Living Rev. Landscape Res., **5**, (2011), 3
http://www.livingreviews.org/lrlr-2011-3

LIVING REVIEWS in landscape research

Landscape Structure, Landscape Metrics and Biodiversity

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Accepted on 6 October 2011
Published on 4 November 2011

Abstract

This paper deals with the question of the role landscape metrics can play in the investigation, evaluation and monitoring of landscape structure, and which linkages between landscape structure and biodiversity are known. In the first part, the scientific state of the art is presented; in the second part, the meaning of landscape metrics for nature protection, landscape management and biodiversity monitoring is discussed. A number of studies indicate that such metrics on an aggregated, overall landscape level are quite appropriate to describe the state of biodiversity. On the other hand, gaps in the knowledge become apparent, and the results of such studies are strongly dependent on the scale of investigation and the underlying database. Nevertheless, the landscape structure approach seems to be expedient for management and planning at the landscape level.

Keywords: landscape mosaic, heterogeneity, landscape functions, biological diversity, landscape pattern, spatial planning, landscape management, nature conservation

Imprint / Terms of Use

Living Reviews in Landscape Research is a peer reviewed open access journal published by the Leibniz Centre for Agricultural Landscape Research (ZALF), Eberswalder Straße 84, 15374 Müncheberg, Germany. ISSN 1863-7329.

Because a *Living Reviews* article can evolve over time, we recommend to cite the article as follows:

> Ulrich Walz,
> "Landscape Structure, Landscape Metrics and Biodiversity",
> *Living Rev. Landscape Res.*, **5**, (2011), 3. [Online Article]: cited [<date>],
> http://www.livingreviews.org/lrlr-2011-3

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1 Introduction

The structure of a landscape, i.e., its composition and arrangement, and the resulting spatial relationships between its individual elements, can be described and quantified by means of landscape metrics. This instrument has been used for more than 20 years in Europe and North America in a variety of studies in the scientific and experimental area. They are now finding their way into such practical applications as assessment procedures for planning (Botequilha Leitão and Ahern, 2002) and monitoring (Wrbka, 2003; Heinz Center, 2008). The present review paper elucidates the role that landscape metrics can play, particularly in the collection of the relevant information, and in the evaluation and monitoring of biodiversity. The focus of the paper is laid on landscape metrics as a means to describe landscape structure and as indicators of biodiversity and the question of which aspects of biodiversity can be met by landscape metrics. Known fields of application in monitoring and landscape management are presented; the impediments encountered, too, are identified.

2 Definitions

First of all, some explanations of the key words of this article should be given. **Landscape structure** means the pattern of a landscape, which is determined by its type of use, but also by its structure, i.e. the size, shape, arrangement and distribution of individual landscape elements. For the delineation of these landscape elements, or so-called "patches", often land use or land cover units are used. In this context, "'land cover' refers to the physical surface characteristics of land (for example, the vegetation found there or the presence of built structures), while 'land use' describes the economic and social functions of that land." (Haines-Young, 2009, 179). Of course, other spatial elements can also be used, e.g. soil units, habitats or vegetation units from phytosociology.

The heterogeneity of landscapes – as a parameter of landscape structure – is connoted as the "quality or state of consisting of dissimilar elements, as with mixed habitats or cover types occurring on a landscape". It is the "opposite of homogeneity, in which elements are the same" (Turner *et al.*, 2003, 3).

As indices of landscape structure, **landscape metrics** can be used to describe the composition and spatial arrangement of a landscape. They can be applied at different levels to describe single landscape elements by such features as size, shape, number or for whole landscapes by describing the arrangement of landscape elements and the diversity of landscape. The reason for using these metrics in spatial analysis may be to record the structure of a landscape quantitatively on the basis of area, shape, edge lines, diversity and topology-descriptive mathematical ratios; to document for purposes of monitoring; or to make the relevant information available as input parameters for landscape ecological simulation models.

Overviews of the current discussions and the application of landscape metrics are given on the use of landscape metrics for landscape analysis with Geographic Information Systems (GIS) by Lang and Blaschke (2007), the application of landscape metrics in nature protection and landscape research by Blaschke (2000) and Uuemaa *et al.* (2009), on existing landscape metrics and software by McGarigal *et al.* (2002) and Walz (2006), and on landscape pattern and landscape indicators by Bolliger *et al.* (2007).

For a definition of **biodiversity** (or biological diversity), the Convention on Biological Diversity (1992) is often cited (United Nations, 1993): "For the purposes of this Convention . . . 'Biological diversity' means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems." Biodiversity thus comprises the fields of genetic diversity, species diversity (number of species in certain units of space) and diversity of habitats and ecosystems at the landscape level (see Blab *et al.*, 1995, 11, Figure 1). Thereby, each level is dependent on each other. The dynamics of natural processes, such as the changing distribution patterns of species and habitats in space and over time, are also part of biological diversity (Blab *et al.*, 1995, 11). At each level of biodiversity, three fundamental characteristics of biodiversity can be considered: composition, structure and function (Noss, 1990; Waldhardt and Otte, 2000). Composition describes the individuality and variety of elements, such as land use units or species within a region. Structure, by contrast, refers to the arrangement or the construction of units, the distribution of elements and their relationship to one another. Function, finally, comprises all processes, such as demographic trends, cycles of material or disturbances (Lipp, 2009, 37). Especially at the landscape level, composition and structure can be described by landscape metrics.

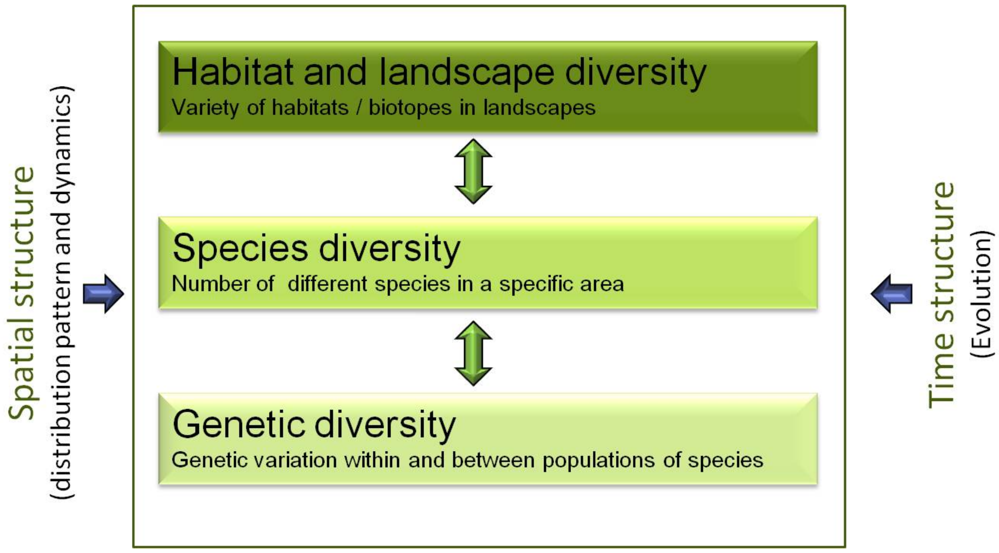

Figure 1: Levels of biological diversity. Adapted from Blab *et al.* (1995).

Biodiversity depends on geo-diversity, i.e., the variety of natural conditions, such as relief, soil characteristics and local climate, but in cultural landscapes also on the land use. Geo-diversity, biodiversity and land use diversity as a whole can be called "landscape or eco-diversity" (Jedicke, 2001, 60). Today, the anthropogenic influence in most regions is very high. A clear distinction between natural and cultural landscapes is virtually impossible. For this reason, it is important not only to consider the natural areas or landscape elements, but also the influence of man, for example, by investigating land use and land use structure.

3 Methods of landscape structure analysis

Use of Geographic Information Systems (GIS) is required to analyse landscape structure using landscape metrics. GIS is necessary due to the need to evaluate a large amount of spatial information (such as land use information, habitat types, soil types) and in order to overlay and intersect this information with other information, enabling the parameters of landscape structure to be calculated. In addition, spatial reference units (e.g., natural or administrative units or regular fishnets) are required. Only by overlaying georeferenced spatial data and computing partial complex mathematical formulas can landscape structures in large areas be analysed.

A number of specialised software programmes are now available for calculating landscape metrics. One of the first programmes to appear on the market was FRAGSTATS (McGarigal and Marks, 1995), followed by PatchAnalyst (Rempel, 2008) and V-LATE (Tiede).

As the data basis, land use data from official land use surveys or remote sensing data, especially for large areas (e.g., Groom *et al.*, 2006), are often used. One of the main problems in analysing landscape structure is that the landscape elements need to be delineated and defined, which may be extremely difficult and arbitrary in some types of landscape. In reality, it is often not easy to delineate a landscape element because sometimes no clear line distinguishes a landscape element from a neighbouring element. Some authors have proposed considering the landscape as gradients (McGarigal and Cushman, 2005; Bolliger *et al.*, 2007), e.g., the transition zones between patches. Indeed, in most studies, the delineation of landscape elements is a simplification of reality, which depends on data source, scale and, ultimately, the interpreter.

The thematic and geometric resolution influences the results of analyses using landscape metrics (Baldwin *et al.*, 2004; Castilla *et al.*, 2009; Mas *et al.*, 2010). It is crucial that the scale of investigation (Wiens, 1989, 386) and the spatial resolution of the data correspond to one another (Corry, 2005, 606). Fine-scale or multi-scale methods may be more informative than those based on only one, or very coarse, scales. For example, in a study by Lawler and Edwards (2002, 242), a coarse resolution of 30 m and higher seemed to be insufficient for statements about bird habitats. The need for multi-scale studies is also illustrated by the fact that studies of habitats often provide different results at different scales for the same species (Corry, 2005, 606). The decision which information on land use classes should be included in the landscape structure analysis (thematic resolution) is dependent on the aim of the investigation. The information depth of the data, such as land use/land cover, should meet the necessary habitat use or habitat types for the investigated species. Sometimes the similarity of types of landscape element is also important for biodiversity at the landscape scale.

Another simplification of reality is that, in most cases of landscape structure analysis, the underlying relief is not considered. In GIS analyses and calculations of landscape metrics, only planimetric areas and distances are calculated. With extreme reliefs in particular, this can lead to differing results from calculations with "real" areas and distances (Hoechstetter *et al.*, 2008; Jenness, 2004; Blaschke *et al.*, 2004; Dorner *et al.*, 2002).

These limitations should be borne in mind and viewed with caution when comparing results from different areas and studies. Care must be taken that the data sources, methods and scales are indeed comparable. The selection of landscape metrics as indicators must also ensure they reflect the real demands of the species under investigation (Dormann *et al.*, 2004, 70-71).

4 Relations between landscape structure and biodiversity – scientific state of the art

Biological diversity in all its dimensions and facets is always tied to habitats, which need a concrete areal section of the earth's surface for their existence. Biological diversity is therefore always defined for a certain reference area, and landscape structure is a key element for the understanding of species diversity. Spatial heterogeneity, as an expression of landscape structure, indicates the variability of the system's properties in spatial terms (Kolasa and Rollo, 1991; Li and Reynolds, 1995). Therefore it is regarded as essential for the explanation of the occurrence and distribution of species from the local to the global level (Ernoult *et al.*, 2003, 240). Against this background, an increasing number of studies analyse the relationship between landscape structure and biodiversity. The goal is to find variables for modelling the spatio-temporal distribution patterns of species and communities (see Bissonette, 1997; Dufour *et al.*, 2006; Schindler *et al.*, 2008, 503).

4.1 Landscape structure and diversity of species

It is often mentioned in very general terms that the spatial pattern of the landscape influences many ecologically relevant processes, e.g., the distribution of materials and nutrients or the persistence and movement of organisms (Turner, 1989, 189). But what connections between the type and structure of land cover and biodiversity can be found in the literature? An initial overview is given in Uuemaa *et al.* (2009, 8–11). Numerous studies have shown such relationships to be determinants of species diversity (Ricotta *et al.*, 2003, 373). In the following sections, examples from the literature of linkages and variables are given. These are considered important to the relationship between landscape structure and species diversity / patterns of species distribution.

Plants

Important preconditions for high biological diversity are the **abiotic site conditions** and the **geomorphology**. Habitats with spatially heterogeneous abiotic conditions provide a greater variety of potentially suitable niches for plant species as habitats with homogenous characteristics. Variations in physical structure (e.g., slope direction, soil structure) have proven to be an appropriate factor for the prediction of the richness, diversity and dominance of plant species (e.g., Hobbs, 1988; Lapin and Barnes, 1995; Burnett *et al.*, 1998; Nichols *et al.*, 1998; Honnay *et al.*, 2003, 241). For example, in studies by Burnett *et al.* in deciduous forests, the sites with high geomorphological heterogeneity were those with the highest plant diversity (Burnett *et al.*, 1998, 367–368). There, the variances in plant abundance and diversity were explained best by slope direction and the water balance. Because of the strong correlation of the abiotic variables and biological diversity, these factors can be used to predict relative levels of biological diversity (Burnett *et al.*, 1998, 368).

By contrast, in a landscape like the Central European cultural landscape, the composition and diversity of plant species depend on the **structure of use** affected by people. With respect to **area size**, Bastian and Haase (1992, 27) found that the relationship between the number of plant species and area size can be described with statistical assurance by means of a logarithmic function. With increasing surface area of shrubs, the proportion of typical forest species in the total number of species also increased (Bastian and Haase, 1992, 27).

The **shape of habitats** can affect the number of species, too. For a greater number of environmental transitions between irregularly shaped habitats, areas can generally include more plant species (Honnay *et al.*, 1999, 2003, 241–242). Therefore, shape complexity can be used to analyse land cover data as an index for species richness (O'Neill *et al.*, 1988; Miller *et al.*, 1997), which improves the accuracy of the prediction of plant richness. Geometric landscape complexity proved to be a sensitive indicator of plant richness, especially in agricultural landscapes (Moser *et al.*, 2002, 666).

In fragmented landscapes, the **distance** to viable habitats **(isolation)** also determines the composition and abundance of plant species (Grashof-Bokdam, 1997; Butaye *et al.*, 2001). Less isolated habitats are generally more species-rich because they can be easily settled. The constant influx of new individuals prevents local extinction due to demographic and environmental coincidences (Shaffer, 1981; Honnay *et al.*, 2003, 241).

An increase in the **degree of urbanisation** (increase in area proportions and sizes of settlements and green spaces, traffic density and shrubs structures) correlates in particular with an increase in the number of species of neophytes, but also with an increase in archaeophytes and indigenous species. The same is true for the increase in **border and seam structures** in the landscape, which create possibilities for settlement (Deutschewitz, 2001, 88). Some species are closely related to elements of landscape structure, such as edges, roads and certain land use types (Brosofske *et al.*, 1999, 212).

Also, in agricultural landscapes, **ecotones**, which are linear landscape structures between different habitat types, have significant benefits, mainly because they provide habitats after the harvest and for hibernation. Ecotones with high structural heterogeneity, such as forest fringes and hedgerows, provide an improvement, too, for regional biodiversity, as they do for the richness and diversity of beneficial organisms (Duelli, 1997, 82).

Natural **disturbances along streams**, the structure and variety of land use in floodplains and natural distribution mechanisms are linked to high biodiversity of indigenous species, but also promote the establishment and spread of neophytes and archaeophytes (Deutschewitz, 2001, 88).

These relationships can be made comprehensible by means of landscape metrics. Honnay *et al.* (2003, 248) were able to show that regional plant variety can be predicted satisfyingly on the basis of relatively simple landscape metrics.

Animals

The linkages between wildlife and landscape structure are similar. However, there are differences, in particular due to the mobility of animals. Thus, species with good ability to spread depend mainly on landscape composition, i.e., the proportion of their preferred habitat type. Landscape structure is less important for these mobile species (Visser and Wiegand, 2004, 59). By contrast, for species with poor dispersal ability, both landscape composition and landscape structure have an arbitrative influence on the frequency of the species. The effect of landscape structure can be reduced to a scale-dependent metric: the average frequency of suitable habitat in a species-specific distance (Visser and Wiegand, 2004, 59). Edge effects and distances between patches can influence the permeability of a landscape. For example, results by Romero (2007) show the dependence of the migration behaviour of beetles on landscape structure.

The process of **fragmentation** of landscapes, in the sense of the piece-meal conversion of a formerly contiguous habitat, usually primarily affects animals with relatively large territories – e.g., birds or large mammals. On the other hand, animals with limited mobility are separated into isolated populations more rapidly by such elements as roads or urban structures (Swenson and Franklin, 2000, 714). However, in science there is no consistent understanding of the term ***landscape fragmentation*** (Jaeger, 2002). Today, the term is increasingly used internationally as synonymous for all anthropogenic invasions of landscapes and habitats. By contrast, the German concept of *Zerschneidung* (lit.: cutting apart), which is usually translated as "fragmentation", emphasises the network of linear and areal artificial land use elements, such as roads and settlements. This is understood to be an active process which "cuts" spatial connections and interrupts functions. Such land use changes caused by the demand for land for settlement and landscape fragmentation are currently seen as a major cause of the continuing loss of biological diversity worldwide (SRU – Sachverständigenrat für Umweltfragen, 2005, 52). Several landscape metrics are now used for the measurement of landscape fragmentation through infrastructure (Walz and Schauer, 2009). The most widespread fragmentation metrics are the number and size of unfragmented areas with low traffic (UVR) (Lassen, 1979; Bundesamt für Naturschutz, 2008) and of effective mesh size (m_{eff}) (Jaeger, 2000).

In many cases, the direct loss of habitats or ecosystems is probably the superior predictor (Strand *et al.*, 2007, 147–148), even ahead of landscape fragmentation, because **habitat size and diversity** play an important part. Certain species prefer more diverse territories (greater number of patches, smaller size, more edges), as demonstrated by Fernández *et al.* (2007, 437), e.g., for the Iberian lynx or the ocelot (Jackson *et al.*, 2005, 733). For bats, relationships between patch size and patch density have been shown in forest areas. Thus, the species richness of bats was highest in partially deforested landscapes (Gorresen and Willig, 2004, 688). Bees also need specific habitat combinations that can be described using landscape metrics. This makes it possible to predict the potential diversity of bees (Bailey *et al.*, 2007, 470).

The **shape** of patches may play a role, too. It was shown for the ruffed grouse (*Bonasa umbellus*) that regularly shaped patches are preferred (Fearer and Stauffer, 2003, 109). Overall, it is clear that animals can react differently to habitat diversity. Different scales have to be taken into account. The identification of such scales remains a key objective in landscape ecology (Turner, 2005, 329).

Ecotones or edges, as transition zones, are often particularly rich in species. In studies of edge biotopes in the agricultural landscape of Saxony-Anhalt, species numbers were almost twice as high as those within the fields. The species composition and dominance of edge biotopes were very different from those in the fields. Introducing edge habitats to forests can also affect the fauna. In such cases, species richness may temporarily increase due to migration of specific edge species, but only at the expense of species of the forest interior. Therefore, birds can be useful as an ecological indicator (Noss, 1983, 702).

The environment of the habitats, i.e., the **context and surrounding landscape matrix**, plays an important part. For the management of grassland birds, for example, it is important to include quantity and context of the embedded habitats, i.e., the surrounding matrix as well as food resources (Hamer *et al.*, 2006, 581).

The **degree of disturbance** by landscape change and other factors of human influences in the surroundings have a significant impact on species richness. Thus, for the correlation of birds communities with road density and forest area, the distance to the nearest built-up area, the density of human settlement, and the degree of imperviousness were found to be significant factors (Sundell-Turner and Rodewald, 2008, 223).

Geomorphological diversity also emerged as a significant impact for the fauna. Due to the mobility of animals, however, it appears to be less limiting than it is to plants. However, many animal species depend on certain plant species (Burnett *et al.*, 1998, 368).

Habitat modelling

Landscape metrics are also used for habitat modelling of individual species or species groups, e.g., by Dormann *et al.* (2004); Fauth *et al.* (2000); Fernández *et al.* (2007); or Grillmayer (2000). For example, Steiner and Köhler (2002) were able to show the existence of a clear dependence of the species diversity on landscape structure in model experiments. With a decreasing degree of landscape heterogeneity in the model, both local and regional species diversity also decreased. The importance of considering space, habitat structure and landscape patterns is illustrated by Dormann *et al.* (2004, 70–71).

Results on linkages between landscape structure and species

In the literature analysed, the following properties of landscape patterns that have a positive effect on biodiversity were mentioned:

- a high proportion of semi-natural biotope types;
- large areas;
- high biotope diversity;
- high structural diversity;
- high connectivity;
- high geomorphological diversity.

However, some of these properties are mutually exclusive (for example, high structural diversity and large surface area of individual patches) (Zebisch, 2004, 27). In addition, properties that are beneficial for a single species can be definitely disadvantageous for another. Depending on the specific characteristics of the organisms, and depending on the spatial scale, the effect of landscape structure on the viability of the organisms can vary greatly (Visser and Wiegand, 2004, 62). No clear assignment to a quality (e.g., "high structural diversity is desirable") is possible (Zebisch, 2004, 27).

Furthermore, land use in and of itself may be not sufficient to predict species richness and distribution. In studies by Cardillo *et al.* (1999, 432–433), it explained less than half of the species richness and occurrence. Therefore, a set of variables should be used, which includes the land use in conjunction with such other landscape characteristics as habitat structure, composition of vegetation and soil characteristics. However, particularly in cultural landscapes, the influence of land use on patterns of species distribution could be greater than the influence of the original and natural landscape parameters. For investigations at the regional level, land use can be crucial for species composition and richness (Deutschewitz, 2001, 78).

All in all, Duelli (1997, 88) and many other authors (e.g., Bailey *et al.*, 2007; Ortega *et al.*, 2004) hold that the evaluation of patterns of the landscape mosaic can serve as a substitute for the recording of regional biological diversity, as a form of knowledge-based assessment. In general, broad environmental diversity leads to high species diversity (Ricotta *et al.*, 2003, 373). Size, surface area and spatial relationships between patches thereby play an important role (Dale *et al.*, 2000, 639). In accordance with the "mosaic" concept, regional biodiversity depends mainly on such structural parameters as habitat diversity or landscape heterogeneity, and the dynamics of meta-communities (Duelli, 1997, 81). As relevant measures, he mentions the diversity and heterogeneity of habitats, and the portions of natural and semi-natural habitats (see Table 2). Thereby it is assumed that such areas rather have a great diversity of habitats due to their size and therefore also greater biological diversity (Dramstad *et al.*, 1996; Botequilha Leitão *et al.*, 2006, 11). Also Honnay *et al.* (2003, 248) come to the conclusion that landscape metrics appear to be suitable to predict biotic processes. Therefore, according to Duelli (1997), the assessment of biodiversity at a higher, integrated level can be based on landscape parameters.

4.2 Landscape metrics for monitoring biodiversity

Since the complexity of biological diversity is difficult to describe, most ecologists have taken the practical way to research and to identify the biological diversity at the species level (Feest *et al.*, 2010, 1078). Therefore, the selection of structural indicators was undertaken specific to the habitat type or tested species studied. Local data on species diversity can provide information as a proxy for regional biodiversity. An investigation of flora and fauna is, however, typically not comprehensive, but rather generally covers only a small proportion of all species. The clear determination of the diversity of various taxonomic groups requires very high efforts, knowledge and money. Hence a good substitute is needed. By combination of indicator species and groups with spatial environmental data (Heino, 2010, 112) and landscape structure, the power and deputy information can be increased and expanded geographically (Faith *et al.*, 2003, 317).

Which parameters are suitable for the characterisation and description of landscape diversity, and can therefore be used as an indicator for biodiversity? In principle, a few indicators are sufficient to ascertain landscape patterns (Riitters *et al.*, 1995; Cain *et al.*, 1997; Lausch and Herzog, 2002, 13). However, biodiversity cannot be described only by a simple number, as there are various qualities of spatial patterns (Tischendorf, 2001; McAlpine and Eyre, 2002; Neel *et al.*, 2004). A selection of indices representing various aspects of biodiversity is much more informative and capable of interpretation (Feest *et al.*, 2010, 1080). However, the use of many highly correlated indices provides no new information, and leads to problems in interpreting the results (Jones *et al.*, 2001; Li and Wu, 2004). For this reason, mutually independent indices should be selected (Schindler *et al.*, 2008, 503).

By means of indicators in monitoring, dramatic changes in values can be detected and serve as an early warning, and as an indication of the necessity for deeper investigation, even if no specific limit values can be defined (Bock *et al.*, 2005, 336). Landscape metrics may also be used to identify hot spots of biodiversity in rural Europe. Although they do not replace direct measurement of species biodiversity, these surveys can help make them more effective and less costly (Bailey *et al.*, 2007, 472). Often mentioned as possible parameters are distribution, abundance and area proportions of land use types (e.g., Schüpbach *et al.*, 1999, 212). Other aspects are the richness (number of land use types) and the uniformity of the landscape (Nagendra, 2002, 178).

Indicator systems

Due to the importance of landscape structure for biodiversity, there are currently a number of activities to develop indicators for monitoring biodiversity at the level of ecosystems or landscapes (EEA, 2007, 2005; BMU, 2007). Ideally, the same biodiversity indicators should be used at the global, national, regional and local level. However, this is not possible for practical reasons. The specific requirements for monitoring and for financial resources vary from country to country. Many monitoring systems have their own historical developments and even the methods for the same indicator differ from place to place (Strand *et al.*, 2007, 17).

In Germany there are a number of indicator systems for monitoring land use change and biodiversity (see also Table 1):

- Indicators of Sustainable Development in Germany (Federal Government, 2002; Federal Statistical Office, 2010).
- The Core Environmental Indicator System of the German Federal Environmental Agency (Umweltbundesamt, 2007).
- Sustainable development indicators of the federal and state governments (LIKI indicators) (LIKI, 2011).
- Indicators of the national strategy on biological diversity (BMU, 2007).

However, there is still no complete and interoperable, nationwide monitoring system for biodiversity at the federal level. An earlier approach that could have served that purpose was so-called "ecological area sampling" *(ökologische Flächenstichprobe)* (Dröschmeister, 2001), whereby indicators of cultural influence and intensity of use, rarity or threat of habitats, and structural diversity were to be surveyed at the landscape and habitat levels in defined test areas (Hoffmann-Kroll *et al.*, 1995, 595, see also Table 2). Complementarily, the Shannon Diversity and Evenness and the Fractal Dimension were proposed (Back *et al.*, 1996, 21–33). Unfortunately, this concept was never fully implemented nationwide.

Stachow (1995) has proposed a system of indicators for *monitoring agricultural landscape change*. As a complex of factors important for the formation of communities, he mentions the natural conditions of the site (terrain, climate and soil type) and the type and intensity of human impact. The indicator system, therefore, is composed of three landscape indicators: the physical or natural diversity of landscapes, the diversity of land use, and the naturalness of land use. He starts from the assumption that increasing naturally the animation of the terrain is associated with an increase in various site conditions. Based on the criteria "length of contour lines in m/ha per community", "height difference between the highest and lowest contour lines in the community", and "river length and area of surface waters", he arrives at statements regarding natural spatial diversity (Bork *et al.*, 1995, 290). The variety of land use is identified based on the diversity of major land use types, length of forest fringes, field sizes and variety of crops within agricultural areas. The degree of naturalness is derived from natural conditions of sites, and the situation regarding crops (Bork *et al.*, 1995, 292–293).

Table 1: Selected indicators reliable to biodiversity and land use change in Germany and their use in the different indicator systems

Indicator set / Institution	**Sustainable development in Germany**	**Core environmental indicators**	**Indicators of the German states**	**National strategy on biodiversity**
Dissection of the landscape (Landscape fragmentation)		x	x	x
Urban sprawl		x		x
Natura 2000 area designations		x	x	x
Size of strictly protected areas		x	x	x
Land use: Increase in land used for housing and transport	x	x	x	x
Recreation areas			x	
Species diversity and landscape quality	x	x	x	x

A number of authors have emphasized the importance of *landscape diversity* as an indicator of species diversity in monitoring agricultural landscapes. In addition to land use practices, especially habitat heterogeneity plays an important part. It has often been noted that even using a few landscape and land use parameters, inferences can be made regarding large-scale patterns of species diversity (Benton *et al.*, 2003; Tews *et al.*, 2004; Billeter *et al.*, 2008, 141–142).

In Germany, the avifauna is used as a *nation-wide indicator of biological diversity* at the species level (BMU, 2007; Sukopp, 2007). This indicator is contained both in the national set of sustainability indicators (Federal Government, 2002) and in the set of indicators for the national biodiversity strategy. For the calculation of the indicator, trends in the stocks of 59 selected bird species are recorded, representing the most important landscape and habitat types and land uses in Germany (agricultural land, forests, settlements, inland waters, coasts and seas, and the Alps). The size of the stocks should directly reflect the suitability of the landscape as a habitat for selected bird species. However, the condition of the landscape (structure and intensity of uses) is not registered.

In the case of *landscape fragmentation by infrastructure*, nationwide regular monitoring takes place. The German Federal Agency for Nature Conservation (BfN) regularly determines unfragmented open spaces equal to or larger than 100 sq. km. Also, “effective mesh size” m_{eff} (see above) has in recent years been applied in several German states, including Baden-Wurttemberg and Hesse, and is now established as a core indicator in the environmental system of indicators (LIKI, 2011).

At the European level, the European Environment Agency already in 2000 submitted a report on *Landscape Diversity in the EU* (EEA, 2000), in which landscape indicators for fragmentation, diversity or heterogeneity, and spatial arrangement and organisation of landscapes were used. The landscape metrics applied were: Patch Density (PD), Edge Density (ED), Perimeter/Area

Table 2: Indicators of quality of landscape structure in the framework of spatial ecological sampling (Dierßen and Hoffmann-Kroll, 2004, 291–293).

Superordinate issue	**Special issue**	**Indicator**
Use intensity	Naturalness / hemeroby	Surface areas of natural and semi-natural habitat types [in %]
	Degree of sealing	Proportion of sealed surface [in %]
	Erosion risk caused by water, depletion of arable soil	Proportional area of arable land, viticulture and intensive woody plants with slope > 9%
	Fragmentation and isolation of habitats	Total length of all roads (5 m wide) outside of settlements [in m/sq. km]
Structural diversity	Habitat diversity / diversity of living conditions	Number of non-technical habitat types per sq. km
	Monotony of living conditions	Average size of parcel of arable land and vineyards [in ha]
	Density of linear refuges and wildlife dispersion axis	Length of linear elements/ edge structures (hedges, forest belts, tree rows, avenues, seams) per sq. km
	Density of small habitats as refuges and dispersal centres for wild species	Number of small habitats (< 400 sq. m) per sq. km (tarns, ponds, springs, rocks, trees, individual trees, small trees, etc.)
	Density of small-scale stepping stones and network structures for species with low range of action	Mean number of quadrants per sq. km, in which structural elements occur
	Diversity of selected species groups	Average number of bird or butterfly species per sq. km
Rarity / threat	Occurrence of rare and endangered habitats of wildlife species	Percentage of endangered habitat types (according to Red List or Habitat Directive) [in %]

Ratio (PAR), Number of Classes (NC), Shannon's Diversity Index (SHDI), the Interspersion and Juxtaposition Index (IJI), and the Land Cover Diversity Index (LCDI).

As part of the EU project *SPIN (Spatial Indicators for European Nature Conservation)* (Bock *et al.*, 2005), the potential of landscape metrics for pan-European nature conservation was explored, especially for the Natura 2000 network. Thereby, landscape metrics were applied, e.g., for the determination of the size of the ecologically effective protected areas. For this purpose, indices such as TCA/TCCA (total core area and total class core area), NCA (number of core areas) and CAI use (core area index) were used.

In a joint project for *Cultural Landscape Research in Austria*, landscape metrics were calculated nationwide (Wrbka, 2003). They have been used, for example, in the fields of landscape composition, habitat area, landscape configuration, ecological functions, habitat fragmentation, diversity and anthropogenic influence. For *biodiversity monitoring in South Tyrol*, five indicators were selected by experts to measure both heterogeneity of landscape structure and human impact (Tasser *et al.*, 2008, 208). These include an index of landscape diversity (EEA, 2000), effective mesh size (Moser *et al.*, 2007), hemeroby (Steinhardt *et al.*, 1999), naturalness of near-river areas (adapted from Xiang, 1996) and agricultural intensity (UNEP, 2001). Tasser *et al.* (2008, 208) expanded this set by two indicators of species diversity: the area-weighted richness of vascular plants, and the frequency-weighted absolute species richness of vascular plants.

In the *United States*, the Heinz Center developed *landscape indicators*, of which eight refer to the landscape structure (Heinz Center, 2008). They are to be used to identify large-scale landscape patterns and human-induced landscape changes at the national level.

Metrics for monitoring

The monitoring of biodiversity is carried out almost solely at the level of species diversity, primarily on the basis of species richness, mostly using surrogate species or groups (especially birds and vascular plants). In the last few years, however, doubts as to the suitability of species or species groups for the estimation of biodiversity have increased. The criticism has concerned, in particular, conclusions drawn from the recording of species regarding the diversity of organisms of other taxa, or at other scales (spatial requirements etc.).

As a result, the focus has been directed towards the importance of landscape diversity for the expression of biological diversity. Increasingly, approaches and indicators for this level of biodiversity are being developed, especially for landscape diversity in agricultural and rural landscapes. It should be noted, however, that despite the presence of previous approaches, indicators of landscape and environmental diversity are not included in the indicator system of the United Nations, or in the German National Biodiversity Strategy. Here, there is a clear need to catch up.

Reference is often made to the potentials of remote sensing for cost-effective collection and presentation of landscape diversity. In particular, due to sophisticated sensor technology and resolution, as well as better availability of data, remote sensing, in combination with climate and environmental data, could lead to a more precise characterisation of landscape diversity, and thus a better assessment of species diversity.

Several examples from the great variety of landscape metrics found in the literature analysed have been compiled; these are repeatedly mentioned, or stand out as particularly significant (Table 3).

It is obvious that landscape metrics must always be selected for different tasks or problems, and in accordance with the available resources. A single index, or always the same set of indices, is not automatically appropriate for all study objects. Similarly, because of their complexity, a combination of indices should generally be preferred to individual indices for the estimation of biodiversity.

Table 3: Important landscape metrics in the field of biodiversity

Function	Index	Source
Prediction and assessment of biodiversity in landscape mosaics of the agricultural landscape	(1) habitat diversity (number of habitat types per unit area) (2) habitat heterogeneity (number of habitat patches, lengths of ecotones per landscape unit) (3) portions of natural, semi-natural and intensive land used	(Duelli, 1997, 88)
Prediction of biodiversity	Surface area of semi-natural ecosystems Patch distribution, edge and patch density	(Dramstad *et al.*, 1996; Botequilha Leitão *et al.*, 2006, 11) (Bailey *et al.*, 2007, 466–467)
Prediction of species diversity	Patch Density PD, Largest Patch Index LPI, Simpson's Diversity Index SIDI, Proximity PROXMN, Patch Richness PR, Edge density ED, Euclidean Nearest Neighbour ENNCV, Circumscribing Circle: CIRCMN Number of species, population sizes, number of viable populations and habitat area Landscape diversity, intensity of agricultural use, frequency weighted absolute species richness of vascular plants	(Bailey *et al.*, 2007, 466–467) (Strand *et al.*, 2007, 121) (Tasser *et al.*, 2008, 219)
Planning of biotope networks	Proximity Index (allows assessment of individual patches depending on functional connection with surrounding habitats) Density of landscape elements, indices of connectivity/ isolation	(Kiel and Albrecht, 2004, 331) (Baguette and Van Dyck, 2007, 1125–1126)
Assessment of protected areas, habitat requirements of species of the core areas and edges	Total Core Area TCA, Total Class Core Area TCCA, Number of Core Areas NCA, Core Area Index CAI, Cority	(Bock *et al.*, 2005)
Landscape fragmentation	Effective mesh size Area of unfragmented open spaces	(Jaeger, 2000) (Lassen, 1979; Bundesamt für Naturschutz, 2008)
Quantification of the floristic diversity (habitat function)	Shannon Diversity SHDI, Number of different classes and their distribution	(Herbst *et al.*, 2007)
Smallness, shape richness as well as structuredness of a landscape (natural spatial diversity)	Edge density ED, Density of patch boundaries or linear elements in a landscape Length of contour lines per area, elevation difference between highest and lowest point, river length and area of surface waters	(Herbst *et al.*, 2007) (Stachow, 1995)
Diversity of land use	Diversity of main land use types, length of forest edges, field sizes	(Stachow, 1995)
Floristic species richness (general)	Distance (isolation) to usable habitat, largest patch index LPI, patch size coefficient of variation PSCV	(Grashof-Bokdam, 1997; Butaye *et al.*, 2001) (Banko *et al.*, 2000, 28)
Floristic species richness (in natural ecosystems)	Topographic and edaphic variables, in particular slope direction and water balance Shape complexity of the habitats	(Burnett *et al.*, 1998, 368) (Honnay *et al.*, 2003, 241–242)
Floristic species richness (in landscapes)	Surface area of land use, Geometric landscape complexity, Number of Shape Characterizing Points NSCP Length of edges	(Bastian and Haase, 1992, 27) (Moser *et al.*, 2002, 666) (Bastian and Haase, 1992, 27)
Faunal species richness	Road density, forested area, distance to nearest built-up area, density of human settlements, degree of soil imperviousness	(Sundell-Turner and Rodewald, 2008, 223)

Limitations

Büchs *et al.* (2003) summarise limitations which occur in relation to the use of indicators for biodiversity monitoring. First, it must be noted that there is no indicator for biodiversity as a whole. Every aspect of biodiversity also requires its own indicator with very specific and well-defined characteristics, with agreed-upon definitions for their use (Tasser *et al.*, 2008, 205). Furthermore, the classification of land use and habitat type mapping must be considered precisely. Default typifications may not necessarily be suitable for a specific question. Often, visually delimitable units are equated with functional structures and habitats (Filip *et al.*, 2008, 534–535).

The indices used must also be questioned. In particular, the Shannon Index is used almost as a "standard" for large-scale landscape analysis (Filip *et al.*, 2008, 536). However, it does not reflect the spatial distribution of classes, although this is crucial for the diversity of a landscape. "Thus, it is irrelevant to the result value of the index whether the landscape elements present a large area or a mosaic, even though this factor should be crucial for the diversity of a landscape." (Filip *et al.*, 2008, 536). Moreover, even at the species level, the Shannon or the Simpson index is generally considered as not useful for large-scale monitoring of the integrity of biological diversity (Lamb *et al.*, 2009, 439). Another problem, not only in the field of biodiversity, is that the selection of indicators is often driven by the availability of information. However, with respect to biodiversity, this can lead to delusive or adverse results (Failing and Gregory, 2003, 129).

A review of the literature makes it clear that a wide variety of indicators and systems is now available which are usually hardly comparable to one another. Especially in the field of sectoral indicators, a large number of other systems can be expected, which – and this seems to be an underlying trend – have been developed and used relatively independently of one another (Müller and Wiggering, 2004, 122).

5 Conservation and management issues – landscape metrics for spatial planning and nature protection

As shown above, the type of land use and the pattern of the landscape, the matrix, and also the arrangement of individual patches and their relative positions are crucial for the conservation of biological diversity. Land use changes in future will have one of the biggest effects on biodiversity, beside climate change (Sala *et al.*, 2000). The management of land use patterns is therefore of great importance. Even in 1979, Haber wrote: "Spatial diversity should be accorded great importance in the planning process, as it identified the arrangement or 'mosaic' (pattern) of different, but similar spatial units or cells in a landscape (γ-diversity)" (Haber, 1979, 21). As an overarching approach to planning, Forman (1995, 139) and others (Forman and Godron, 1986; Franklin and Forman, 1987; Turner, 1989) have suggested a so-called "aggregate-with-outliers" model. This means that areas used by humans should be aggregated as closely as possible, while small natural patches and corridors through developed areas are preserved. At the borders of the remaining large natural areas in the surroundings, human-used areas should be arranged as ever smaller and more distant islands. In their opinion, this model increases genetic diversity, provides a distribution of risk of strong interferences, and has other environmental benefits (Forman, 1995, 139–140). However, in already highly developed regions of the world, where nearly every place is subject to human use, such a model is hardly suitable. Therefore, Haber (2008, 95) proposes a land use pattern as slender and diverse as possible. In his opinion, this is the only promising approach for maintaining biodiversity, since land use change – along with climate change, with which it interacts – will have the greatest future impact on biodiversity (Haber, 2008, 95). Hence, he argues, it is necessary to reverse the homogenisation of land use, at least partially (Haber, 2003, 37). The goal of his **concept of differentiated land use** is to implement the objectives of nature and landscape conservation area-wide (Haber, 1989, 21). It provides that:

1. environmentally harmful, intensive land use not take 100% of the surface within a spatial unit, but should keep sufficient space available for relieving or buffering uses (10 – 15%);

2. to avoid large, uniform surfaces, the prevailing land use be diversified in itself; this should apply both to agricultural land and to urban areas;

3. in an intensively used unit, at least 10% of the area be kept in, or developed to a "nature-emphasized" state, as is possible with netlike distribution.

The issues raised under 1 and 3 could be partially identical, or overlap, but there are different objectives (Haber, 1998, 60). Other authors have adopted this concept, e.g., Buchwald (1982, Figure 2). He assigned protection categories to different landscape elements.

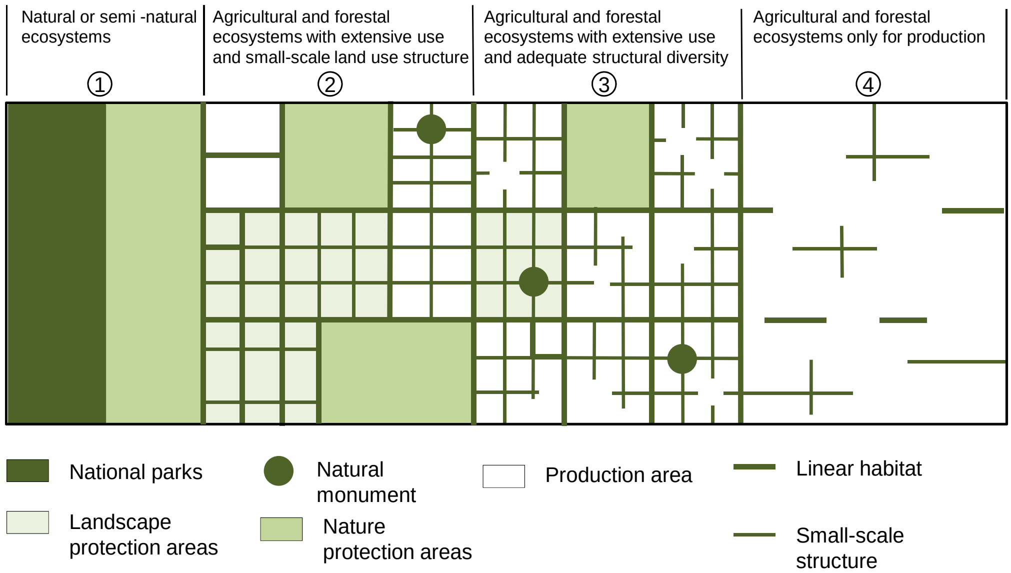

Figure 2: Differentiated agricultural land use. Adapted from Buchwald (1982, 103). In category 3, measures for structural enrichment are necessary.

This approach is also supported by the **concept of a tiered target system of nature protection** at 100% of the area (Plachter, 1991). There, Erz (1980) distinguishes four stages of the influence of nature conservation, ranging from strict nature reserves to extensively used areas and land which could be opened for additional intensive land use. On the latter, however, a minimum diversity of habitat conservation should be preserved by accompanying measures, or restored.

All these concepts emphasise the need to integrate the entire area of the landscape into the effort to maintain biodiversity. In this sense, dynamic conservation and development strategies for the cultural landscape must be found. More attention should be paid to ecosystem-specific development processes (succession) and spatial-functional aspects, as they play a key role, particularly for animals. Nevertheless, the designation of protected areas is evidently still necessary. They are included in the above concepts as a system of "core areas" for the protection of hard-to-renew ecosystems, i.e., those with long development periods, and to preserve severely threatened elements of nature. But it is absolutely necessary to include the surrounding landscape. This means that there is not only a need for a large-scale ecological network (see below) outside of the core areas, but also for the preservation of a minimum share of small-scale structures. For example, in agricultural areas, field edge structures are particularly important as habitats for the preservation of biodiversity, both between the fields towards neighbouring areas with other land use types (Hietala-Koivu *et al.*, 2004, 75). "A minimum of border structures amounting to at least 1 – 2% of the total agricultural land area can be justified on the basis of the data in the literature." (Knickel *et al.*, 2001, 46). Also, the German Federal Nature Conservation Act (BNatschG, 2009) stipulates a minimum percentage of such elements (§5 (2) and §20 (6)). One example is provided by the landscape framework plan in Mecklenburg-Western Pomerania, where regional minimum densities of landscape elements are defined (Müller *et al.*, 2008). Using a GIS based on available digital data, regional densities of structures were determined and objectives for regional minimum densities per spatial unit were quantified. For approximately one third of the municipalities, an urgent need for the enrichment of landscape elements was ascertained.

Conservation of nature

What do the findings from these various studies mean for nature conservation? First, it is clear that the landscape level requires much more attention. Understanding the importance of the landscape matrix is important for the conservation of biological diversity. A variety of studies have shown that the protection of the widest possible diversity at the landscape level and a corresponding control of the development of the landscape matrix is more effective than the protection of individual species and habitats (Franklin, 1993). At the species level, however, it is difficult to develop general conservation strategies while managing a variety of species, as different demands on the vegetation or on landscape features and territorial claims often lead to conflicting objectives (Rey Benayas and de la Montaña, 2003, 365; Howell *et al.*, 2000, 559). Against this background, there is a growing consensus that the landscape level is the most important level for the management of biodiversity. Conservation strategies must therefore be implemented at this scale to be successful (With, 2005, 240).

In a system of graded protection intensities of the entire landscape, protected areas certified as "core areas" are still important, but these should be designed to be significantly larger than is currently the case. So far, only a few reach the threshold of effective habitat size (Wiersma *et al.*, 2004, 783; Schmitt, 2004, 94; Kaule and Henle, 1991, 17). Particularly in relation to possible changes that may result from climate change, the goal of protected areas should be to maintain as high as possible a level of ecosystem diversity, with a maximum of ecological gradients, and thus maximum biodiversity (Swenson and Franklin, 2000, 714; Juutinen *et al.*, 2008, 3750–3751). The effectiveness of protected areas for the conservation of biological diversity is, however, affected not only by size but also, and essentially, by the landscape matrix of interdependent connectivity, and by human activity in the surrounding area (Franklin, 1993, 202; Wiersma *et al.*, 2004, 773; With, 2005, 240). Therefore, for the designation and management of protected areas, such factors at the landscape level as land use types and intensities, or landscape and habitat change in relation to the population density in and around the protected area, should be considered. In the surrounding landscape matrix, small and medium-sized areas located close together are needed (Franklin, 1993, 203). This it is not achievable only with protected areas, but must be considered in the context of the management of traditional agricultural and forestry systems outside of protected areas (Rey Benayas and de la Montaña, 2003, 366).

Opinions differ somewhat with respect to the importance of protecting natural spatial diversity. Although it is often argued that the protection of geomorphological heterogeneity could be an efficient strategy for the preservation of existing and potential biodiversity, it has been shown that this factor is closely linked to biodiversity in discontinuous landscapes (Nichols *et al.*, 1998, 378). Especially in relation to long-term environmental change (e.g. climate change), landscapes with high geomorphological heterogeneity are considered important, since they have the potential for accommodating many plant communities, despite changing species composition (Burnett *et al.*, 1998, 369). However, other voices warn against limiting efforts in protection of biodiversity only to achieving maximum possible landscape heterogeneity, as this would neglect the needs of specialised or endangered species. The high diversity of species in a heterogeneous landscape, it is argued, largely reflects the large number of generalists, which is then promoted by diversity-enhancing measures (Atauri and de Lucio, 2001, 157).

The different goals of protection of biodiversity can lead to conflicts with very real policy implications. Examples are the maintenance of ecological services, consideration of ethical principles, protection of single target species (e.g., "charismatic" large animals), the avoidance of aesthetic loss, or the protection and improvement of social and economic values. To address these problems, the goals must be described in detail, and matching indicators defined (Failing and Gregory, 2003, 123). For this purpose, specific landscape metrics can be applied to define minimum equipment numbers of the landscape. Examples include the Nature Protection Act in Germany (BNatschG, 2009) and state laws which demand the determination of structural minimum densities of landscape elements (see above), or, related to this, restrictions on the use of agricultural pesticides if minimum standards are not achieved (Enzian and Gutsche, 2004).

Biotope networks

One of the points of departure for the design of ecological networks is the assumption that the connection between landscape elements for the conservation of biological diversity can be at least as important as their size. Landscape structures that support the connectivity of species, biological communities and ecological processes are therefore a key element of conservation in a human-altered environment (Bennett, 2003, 8). The importance of wild animal migration corridors for the protection and management of biodiversity is widely known (Hargrove *et al.*, 2005, 361). Landscape elements in the open countryside can contribute effectively to the conservation of biodiversity as habitat islands if they are interconnected by corridors (Ahern, 1991, 139). For example, it was pointed out that connecting elements such as forest corridors or small forest patches serving as stepping stones can reinforce the distribution of species in the forest interior. The spread between the individual elements (patches) is crucial for the prevention of genetic stagnation in small populations (Noss, 1983, 703–704).

Again, however, the entire landscape matrix plays a significant role. Efforts to improve the connectivity of fragmented landscapes often focus on the remnants of natural and semi-natural habitats, and the distribution of stepping stones and corridors. However, it would often be more practical, and perhaps more effective, to reduce the virtual isolation of fragments by changing management practices in the surrounding matrix, e.g., by laying out corridor or stepping stone habitats (Ricketts, 2001, 97). Such networking is not necessary for all types, or in every case. Self-pollinating plant species have done without genetic exchange for eons. Studies by Öckinger and Smith (2008, 27) on the spread of insects also show that corridors do not necessarily have a positive effect, but that the quality of the surrounding matrix plays an important role. Even highly propagating species are relatively independent of such networking elements, as shown above.

Landscape metrics have been used to design ecological networks for quite some time. For example, indicators such as the density of landscapes elements, or metrics on connectivity or isolation, need to be stated for the configuration of landscapes. Baguette and Van Dyck (2007, 1125–1126) show that even simple measures can be beneficial landscape tools for the assessment of landscape connectivity. Nevertheless, they advocate cautious use in generalisation of the relationship between landscapes and species (Baguette and Van Dyck, 2007, 1125–1126). Kiel and Albrecht (2004, 331) recommend especially the proximity index for habitat network design, as it allows an assessment of individual areas in terms of functional integration with the living spaces of the surroundings.

Metrics in planning and nature protection

The successful protection of biodiversity requires the preservation of adequate habitats and ecosystem functioning in the context of the entire landscape complex at various spatial and temporal scales. Particularly in light of future land use changes – which will increase further – and expected climate change, landscapes with high geomorphological heterogeneity are considered important. Therefore, in planning and nature conservation, the landscape level needs much more attention than has been the case to date. An understanding of the importance of the landscape matrix and an appropriate management are important for maintaining diversity.

Protected areas should still be included in the strategy; however, they should be designated as much larger areas than before. Above all, more emphasis should be placed on their contribution to ecosystem diversity and thus a maximum of possible (potential) species diversity. The selection of protected areas, therefore, must not only focus on endangered species.

Outside of protected areas, the management of traditional agricultural and forestry systems remains a key element of nature conservation. The consideration of the entire landscape matrix should also include the preservation or development of a functioning mosaic of interconnected habitats as an ecological network associated with areas of intermediate intensity cultivation (agriculture, settlement, etc.), with a minimum number or density of small-scale, semi-natural landscape elements.

In this area, landscape metrics can help improve the theoretical foundation of the methods of landscape planning and their practical application, with the goal of sustainability (Botequilha Leitão and Ahern, 2002, 65). Examples of the use of landscape metrics in spatial planning can be found in landscape planning, in the design of ecological networks and in nature conservation. Landscape metrics can thus be used for the selection of protected areas (Sundell-Turner and Rodewald, 2008; Harrison and Fahrig, 1995), the evaluation of the landscape (Botequilha Leitão *et al.*, 2006; Herbst, 2007), or the analysis of equipment deficiencies of the landscape (Müller *et al.*, 2008) (see below). For example, Herbst *et al.* (2007, 236) examined landscape metrics for usefulness as an assessment tool in strategic landscape planning. In the range of species and communities, particularly the measures Shannon-Diversity and Edge Density were found to be useful.

6 Conclusions

Due to increasing demand and intensification of land use by humans, land use changes are expected to be the most significant driver of change in biological diversity in future (Sala *et al.*, 2000, 1772). Against this background, it seems all the more important to explore the relationships between land use structure and biological diversity, and to understand the consequences of different landscape patterns for the composition and diversity of plant and animal species. On this basis, alternatives for the design of the landscape can – and must – be developed (Brosofske *et al.*, 1999, 214).

In the context of biodiversity, landscape metrics can be used to assess landscape patterns, to define the minimum equipment, to carry out isolation or connectivity analysis and to recognise and monitor the results in changing landscapes. Moreover, landscape metrics have come to play a considerable role in the analysis and assessment of biodiversity, especially in local studies of species distribution and modelling, analysing and characterising the diversity of landscapes (as part of biodiversity), and for monitoring. It can be stated that:

- Landscape metrics are applied in a variety of local studies and research projects. Only a few indices are used constantly in different studies. Thus, there is a lack of comparability of studies and problems in the formation of general statements.
- Landscape metrics are already used in monitoring, but there is no "standard set" of landscape metrics which is frequently used.

- Usually very simple measures are used, especially for planning purposes, because they are more demonstrative and more accessible to the public.
- In studies a large number of numerical values are often generated, but it should be kept in mind that many landscape metrics are highly correlated.
- Usually temporal dynamics are not considered, or not sufficiently considered. The ecological significance of a measured pattern is difficult to assess without an understanding of the historical variability of that pattern.
- Vertical complexity is too little considered. However, it can be important for habitat modelling (e.g., for birds). Some developments are currently in progress (McGarigal and Cushman, 2005; Hoechstetter, 2009; Hoechstetter *et al.*, 2011), but further developments on ecological transitions and vertical structures appear necessary.
- A comprehensive overall view on the state of research is lacking.

Often, one finds only very general statements on the relationship between landscape structure and biological diversity. Generally, there is still a deficit in converting findings about individual species to general knowledge about the relationship between landscape structure and biodiversity (Turner, 2005, 331). The evaluation and prediction of species richness in complex landscapes remains a problem, because there is no simple scaling function of species diversity in a heterogeneous environment (Wagner and Edwards, 2001, 121). At the species level, it is also difficult to postulate a general correlation between biodiversity and landscape parameters (Brotons and Rosell, 2001). Hence, for certain species, only land use is crucial; for others, the landscape structure in terms of relationships to neighbouring land uses or edge lengths of hedges, etc. are important (see also, e.g., Burel *et al.*, 1998; Zebisch, 2002, 5). Moreover, the potential value of an area for conservation of biological diversity from the perspective of nature conservation does not depend on how many species are present, but rather which ones (Wagner and Edwards, 2001, 121). In addition, qualities of biodiversity which are recordable by landscape metrics are only a part of the reality. Biodiversity objectives should also be set on the basis of non-measurable qualities, such as natural beauty, wilderness and perceptibility of a landscape (Weinzierl, 2004, 20).

Overall, it can be stated that the possibilities for the application of indices of landscape structure for spatial planning and for environmental and nature conservation have not been fully exhausted. Since they are suitable as indicators of processes of land use development and environmental status, such indices should more than ever find their way into spatial environment monitoring and information systems.

7 Acknowledgements

The author thanks Ms. Jürgens for her support in the extensive literature review, and Mr. Wende for the review of the manuscript (both of the Leibniz Institute of Ecological Urban and Regional Development).

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