelle zur Quantifizierung der Beziehungen von Landschaftselementen. *Wissenschaftliche Abhandlungen der Geographischen Gesellschaft der DDR* 14:91–100.

Stroebl, B., Gottsmann, F., Pfusterschmid, S. (2004): Landnutzungswandel in zwei Biosphärenreservaten von 1990 bis 2015; in Beiträge zum 16, AGIT Symposium Salzburg, 2004

Turner, M., Gardner, R., O'Neill, R. (2001): Landscape ecology. Theory and practice - pattern and process. 401 S., New York

Walz, U., Syrbe, R.-U., Donner, R., Lausch, A. (2001): Erfassung und ökologische Bedeutung der Landschaftsstruktur. In: Naturschutz und Landschaftsplanung, Vol. 33, H. 2/3, S. 101-105

Yue, T.X., Haber, W., Herzog, F., Cheng, T., Zhang, H.Q., Wu, Q.H. (1998): Models for DLU strategy and their applications. Ecologica (Bratislava) 17:118-128