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5 authors, including:

Evelyn Uuemaa
University of Tartu

Marc Antrop
Ghent University

Jüri Roosaare
University of Tartu

Riho Marja
Estonian Ornithological Society

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Landscape Metrics and Indices: An Overview of Their Use in Landscape Research

Evelin Uuemaa
Department of Geography, Institute of Ecology and Earth Sciences, University of Tartu,
46 Vanemuise St., Tartu, Estonia, 51014
email: kevelyn@ut.ee

Marc Antrop
Department of Geography, University of Ghent, Krijgslaan 281 S8, 9000 Gent, Belgium
email: Marc.Antrop@UGent.be

Jüri Roosaare
University of Tartu (see above)
email: juri.roosaare@ut.ee

Riho Marja
University of Tartu (see above)
email: riho.marja@ut.ee

Ülo Mander
University of Tartu (see above)
email: ulo.mander@ut.ee

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Abstract

The aim of this overview paper is to analyze the use of various landscape metrics and landscape indices for the characterization of landscape structure and various processes at both landscape and ecosystem level. We analyzed the appearance of the terms landscape metrics/indexes/indices in combination with seven main categories in the field of landscape ecology [1) use/selection and misuse of metrics, 2) biodiversity and habitat analysis; 3) water quality; 4) evaluation of the landscape pattern and its change; 5) urban landscape pattern, road network; 6) aesthetics of landscape; 7) management, planning and monitoring] in the titles, abstracts and/or key words of research papers published in international peer-reviewed scientific journals indexed by the Institute of Science Information (ISI) Web of Science (WoS) from 1994 to October 2008. Most of the landscape metrics and indices are used concerning biodiversity and habitat analysis, and also the evaluation of landscape pattern and its change (up to 25 articles per year). There are only a few articles on the relationships of landscape metrics/indices/indexes to social aspects and landscape perception.

Keywords: Biodiversity; FRAGSTATS, Landscape aesthetics, Landscape ecology, Landscape pattern; Landscape planning

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1 Introduction

The quantification of spatial heterogeneity is necessary to elucidate relationships between ecological processes and spatial patterns (Turner, 1990; Turner *et al.*, 2003). Therefore the measurement, analysis and interpretation of spatial patterns receive much attention in landscape ecology (Haines-Young and Chopping, 1996). A great variety of metrics for landscape composition (e.g., the number and amount of different habitat types) and configuration (the spatial arrangement of those classes) were developed for categorical data. Software packages are widely used (e.g., FRAGSTATS, see McGarigal and Marks, 1995; McGarigal *et al.*, 2002), and many metrics have also been integrated into existing geographic information system (GIS) software (e.g., Patch Analyst in ArcView; and module Pattern in IDRISI).

Although spatial pattern analysis should be considered to be a tool rather than a goal in and of itself, and the objectives or questions driving any analysis must include the qualities of the pattern to be represented and why, there are many examples in the literature when this has not been correctly followed (Li and Wu, 2004). Several issues associated with the interpretation of landscape metrics are widely used by practitioners (Gustafson, 1998; Haines-Young and Chopping, 1996; Li and Wu, 2004; Turner *et al.*, 2003). Many metrics are sensitive to changes in the spatial resolution (grain size) of the data or the area (extent) of the landscape (Wickham and Riitters, 1995), and numerous correlations occur among landscape indices (Riitters *et al.*, 1995; Cain *et al.*, 1997). The downscaling and upscaling of landscape metrics as functional and structural landscape indicators at different scales still remains a challenge (Mander *et al.*, 2005).

On the other hand, the common usage of the term "landscape metrics" mostly refers to indices developed for categorical map patterns (McGarigal *et al.*, 2002), but it is sometimes also used for topographic measures (Iampietro *et al.*, 2005; Vivoni *et al.*, 2005) that characterize landscape, or it may also just refer to some combination of several characteristics that are important to a particular species (Schils, 2006; Fernández *et al.*, 2007).

The main aim of this paper is to give an overview of the development and state of the art of the applications for landscape metrics, one of the classical landscape ecological tools, and study objects that help us better understand the relationships between landscape pattern and processes.

2 Methods

We analyzed papers published in international peer-reviewed journals that are indexed by the Institute of Science Information (ISI) Web of Science (WoS) from 1994 to October 2008. The terms "landscape metrics", "landscape indexes" and "landscape indices" were searched as both separate items and in combination with the following terms:

"biodiversity", "habitat", "urban landscape", "road network", "water quality", "watershed(s)", "catchment(s)", "landscape pattern", "landscape structure", "Fragstats", "land use", "land use change", "landscape aesthetics" and "aesthetics of landscape", "landscape planning", "landscape management".

The appearance of these terms and combinations thereof in the titles, abstracts and/or key words of papers was taken into account. The overlapping issues (if the terms or combinations appeared in the same paper) were not double-counted.

3 Results and Discussion

There are 331 articles for the term "landscape metrics", 131 articles for the term "landscape indices", and 17 for "landscape indexes" in the ISI Web of Science literature database (October 14, 2008). In fact, some of the articles overlapped, and a few articles were added by using the singular form of the two terms. We therefore eventually reviewed 337 articles for the term "landscape metrics", and 141 articles for the term "landscape indices" and "landscape indexes".

3.1 "Landscape metrics" vs "landscape indices"

The term "landscape metrics" appears more frequently, but there are no definite rules or traditions as to when one or the other term is used. It seems that the term "landscape metrics" is used more often only for metrics calculated by Fragstats or by some of its developments in other programs (FRAG*ARC, Fragstats for ArcView, Patch Analyst etc). The term "landscape indices" is more frequently used in a broader sense, i.e., metrics have similar or the same formulae as in Fragstats but are named differently. Also, in terms of the timeline of their use (Figure 1), it can be seen that the term "landscape indices" was more often used in the 1990s, and now the term "landscape metrics" is prevalent. From here on we will only use the term "landscape metrics".

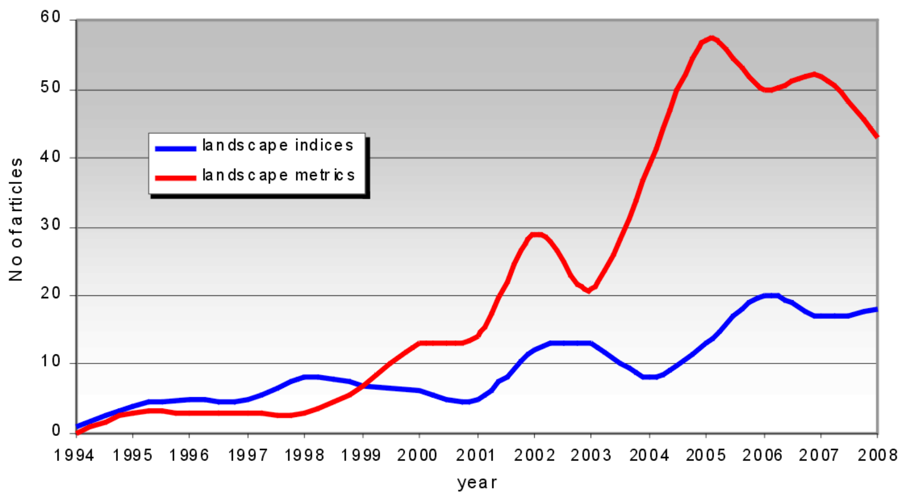

Figure 1: The use of the terms "landscape metrics" and "landscape indices" in titles, abstracts and/or key words of international peer-reviewed scientific papers. The analysis has been performed on the basis of journal papers indexed by the ISI Web of Science from 1994 to October 2008.

The usage of landscape metrics is very broad, and can be grouped into seven general categories: a) use and misuse/ selection of metrics; b) biodiversity and habitat analysis; c) estimating water quality; d) evaluation of landscape pattern and changes therein; e) urban landscape pattern, road network; f) aesthetics of landscape; g) management, planning and monitoring. Category e) is actually more like a subcategory of d), but since the human impact on landscapes is so important and has been very widely explored, we decided to analyze it separately. Most of the studies published from 1994 – 2008 are on biodiversity and habitat analysis, and the evaluation of landscape pattern and changes therein (up to 25 articles per year; Figure 2). There are up to 15 articles per year about the use and misuse / selection of metrics. The number of articles published each year has generally increased since 1994, but for example articles published on the relations between landscape aesthetics relations and landscape metrics has been surprisingly low.

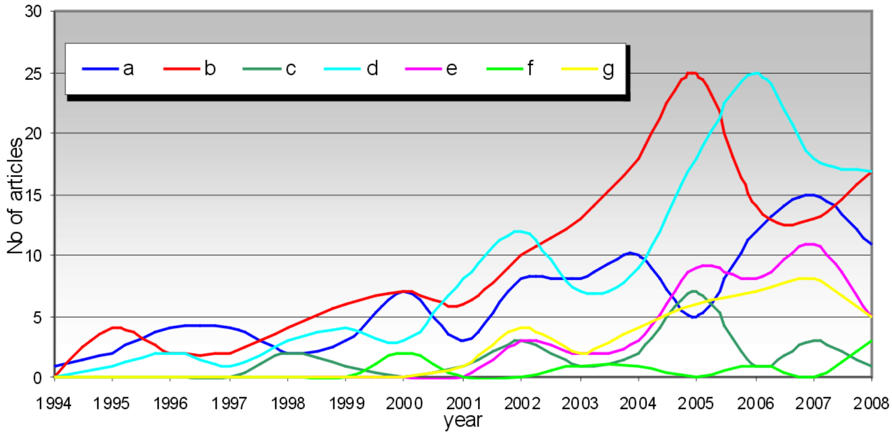

Figure 2: The use of the following terms and their combinations in titles, abstracts and/or key words of international peer-reviewed scientific papers: a) use and misuse/selection of metrics; b) biodiversity and habitat analysis; c) estimating water quality; d) evaluation of landscape pattern and changes therein; e) urban landscape pattern, road network; f) landscape aesthetics; g) management, planning and monitoring. The analysis has been performed on the basis of journal papers indexed by the ISI Web of Science from 1994 to October 2008.

3.2 Use and selection of metrics

Many of the articles have been written on the use and misuse and selection principles of landscape metrics. As there are literally hundreds of landscape metrics, many of the landscape metrics are correlated to each other, which makes interpretation more difficult. Riitters *et al.* (1995) found that the first six factors explained about 87% of the variation in the 26 landscape metrics, and these factors were interpreted as composite measures of average patch compaction, overall image texture, average patch shape, patch perimeter-area scaling, the number of attribute classes, and large-patch density-area scaling. Cushman *et al.* (2008) performed principal component analysis (PCA) and cluster analysis to identify independent components of landscape structure and group them, and found that there were eight universal and consistent combinations of Fragstats metrics that universally describe the major attributes of landscape structure at the landscape level. Botequilha Leitão and Ahern (2002) even proposed a core set of metrics that are most useful and relevant for landscape planning and Schindler *et al.* (2008) proposed set of metrics for establishing a landscape monitoring program, to detect the local drivers of biodiversity in Mediterranean area. The interpretation of some of the landscape metrics is also complicated because their behaviour has not yet been evaluated (McGarigal *et al.*, 2002). In that field, neutral landscapes are useful (see for example Neel *et al.*, 2004; Li *et al.*, 2005a).

Another important issue is that the results of spatial data analysis depend on data aggregation methods and the zoning scheme. Its general formulation is known as the modifiable areal unit problem (MAUP), created by (Openshaw and Taylor, 1981). MAUP in the context of landscape ecology consists of three related aspects: how the grain size, zoning and areal extent of investigation influence results, and how to determine their optimal values for each particular case. The dependence of landscape metrics on grain size is studied by (Wickham and Riitters, 1995; Uuemaa *et al.*, 2005; Buyantuyev and Wu, 2007). Wickham *et al.* (1997); Huang *et al.* (2006); Langford *et al.* (2006) have studied the influence of map classification, and Wu *et al.* (2002) and Wu (2004) have studied the extent of the study area on the value of landscape metrics.

Although there are already hundreds of landscape metrics, several researchers have proposed new landscape metrics. Jaeger (2000) proposed a degree of landscape division (D), splitting index (S), and effective mesh size (m), which characterize the anthropogenic penetration of landscapes from a geometric point of view and are calculated from the distribution function of the remaining patch sizes. (He *et al.*, 2000) proposed new metric (aggregation index-AI) for measuring aggregation in landscape pattern. AI is class-based, and contrary to contagion, it is independent of composition. All of these metrics are now also available in Fragstats. The fact that researchers are still working out new metrics indicates the need for measuring new aspects of landscape pattern but also researchers' aspiration to overcome the collinearity in Fragstats metrics.

3.3 Biodiversity and habitat analysis

The relationship between landscape metrics and bird species richness and their habitat preferences has been studied most extensively. There are many studies that have been performed on the relationships between landscape parameters and specific species – owls (Carey *et al.*, 1992; Ribe *et al.*, 1998), sparrows (Perkins and Conner, 2003), turkeys (Chamberlain *et al.*, 2000; Miller and Conner, 2007), woodpeckers (Wigley *et al.*, 1999), bobwhites (Guthery *et al.*, 2001; Twedt *et al.*, 2007), grouses (Fearer and Stauffer, 2003), pheasants (Clark *et al.*, 1999) and ducks (Stephens *et al.*, 2005). Different studies have shown that most bird species responded more strongly to the composition of land-cover classes than to the configuration of the landscape (Table 1). Of landscape configuration metrics, patch size has given the most important relationships with bird species richness, i.e., fragmentation plays an important role for birds.

Landscape metrics have been used to determine the landscape preferences of raccoons (Henner *et al.*, 2004), gray wolves (Mladenoff *et al.*, 1995), wild hogs (Gaines *et al.*, 2005); moose (Maier *et al.*, 2005), deer (Foster *et al.*, 1997; Finder *et al.*, 1999; Kie *et al.*, 2002), black bears (Kindall and Van Manen, 2007), ocelots (Jackson *et al.*, 2005), elk (Stubblefield *et al.*, 2006), possums (Eyre and Buck, 2005) and bats (Limpert *et al.*, 2007). Different species provide different correlations with landscape metrics depending on their landscape preferences, i.e., large compact patches are preferred by wild hogs (Gaines *et al.*, 2005), moose (Maier *et al.*, 2005), deer (Table 1; Foster *et al.*, 1997; Plante *et al.*, 2004) and possums (Eyre and Buck, 2005), while ocelots (Jackson *et al.*, 2005) and gliders (Table 1; McAlpine and Eyre, 2002) preferred areas that had a greater degree of fragmentation (i.e., a larger number of patches of smaller size, and with more edge).

Several studies have even shown the significance of landscape pattern (measured by landscape metrics) on frog populations (Table 1; Knutson *et al.*, 1999; Pellet *et al.*, 2004) and on insect population levels (Radeloff *et al.*, 2000; French *et al.*, 2004; Roschewitz *et al.*, 2005). The structure of the landscape may be important to explain and understand the epidemiology associated with insects (Graham *et al.*, 2004). Overgaard *et al.* (2003) studied the influence of landscape structure on Anopheline mosquito density, and based on their results suggested that if landscape management were to be used for malaria control, the large-scale reduction and fragmentation of forest cover would be needed in the case of northern Thailand. The risk of transmission of Lyme disease has been found to be influenced by landscape structure and the spatial arrangement of land cover types (Turner, 1989). Brownstein *et al.* (2005) performed an analysis of the landscape pattern of forest patches using satellite imagery, and calculated landscape indices revealed a positive link between fragmentation and both tick density and the prevalence of infection in ticks. Yang *et al.* (2008) investigated ecological variability related to the distribution of *Oncomelania hupensis*, the snail intermediate host of *Schistosoma japonicum*, and found that the reduction of the heterogeneity of the landscape could reduce snail density.

It is known that habitats composed of spatially heterogeneous abiotic conditions provide a great diversity of potentially suitable niches for plant species. The scientific premises of landscape ecology suggest that, at a higher spatial level, the composition and structure of the landscape mosaic also influences biotic processes and hence species richness (Honnay *et al.*, 2003). There are several studies on the determining of relationships between landscape structure (estimated with landscape metrics) and plant diversity (Table 1; Moser *et al.*, 2002; Burton and Samuelson, 2008; Hernández-Stefanoni and Dupuy, 2008). A growing number of ecological studies have focused on alien plants' invasive processes in order to predict further invasions and associated potentially negative effects. The introduction of alien plants or plant species new to an area due to human activity and their spread and establishment is thought to cause a decline in the diversity of native species (Williamson, 1999). Deutschewitz *et al.* (2003) found that the species richness of native and alien plants increases with moderate levels of natural and/or anthropogenic disturbances, coupled with high levels of habitat and structural heterogeneity in urban, riverine, and small-scale rural ecosystems. Kumar *et al.* (2006) found that both native and non-native plant species richness were positively correlated with edge density, Simpson's diversity index and the interspersion/juxtaposition index, and were negatively correlated with mean patch size (Table 1). Landscape metrics of watersheds have also proven to be useful for the identification of estuarine benthic conditions and degraded bottom communities (Hale *et al.*, 2004).

Table 1: Correlations between various landscape metrics and biological variables indicating biodiversity and habitat features. Significance: * p<0.05, ** p<0.01, *** p<0.001, **** p<0.0001.

Taxa	**Landscape metrics**	**Dependent variables**	**Pearson r**	**References**
Amphibia	Density of urban land-cover in a buffer of 30 m around the pond	calling sites selection by males of tree frog *(Hyla arborea)*	−0.23***	Pellet *et al.* (2004)
Mammals	$\log_{10}$ forest patch area	carnivores species richness	0.69***	Michalski and Peres (2005)
		primates species richness	0.65***	
	Mean woods patch size (log)	deer vulnerability to harvest (log)	−0.75****	Foster *et al.* (1997)
	Proximity index (log)		−0.76****	Foster *et al.* (1997)
	mean woods patch shape (log)		−0.7****	Foster *et al.* (1997)
	Mean nearest neighbour distance		0.76****	Foster *et al.* (1997)
	Number of patches	Deer density	0.43*	Plante *et al.* (2004)
	Edge density		0.37***	Plante *et al.* (2004)
	Mean Patch Size	Count of the Yellow-bellied Glider (*Petaurus australis*)	−0.25*	McAlpine and Eyre (2002)
	Edge density		0.29*	McAlpine and Eyre (2002)
	Contrast weighted edge density		0.28*	McAlpine and Eyre (2002)
	Largest patch index	Diversity of exudivore species	−0.26*	McAlpine and Eyre (2002)
	Shannon's evenness index		0.33*	McAlpine and Eyre (2002)

Table 1 – *Continued*

Taxa	**Landscape metrics**	**Dependent variables**	**Pearson r**	**References**
	Contagion		−0.33*	McAlpine and Eyre (2002)
Birds	Agricultural land (ha)	Number of hooded crane	0.79**	Liu *et al.* (2003)
	Proportion forest	Abundance of female cowbirds	0.62**	Fauth *et al.* (2000)
	Proportion forest	Abundance of indigo buntings	−0.77**	Fauth *et al.* (2000)
	Proximity index		−0.35**	Fauth *et al.* (2000)
	Edge density	Abundance of wood thrushes	0.37**	Fauth *et al.* (2000)
Insects	Total area of host patches	Mean abundance of *(Delphacodes kuscheli)*	0.79***	Grilli (2008)
	Mean proximity index (host patches)		0.96***	Grilli (2008)
	Class area (maize)	Total number of western corn rootworm	0.91*	Beckler *et al.* (2004)
	Number of patches (maize)		0.9*	Beckler *et al.* (2004)
	Proximity (maize patches)		0.99**	Beckler *et al.* (2004)
	Edge density	Mean jack pine budworm (*Choristoneura pinus pinus*) population levels	0.26*	Radeloff *et al.* (2000)
		Corrected mean perimeter area ratio	0.34*	Radeloff *et al.* (2000)
	Modified Simpson's diversity index	Anopheline species diversity (Shannon–Weaver diversity index)	−0.74*	Overgaard *et al.* (2003)
Plants	Forest cover (%)	Riparian woody plant species richness	0.78**	Burton and Samuelson (2008)
	Shannon's diversity index		−0.74**	Burton and Samuelson (2008)
	Number of patches	Species richness of vascular plants	0.61**	Moser *et al.* (2002)
	Edge density		0.56**	Moser *et al.* (2002)
	Mean shape index		−0.7**	Moser *et al.* (2002)
	Number of patches	Species richness of bryophytes	0.6**	Moser *et al.* (2002)

Table 1 – *Continued*

Taxa	Landscape metrics	Dependent variables	Pearson r	References
	Edge density		0.57**	Moser *et al.* (2002)
	Mean shape index		−0.51**	Moser *et al.* (2002)
	Simpson's diversity index	Native species richness	0.28*	Kumar *et al.* (2006)
	Interspersion and juxtaposition index		0.31*	Kumar *et al.* (2006)
	Patch richness density		0.35*	Kumar *et al.* (2006)
	Simpson's diversity index	Non-native species richness	0.43*	Kumar *et al.* (2006)
	Interspersion and juxtaposition index		0.29*	Kumar *et al.* (2006)
	Patch richness density		0.4*	Kumar *et al.* (2006)

3.4 Estimating water quality

Landscape structure is one of the most important factors influencing nutrient and organic matter runoff in watersheds (Turner *et al.*, 2003; Wickham *et al.*, 2003; Uuemaa *et al.*, 2007). Therefore there is increasing demand for indicators and methods that make it possible to evaluate the landscape factors influencing water quality in freshwater management (Griffith, 2002). Several studies have attempted to determine the relationship between land use/land cover structure and water quality but most studies have largely relied on compositional landscape metrics (Kearns *et al.*, 2005). It is, however, clearly important to understand not only the total area of sources and sinks in the landscape, but also their spatial arrangement relative to flowpaths (Gergel, 2005). The importance of the spatial arrangement of land cover within watersheds on water quality has been studied by Jones *et al.* (2001); King *et al.* (2005); Li *et al.* (2005b); Snyder *et al.* (2005); Xiao and Ji (2007); Uuemaa *et al.* (2005, 2007); see Table 2.

The spatial pattern of riparian zones is also an especially powerful landscape indicator for water quality, because the variation in length, width, and gaps of riparian buffers influences their effectiveness as nutrient sinks (Gergel *et al.*, 2002). Weller *et al.* (1998) developed and analyzed models predicting landscape discharge based on material release by an uphill source area, the spatial distribution of a riparian buffer along a stream, and retention within the buffer, and found average width to be the best predictor of landscape discharge for unretentive buffers. Baker *et al.* (2006) quantified the effects of riparian buffers on watershed nutrient discharges by using, in addition to traditional fixed-distance measures, mean buffer width, gap frequency, and measures of variation in buffer width using both "unconstrained" metrics and "flow-path" metrics constrained by surface topography.

3.5 Evaluation of landscape pattern and changes therein

Land use changes are mostly caused by humans, but also by natural disturbances. For example, Lin *et al.* (2006) used landscape metrics and spatial autocorrelation to assess how earthquakes and typhoons affect landscape patterns, and found that the disturbances produced variously fragmented patches, interspersed with other patches and isolated from patches of the same type across the entire Chenyulan watershed in Taiwan. Results of fire disturbances studies Keane *et al.* (1999) and Hudak

Table 2: Correlation between various landscape metrics and water quality parameters. Significance: *p<0.05, ** p<0.01, *** p<0.001, **** p<0.0001.

Landscape metrics	**Dependent variables**	**Pearson r or *Spearman* ρ**	**References**
Cropland (%)	Log (NO_3-N)	0.67*	King *et al.* (2005)
Canal line density	Soluble reactive phosphorus reduction	0.8*	Li *et al.* (2005b)
Canal connectivity		0.83*	Li *et al.* (2005b)
Canal circuity		0.85*	Li *et al.* (2005b)
Canal line density	Total nitrogen reduction	0.84*	Li *et al.* (2005b)
Canal connectivity		0.92*	Li *et al.* (2005b)
Canal circuity		0.94*	Li *et al.* (2005b)
Edge density (forest)	Conductivity	−0.34*	Xiao and Ji (2007)
Patch density		0.33*	Xiao and Ji (2007)
Contagion		−0.49*	Xiao and Ji (2007)
Edge density (forest)	Total Cd	−0.53*	Xiao and Ji (2007)
Edge density (forest)	Total Zn	−0.49*	Xiao and Ji (2007)
Contagion		−0.36*	Xiao and Ji (2007)
Patch density	BOD_7 (biological oxygen demand)	***−0.53****	Uuemaa *et al.* (2005)
Edge density		***−0.47****	Uuemaa *et al.* (2005)
Patch density	COD_{KMnO4} (chemical oxygen demand)	***−0.49****	Uuemaa *et al.* (2005)
Mean shape index		***0.66****	Uuemaa *et al.* (2005)
Edge density	Total-N	***−0.56****	Uuemaa *et al.* (2005)
Mean shape index		***−0.44****	Uuemaa *et al.* (2005)

et al. (2004) found that fire creates more diverse, fragmented and disconnected landscapes, and Kashian *et al.* (2004) found that large, stand-replacing fires may result in heterogeneous forest landscapes rather than homogenous forests of uniform structure. According to Viedma *et al.* (2006), on the contrary, fire had made the landscape less fragmented and more continuous.

Teixidó *et al.* (2007) used landscape metrics to study the spatial patterns of the Antarctic benthos in terms of the succession process after iceberg disturbance, and found the first stages of recovery to have low cover area, low complexity of patch shape, small patch size, low diversity and patches that were poorly interspersed to samples from later stages with higher values of these indices.

Many studies have been done on the mapping of forest cover change. Human influence also causes forest fragmentation that also affects species richness (Fuller, 2001; Cayuela *et al.*, 2006; Echeverría *et al.*, 2007; Altamirano *et al.*, 2007). Twentieth century management activities have significantly influenced the structure of the forest landscape (Wolter and White, 2002; Löfman and Kouki, 2003), and altered spatial patterns of physiognomies, cover types and structural conditions, and vulnerabilities to fire, insect, and pathogen disturbances (Hessburg *et al.*, 2000). Logging is one of the main reasons for forest fragmentation, and although it may change the landscape structure at a small spatial scale and not alter the structure of the entire forest mosaic (Leimgruber *et al.*, 2002), it can be associated with dramatic changes in the structure and composition of the forests (Echeverría *et al.*, 2007). Etheridge *et al.* (2006) also found, using landscape metrics as an indicator, that clearcuts result in the loss of large patches. Zhang and Guindon (2005) used landscape metrics and cellular automata to analyze human impacts on forest fragmentation, and showed that the observed values of scalar landscape metrics and their interrelationships can only be understood by taking into account the spatial pattern aspects associated with causal human drivers of the deforestation process.

3.6 Urban landscape pattern, road network

Urbanization has significantly changed natural landscapes everywhere. Urban growth and fragmentation caused by urban sprawl have been extensively studied (Herold *et al.*, 2002; Ji *et al.*, 2006; Tang *et al.*, 2006; Gonzalez-Abraham *et al.*, 2007). It has been shown that landscape pattern is more fragmented around city centres and along coastlines, where urbanization and human economic activities are more concentrated (Yang and Liu, 2005). There are several possibilities as to how to use landscape metrics to detect spatial patterns caused by urbanization. For example, Seto and Fragkias (2005) calculated and analyzed landscape metrics spatiotemporally across three buffer zones, but another effective approach for analyzing systematically the effects of urbanization on ecosystems is to studying the changes in ecosystem patterns and processes along an urban-to-rural gradient (McDonnell *et al.*, 1997). Studies of landscape pattern change along an urban-to-rural gradient focus on the identification of urban texture – whether urban landscapes have unique “spatial signatures” that are distinguishable from other types of landscapes (Weng, 2007). In many studies only land use changes in space are considered (Luck and Wu, 2002; Hahs and McDonnell, 2006; Conway and Hackworth, 2007), but landscape pattern also changes over time. Spatiotemporal gradient analysis makes it possible to determine how the urban centre has shifted in space and time (Wu *et al.*, 2006; Xie *et al.*, 2006; Weng, 2007).

Another critical issue is fragmentation caused by infrastructure, and many studies have revealed that road corridors in the urban landscape increased habitat fragmentation (Saunders *et al.*, 2002; Zhu *et al.*, 2006; Hawbaker *et al.*, 2006; Jaeger *et al.*, 2007).

3.7 Landscape aesthetics

Human perception and intuition can strongly influence how we measure and interpret landscape pattern (D'Eon and Glenn, 2000). Antrop and Van Eetvelde (2000) also emphasise the importance of holism, and found that summed entropy corresponds most closely to the landscape units defined by visual image interpretation, and can be used as a quantitative characteristic of holistically defined landscape units. (Franco *et al.*, 2003) also found strong explanatory relationship between citizens' scenic beauty estimation and the Shannon's diversity index (Table 3).

Table 3: Correlation between various landscape metrics and parameters characterizing landscape aesthetics. Significance: * p<0.05, ** p<0.01, *** p<0.001, **** p<0.0001.

Landscape metrics	Dependent variables	Pearson r or *Spearman ρ*	References
Shannon's diversity index	Scenic beauty estimation	***0.82*******	Franco *et al.* (2003)
Edge density	Scenic beauty estimation	0.42***	Palmer (2004)
Agricultural and open land		0.38***	Palmer (2004)
Recreation		0.31**	Palmer (2004)
Other urban		−0.45***	Palmer (2004)
Waste		−0.33**	Palmer (2004)
Wetland, open water		0.33**	Palmer (2004)
Largest patch index	Neighbourhood satisfaction (0= not satisfied; 6= very satisfied)	0.18**	Lee *et al.* (2008)
Patch density		−0.13*	Lee *et al.* (2008)
Total core area		0.21**	Lee *et al.* (2008)
Mean Euclidean nearest neighbour distance		−0.23**	Lee *et al.* (2008)
Area-weighted mean shape index		0.15**	Lee *et al.* (2008)
Mean shape index		−0.21**	Lee *et al.* (2008)
Cohesion		0.14*	Lee *et al.* (2008)
Shannon's diversity index	Preference scores (1= least preferred; 5= most preferred)	***0.58*****	Dramstad *et al.* (2006)
No. of land types		***0.53*****	Dramstad *et al.* (2006)
No. of patches		***0.45****	Dramstad *et al.* (2006)
Percent open area		***−0.45****	Dramstad *et al.* (2006)

Palmer (2004) investigated residents' perceptions of scenic quality in the Cape Cod community of Dennis, Massachusetts over a period of significant landscape change, and used landscape metrics to predict residents' perception of scenic value for each time period. The results indicated that landscape composition metrics were more closely related to scenic value than the configuration metrics (Table 3). Scenic value was most positively related to the relative amount of agricultural and related open lands, and the most intensive urban land uses were negatively associated with scenic value. From configuration metrics only edge density was positively related to scenic value. Lee *et al.* (2008), however, found that residents' neighbourhood satisfaction was more likely to be high when tree patches in neighbourhood environments were less fragmented, less isolated, and well connected (Table 3). Dramstad *et al.* (2006) also found that spatial configuration is related to people's landscape preferences, and these may therefore be suitable as indicators for the visual landscape (Table 3).

The embedding of the concept of valuable landscapes in legislation such as the European Landscape Convention (Council of Europe, 2004) has led to the need for an 'objective' assessment of these values and the potential impact of changes to them (Sang *et al.*, 2008). The visual characteristics of a landscape are some of the most widely experienced but also most difficult, and controversial (Walker, 1995), to define. Sang *et al.* (2008) investigated how well landscape metrics predict the results on preference from the Visulands Pan European Survey (http://www.esac.pt/visulands) and the implications of this for the role of preference metrics and visualisation methods in planning processes such as landscape character assessment. Furthermore, Fry *et al.* (2009) find that landscape metrics have a strong conceptual base in landscape ecological principles but for the visual aspects of landscapes this conceptual base is often missing and thus hindering progress in the development of indicators. Therefore they proposed hierarchical framework for establishing and strengthening links between theory and indicator application.

3.8 Management and planning

Landscape metrics are useful for the application of the concepts of landscape ecology to sustainable landscape planning (Botequilha Leitão and Ahern, 2002) and landscape monitoring (Herzog and Lausch, 1999). Lin *et al.* (2007) combined a land use change model, landscape metrics and a watershed hydrological model with an analysis of the impacts of future land use scenarios on land use pattern and hydrology for a landscape management plan. Landscape metrics also make it possible to detect potential areas for greenways (Colantonio Venturelli and Galli, 2006; Zhang and Wang, 2006), and assess habitat suitability (Holzkämper *et al.*, 2006; Kim and Pauleit, 2007) for landscape planning and management.

Landscape metrics can be useful for assessing soil erosion on large territories (Li, 2008) and help landscape managers to indicate how well landscapes function to retain, not "leak", vital system resources such as rainwater and soil (Ludwig *et al.*, 2002).

Agricultural activities have major effect on floral and faunal species richness of anthropogenic landscapes. As European Union is providing subsidies to farmers for environmentally friendly agricultural practices, there is an urgent need to assess the effectiveness of these subsides. Wrbka *et al.* (2008) investigated the agri-environmental measures in a parcel-wise manner and analyzed their effects on landscape values and biodiversity. They found that reduction of agrochemicals showed positive effects on biodiversity of vascular plants in grassland and birds in arable land and targeted measures that directly address threatened species were most effective, but had much less coverage. Wrbka *et al.* (2008) also concluded that agri-environmental measures are currently not targeted enough to effectively halt biodiversity losses. Therefore we also find that researchers should aim for more specific guidelines to evaluate different management schemes. For example, (Greenhill *et al.*, 2003) determined typical ranges of the metrics in environmentally sustainable localities for an extensive suburban area on the southwest edge of London using multispectral IKONOS-2 imagery. The spatial distributions of the metrics provide new insight into landscape structure, which can be exploited in land use planning and in the construction of empirical spatial planning heuristics for sustainable urban development. If researchers determine the critical values or ranges of the landscape metrics where landscape retains its identity or there is positive effect on biodiversity then landscape metrics can be extremely useful indicators for measuring the effectiveness of the management schemes.

4 Conclusions

The landscape metrics is one of the hot topics of modern landscape ecological research. However, there is a decreasing trend since 2005 of the papers published in this particular field in high-quality international scientific journals. It indicates that researchers and also practitioners have begun to use pattern metrics more often, skipping correlating ones and choosing only the most informative metrics that truly indicate some relationships between patterns and processes. Yet new metrics are being developed and this fact indicates that there are still some aspects of landscape pattern that existing metrics do not cover or there are problems with scale, interpretability etc. Nevertheless, one should not underestimate the role of landscape metrics in determining the relations between landscape pattern and process.

The majority of papers using landscape metrics/indices/indexes are dedicated to biodiversity and habitat analysis. Also, many articles analyze the relationship of landscape metrics with the evaluation of landscape pattern and changes therein. On the other hand, there are very few articles related to social aspects and landscape perception and therefore one large potential research field is uncovered. Likewise, a lot of research is needed in order to determine landscape metrics useful for landscape management and planning including specifying significant values and ranges of landscape metrics depending on the planning or management purpose.

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