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The Application of Landscape Indices in Landscape Ecology

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1. Introduction

Landscape ecology is essentially the ecological approach of landscape research, the theoretical background that facilitates landscape use and planning in practice (Mander & Jongman, 2000; Richling et al., 1994; Wu & Hobbs, 2007; Szilassi et al., 2010). It is a study of spatial variation in landscapes, research of the biophysical and societal causes and consequences of landscape heterogeneity. In order to plan the proper landscape use according to the constantly changing social requirements, we should know the actual condition of the landscape, its function, its spatial structure and history (Tress et al., 2003).

In undisturbed landscapes, landscape function indicates the analysis of the complex relations of several landscape factors – relief, climate, hydrogeology, soil etc. In the large part of our planet, the function of the environment is not natural. Anthropogenic effects deformed it (Odum, 1963). It is more difficult to understand the function of this anthropogenic-technical (Ellenberg, 1983), biogeocybernetician (Naveh & Lieberman, 1984) system. Additionally, in countries with different level of development, the social requirements are also different. In some countries the primary objective is the excavation of raw materials or the maximum use of soil potential, while in other places the sustenance of a landscape beauty and augmentation of its role in personal, local, national identities are inevitable requirements (Pedroli, 2000; Wöbse, 2002).

Globally, population increase results in intensified landscape use. The execution of social objectives is often observable – for example increased water demand, larger construction, infrastructural or recreation areas, etc. – but is ultimately limited by landscape characteristics and capacities. The multifunctional use of landscapes (Antrop & van Eetvelde, 2000, Brandt et al., 2000; MacFarlane, 2007) requires social compromise and landscape ecology has an important role in this process (see: landscape management; Jongman, 1995). Landscape use should adapt to existing land use or to the consequences of the former land uses (Wascher, 2005) in several places. Therefore, one of the main objectives of practical landscape research is the examination of the landscape's capacity, sensitivity, vulnerability, susceptibility, resistibility and elasticity (Haines-Young, 2005; Wiens & Moss, 2005; Wu & Hobbs, 2007).

The analysis of landscape function deals with small pilot areas. However, the interpolation of the results is significantly facilitated by remote sensing. The technical quality and the

resolution of satellite images are sufficient to recognize several ecological processes. A new field of science called landscape metrics (Blaschke, 2000; Klopatek & Gardner, 1999; Farina, 1998; Ingegnoli, 2003) studies the ecological consequences of landscape patterns and landscape mosaics (Forman, 1995).

Much of the actual research of the International Association for Landscape Ecology is related to landscape pattern. The core themes are:

- the spatial patterns or structures of landscapes, ranging from wilderness to cities;
- the relationships between patterns and process in landscapes;
- the relationships of human activities to landscape pattern, process and change;
- the effects of scale and disturbance on the landscape (www.landscape-ecology.org).

The spatial arrangement of the patch-matrix-corridor tells a lot about the ecological function, the condition of the landscape and the landscape planning possibilities (Benson & Roe, 2007; Leitão, et al., 2006). Based on the spatial configuration and the temporal change of the landscape mosaic we can draw conclusions about the isolation-migration conditions (Opdam, 1991), the fragmentation-metapopulation processes (Hanski, 1999) and the spatial distribution of the nutrients. In situ control is always necessary since we can identify the ecological materials and energy processes only indirectly from landscape patterns.

2. Landscape metrics and landscape ecological background

2.1 Landscape pattern as ecological frame

There are fewer sharp boundaries in the nature than those found in anthropogenic land uses. For example, there is the wide zone of dwarf mountain pine between the forest associations of the mountains and the alpine grasslands. There is also a wide zone between taiga and tundra. Relatively sharp boundary can be found between the terrestrial and aquatic ecosystems, but even near the seaside or along riverbanks there is a narrower-wider transitional habitat (e. g. the brackish water zone of the Wadden-see). The examination of these transitional zones (ecotones) is an actual ecological or landscape ecological topic, since these zones become more and more important parts of our environment and the material and energy processes (Burel & Baudry, 2005; Hansen et al., 1988).

Sharp land use boundaries (i.e. the large ecotone contrast) reduce the stability of the populations in protected areas. Every natural and semi-natural association has a core area and a boundary zone, and if this boundary or transitional zone is lacking, the core zone will shrink so a transitional ecotone appears spontaneously within the area (Pietrzak, 2001).

In the cases of the intensively used cultural landscapes in developed European countries, the protected areas often directly border on areas with higher hemeroby values (Krzywinski et al., 2009). It is not rare that – due to obvious causes – a protected wetland, a forest patch or a valuable sandy grassland is surrounded by inhabited, industrial or mining areas. In many cases the buffering zone is not assured and within meters from the protected patch there is a motorway, an industrial area or a mine. Sharp boundary lines characterize these landscapes in the hemeroby map that shows the intensity of the anthropogenic effects; there is a large difference between the levels of naturalness of adjacent patches.

Regarding landscapes strongly influenced by anthropogenic effects, the success of nature protection significantly depends on the land use pattern of the wider surroundings. Nowadays, area isolation or the artificial fragmentation of habitats is considered to be the process that most endangers the ecological value of cultural landscapes.

In the landscape ecology literature a common question regards the size of an area necessary for a particular species. There are data for several animal species. For example it is known that a field cricket (*Gryllus campestris*) population needs 3 hectares for long-term viability, but a minimum of 100-150 km² area is necessary for a brown bear (*Ursus arctos*) population (Farina, 1998; Fahrig, 1997; Margóczy, 2005; Šimanauskienė et al., 2008). These data are very useful, but since the protection of nature has evolved from species from species protection towards association protection and more complex landscape protection over the last few decades. It is better to examine associations or landscape types. The minimum area requirements for some associations are also well-known. For example, in the cases of softwood forests in the Carpathian Basin, 30-40 hectare patches are considered to be viable.

As nature conservation and landscape protection approach each other, it is a more and more urgent task to determine the minimum area needed for the most important landscape types that survive as a fragment of a given landscape. In the case of European landscape types, the minimum extent is thought to be 10-50 km², supposing well-functioning natural or semi-natural landscapes. Unfortunately, few European landscapes have truly natural material and energy processes, thus in our opinion, European landscape protection should aim to protect 50-100 km² continuous landscape types. The more severely anthropogenic influences affect a region, the larger the area needed a proper frame of a given biogeographic unit in terms of viable population and complete associations and regarding landscape aesthetics. A 150-200 km² large landscape can probably represent the given ecological landscape type in the case of an average European cultural landscape – such as the Breton bocage, the Tuscan coltura promiscua – that is moderately altered by anthropogenic effects (meso- or euhemerob level). An area of this size corresponds to the category of microchore, namely a “Kleinlandschaft” in the European landscape hierarchy (Bastian, 2000).

Optimal area size is not necessary in every case to maintain the functioning of the landscape. Depending on the landscape type, not only one but several smaller and connected patches might also proper for a healthy landscape. Since the 1980s landscape ecology has intensively examined the linkage of habitats, landscape patches, and ecological corridors for landscapes (Brandt, 1995; Csorba, 1996; Linehan et al., 1995; Konkoly-Gyuró, 2005; Schreiber, 1988). Through research the nomenclature of these linkage elements has been specialized significantly. Several terms have appeared: ecological networks, riparian buffers, greenways, ecological infrastructure, and others. An excellent summary of this can be found in Ahern (1995). We use the most prevailing term: ecological corridors.

Although ecological corridors is not controversial in nature conservation, assessment of their effectiveness varies (Wrbka et al., 2005). It has been proven that ecological corridors can be very useful for certain components of the biosphere – such as small mammals, reptilians, amphibians – and often help to avoid isolation and the “extinction vortex”. However, it is obvious that complete associations in landscape ecological corridors do not function with similar efficiency. There are positive experiences with conserved or created corridors (riparian buffers) along rivers. But for other associations, the fragmentation-

compensating effect of the corridors is only partly proven. It is obvious that the often artificially created “way of escape” is improper for some species within the associations, the linkage do not function with adequate efficiency.

There is scant data regarding the function of landscape linkage elements and landscape corridors; they would be useful for the landscape nature protection. Unfortunately, in intensive cultural landscape environments (i.e. most of Europe), the conservation or the creation of this system is difficult. Due to the built-up area of the continent, and particularly the density of highways, it is impossible to connect the isolated landscape types with wide landscape corridors. On the other hand, it is also true that artificial linkages, for instance, of the forests of two adjacent mountains, would be unnatural since they were not connected originally. Otherwise, migration through such ecological corridors can be harmful, for example when the habitat is special, or if the immigration of the affinitive species and the genetic combination change the species composition. In these circumstances the level of genetic variation decreases between populations (this is so called outbreeding depression, Fenster et al., 1999). What one has managed to save artificially is not the same association as it was before. In this case the only solution would be to decrease fragmentation isolation, specifically by increasing the size of the habitat.

Unconnected landscape ecological corridors, the so-called stepping stone corridors can function well regarding certain species and can compensate for habitat fragmentation (Opdam, 1991). This, however, is only species protection. It does not strengthen the functioning of associations or landscape types.

2.2 Fundamentals of landscape metrics

Landscape metrics are used in research of landscape structure to analyse the spatial heterogeneity of landscapes and to understand the ecological function of the landscape. In landscape metric studies patches are examined since their geometric characteristics (area, perimeter, shape, etc.) and relative spatial situation (such as the proximity of patches, connectivity) can be easily calculated in mathematically (Voss et al., 2001).

At present, the indices not only describe the characteristics of a unique patch but remain an important part of landscape analysis. Landscape indices can be determined at 3 levels: (1) standard patch level, (2) class level and (3) landscape level. At patch level the indices give the area, the perimeter, the area/perimeter ratio etc. of the patches. Class-level indices describe the simple or weighted mean of the aggregated characteristics of the patches that belong to the same category, or can also be considered in terms of characteristics to allow discernment of their spatial patterns (spatial distribution, proximity, connectivity). At the landscape level, indices are calculated using the characteristics of all the patches in the landscape (Cushman et al., 2008; Forman & Godron, 1986; McGarigal & Marks, 1995; Szabó et al., 2008).

In the 1980s many landscape indices were developed (Lóczy, 2002). Their use was significantly facilitated by the appearance and spread of GIS software, and relatively cheaper and more readily available aerial photos as well as satellite imagery (Szabó, 2010).

Mathematically, landscape indices quantify the landscape characteristics in reproducible i.e. controllable ways. The shape and the spatial configuration of the patches and the situation,

isolation and connectivity of the patch types can be determined using these indices. Based on these indices we can determine how suitable a given patch or patch network is for the presence or survival of species that have narrow tolerance limits or are sensitive to anthropogenic disturbance. Botanical and zoological assessments determine the species composition of habitats; the landscape metric completes the studies so that the processes of the landscape can be identified, their existence can be confirmed and the direction of the expected changes can be predicted. Their use was significantly facilitated by the appearance and spread of GIS software, and the cheap and easily available aerial photos as well as satellite images.

There is a lot of overlap among indices and they often have high correlations. Attempts to eliminate redundancies have been made; the most well-known is the work of Riitters et al. (1995) in which 55 landscape metric indices calculated from 85 maps were evaluated. The number of variables was reduced to 26 due to the contravention of the strong cross-correlations and the normality conditions. The 26 metrics were integrated to 6 main components: average patch compactness; patch texture; average patch shape; the number of the attribute classes and the perimeter/area fractal dimension of the large patches. It is also important that the authors doubted the significance of the results since they were able to identify only one research area (and it was an extreme value). The factor structure is not constant; based on our earlier results (Szabó et al., 2008; Szabó, 2010). It seems that the significance of the cross-correlations depends on the metrics used, the characteristics of the unit examined and the design of the map used. Accordingly, it is impossible to determine all the indices that can generally be used anywhere in the landscape analysis since the aforementioned indices correlation of the indices is not constant and statistical analyses do not produce a consistent value.

2.3 Landscape metric software

Landscape indices can be extracted from land use maps derived from aerial photographs, satellite images or field surveys. Base data can be in raster or vector format, depending on the requirements of the landscape metric software.

Software using categorical raster maps include FRAGSTATS, Leap II, and we have to mention the Pattern Module (Eastman, 2003) of the Idrisi. The most popular of these is FRAGSTATS (McGarigal & Marks, 1995), because it was the first and its output easily can be easily imported into other statistical software for further analysis. These calculations are significantly biased by the "grain size" of the raster map. The coarser the grain, the more error and uncertainty is in the results (Szabó, 2009).

Calculation of landscape indices based on vector maps is more precise, faster and more reliable. The results do not depend on resolution, but the number of indices that can be calculated are limited (some metrics can be determined only from rasters). The vLATE (Lang & Tiede, 2003) and the Patch Analyst Extension of ArcGIS 9.3 (Rempel, 2010) are well-known vector based landscape metric software. In addition, there is a software package for habitat-patch connection evaluating called Conefor Sensinode that determines the probability that a focal species will be able to reach the next habitat patch (Saura & Torné, 2009).

2.4 Limits of landscape metrics

During the processes of landscape measurement we must accept some limiting ecological-landscape ecological fundamentals (MacArthur & Wilson, 1967; Harris, 1984). These factors influence the interpretation of the results landscape metrics. This is explained by computer analysis limitations to be precise: sometimes the methods have not properly designed.

The first important limiting factor is our inability to differentiate the linear and the patch-like landscape elements; every unit that is different from its surrounding environment is considered to be a patch.

Patches usually border on the matrix, but the matrix often consists of patches so they are treated like patches during the processing. Since there is no difference between the matrix and the patch with regarding their geometry and topology, two actions can be taken: either (1) accept this fact and evaluate the matrix as a patch; or (2) leave the matrix out of the calculation. The latter one is recommended only when the matrix consists of one or only some large patches as it would confuse the calculations (especially at the class and landscape levels).

The distances between the patches are usually determined using Euclidean distance (in the present case the shortest distance between habitats) and ecological distance (using a so called friction surface [Gonzalez et al., 2008; Gyenizse, 2009] that reflects the movement characteristics of the focal species). Both solutions are inaccurate. Ecological distances are more realistic but during the definition of the friction surface we are not able to consider every influential factor.

Most of the software does not deal with the anthropogenic barrier. This was prepared for only the effective mesh size index elaborated by Jaeger (2000), due to Girvetz et al. (2008). In several cases we can calculate the ecological distances described above instead of the Euclidean distance, but they may not properly reflect the linear anthropogenic elements (linear elements appear as pixels bordering one another in a raster and there can be permeability if the line is diagonal; with low resolution, a 2-pixel-thick implementation over-represents the width of the linear element). Therefore, during the landscape metric analyses using Euclidean distances, fragmentation, isolation and connectivity pertain to natural landscapes that are free from anthropogenic ecological barriers. Thus fragmentation actually refers only to the mosaics of the natural landscapes. While interpreting the results, if the conceptional background is explained, the user will know whether the results refer to anthropogenic or natural landscapes.

In landscape ecology, we can talk about the connectivity of the matrix or the corridors (Forman, 1995; Jordan et al., 2003), but using software of landscape metrics these distinctions cannot be separated. Thus, in this case, connectivity is based on the corridor system of patches (stepping stones). Connectivity refers to the potential for species to reach landscape elements (Báldi, 1998; Whitakker & Fernández-Palácios, 2007). If we define the minimum distance that a species unconditionally covers to get to the next patch, and if the patches are within this distance, then we can call this connectivity (this is actually a nomenclatural problem since in the cases of discontinuous corridors the species must also cover the same distance to move on).

3. Landscape indices and landscape ecology

3.1 Evaluation of habitat size and habitat availability

Mosaics are the product of heterogeneity. They are the characteristics of natural landscapes and should not be confused with fragmentation: fragmentation is the breaking-up of the habitat patches or land use units, while mosaics are the form of appearance of the landscape elements (Forman, 1995). A population or an association are not necessarily only associated with large and coherent areas, but can also be found in networks of smaller patches (such as mosaic loess oakwoods with open grasslands, G. Fekete et al., 2000). If this pattern had evolved naturally, it would be considered a mosaic; but if it were anthropogenically produced then it is considered a fragment (Bissonette & Storch; 2003; Kerényi, 2007).

In the process of fragmentation there is an initial condition (a large patch that is not disturbed) and disturbance (breaking the large patch into smaller patches). In order to model the fragmentation process, Jaeger identified 6 phases:

- perforation,
- incision,
- dissection,
- dissipation,
- shrinkage,
- attrition (Jaeger, 2000, 2002).

These phases also correspond to population-degradation stages and the degradation of the quality of habitats.

Where the average land use patch size of the landscape do not reach 0.5 km² (i.e. approximately 200-300 m diameter units form the main part of the landscape), habitat fragmentation is probably significant there. This fragmentation datum is useful for comparison of adjacent landscapes, and can be informative for practical landscape planning and regional design in that it helps technical experts understand landscape functions.

The landscape ecology interpretation of the patch size significantly depends on what kind of patches to which the tierce or the half km² average refers. It is obvious that an upland grassland area of 0.5 km² is ecologically more valuable than a mono-cropped farm field of the same size. This difference can be well represented if fragmentation is determined with a hemeroby index.

The minimum habitat size depends on the requirements of the organisms, but the environmental factors can modify it (for example either adjacent to a busy road or distant from any anthropogenic disturbance). The characteristics of the adjacent patches, the quality of the matrix and the distance of the closest identical patch are also important determinants (Pope et al., 2000; Sisk & Haddad, 2002). Generally we can say that the smallest necessary patch size is adequate for the species that need the largest area among all local species and also takes into consideration possible disturbances (Margóczy, 2005). Thus, knowing only the patch size is insufficient to determine the probability of a species' survival, but it is a good start for its assessment.

3.2 The deviation of patch size, the SLOSS debate: Single Large or Several Small?

The deviation of landscape patches shows whether there are significant differences in landscape patch pattern within the landscape in terms of scenery and landscape functioning. If the variability of the patch size is small, the landscape consists of land use units of more identical size.

Thus, patch size alone is also important information; its differential interpretation resulted in the SLOSS (Single Large or Several Small) debate in the 1970s. It has also been a controversial issue recently: can several small patches provide for as much species richness as a large patch (or some large patches)? The answer is not obvious. Both have advantages and disadvantages (Margóczy, 2005; Simberloff & Abele, 1981; Whitakker & Fernández-Palacios, 2007). Studies have shown that in several cases (butterflies, birds and forest associations) that small fragments result in higher species richness than a single large patch of the same size (Baz & Garcia- Boyero, 1996; Bánszegi et al., 2000; Tscharntke et al., 2002). This does not mean that large patches are not valuable, they are significant for the preservation of specialist species.

Several ecologists feel that neither of the two landscape structures is favourable. There is no conclusive evidence as to the most stable eco-geometrical pattern for landscape structure. Thus, a mosaic of 2-3 medium-sized and some small patches can be very advantageous. This is a landscape structure that is the least vulnerable to external forces, such as natural catastrophes or anthropogenic threats.

3.3 Connectedness

The SLOSS debate brings us to the problem of patch availability. Small patches form a functional system only if the distance between them is small enough that resident species can reach them. Every system of habitat patches is stable only if there is functional connectedness between patches. Landscape connectivity indices numerically determine whether the landscape structure facilitates or impedes the movement of the animals.

The numerical definition and the interpretation of the results are not easy, however. There are several questions about what ensures connectivity. Is the distance between the patches sufficient? What effects does the matrix have on species movement? For example, birds require no connection between habitat patches since they can easily fly over long distances, but a small reptile or amphibian require connections. Not only the distance is important, but the characteristics and quality of the matrix between the habitat patches are also important factors. Therefore, connectivity cannot be determined by a single number. Species-specific calculations are necessary (Crooks & Sanjayan, 2006). There is often little information about the movement of species, we can usually only identify the distance that a given animal can move (a threshold distance), and connectedness is calculated based on this value.

3.4 Shape

The determination of the area/perimeter ratio can be an indicator for landscape metric analyses. This method appeared in the earliest studies (Jurko, 1987) and eventually became a prevalent index (Farina, 1998; Fekete & Fekete 1998; Turner & Gardner, 1991).

If the area/perimeter ratio of the patches is high, the patches have short perimeter on average, i.e. zigzag patch shapes do not dominate. In terms of ecology, these landscapes have less ecotone than other areas of a similar size, and they are more stable ecologically. Patches encompassed by long border zones (low area/perimeter ratio), are unstable ecologically are more likely to be threatened by external forces.

Obviously, there are communities (such as those surrounding a hot spring) that require only an area of 0.5 km², long, narrow habitat patch providing stable living conditions, but probably a large, homogeneous habitat geometrical characteristic that have extensive, inner patch section is necessary for most ecological patches.

The shape indices of patches determine the compactness and help to indicate the sensitivity of the patches. The more the border line of the patch is similar to a straight shoreline (with few “bays” or “peninsulas”), the more likely the patch is ecologically stable. Peninsulas reduce the area in which disturbance-sensitive species can reside as matrix interaction is more intensive.

In the course of our studies of shape indices (Szabó, 2009) we examined the dependence of the indices on the patch size, pixel count (in the case of raster analysis), orientation (whether rotation of the patches affects the values) and uniqueness (whether the value of a given index belongs to only one patch shape). Accordingly, the results are that:

- the patch size does not or only slightly influences the Shape Index, Related Circumscribing Circle;
- the number of pixels does not or only slightly influences Area, Perimeter, Radius of Gyration, Perimeter/Area, Fractal Dimension, Related Circumscribing Circle, Shape Index;
- the azimuth of the object does not or only slightly influences: Radius of Gyration, Fractal Dimension, Related Circumscribing Circle, Contiguity Index;
- unique, namely does not or only slightly correlates with the other indices: Radius of Gyration, Related Circumscribing Circle;
- their value is definitely true for only one form (patch shape): Shape Index, Related Circumscribing Circle.

Accordingly, the most useful index is the Related Circumscribing Circle, but its use is not prevalent in practice. The area/perimeter ratio of the patches is often applied, as it was mentioned above, to characterize the eco-geographic stability since both its calculation and interpretation is easy. At the same time, it can be deceptive because the value of the index also changes in the case of the patches of the same shape but different size, and the ratio can be the same regarding the patches of different shape. In terms of the use in landscape ecology, other authors emphasize Fractal Dimension and indices related to a reference shape e. g. Shape Index (Krummel et al., 1987; Mezősi & Fejes, 2004). Leitão et al. (2006) do not recommend the use of the Shape Index in patch morphology examinations since the values can be the same if patches have identical perimeters and areas.

There are several other indices that are not implemented in landscape metric software, but they can contribute to the identification of sensitive patches, such as the elongation and the convolution index suggested by Forman (1995). Among the metrics, the Radius of Gyration is the most favourable to estimate the elongation: of two case of the same size, the patch of

having a higher value is the elongated patch (Leitão et al., 2006). This can be useful in morphometric analyses, but size dependence of Radius of Gyration must be considered; the comparison is not clear – patches in the nature are usually of different sizes.

3.5 Patch gradients

The system of landscape ecology corridors with stepping stone habitat patches can sustain the oligo- or mesohemerobe level of the cultural landscape. However, this complete ecological system provides sufficient linkage to sustain and stabilize neither populations of less mobile animals nor of the whole ecosystem. The only migration option for them is movement toward a patch that is only slightly different from their original natural habitat (forest, scrub forest, or grassland), when possible. For example, if a shrubby-grassy connection exists between two isolated grass patches, then this direction is a real migration possibility for the species. If the grass patch is surrounded by ploughed farmlands or plantations, and there is only one way to reach adjacent grassland through a single shrubby-grassy patch, then this connection is strategically important. Based on the landscape types of Central Europe, the members of the patch gradient can consist of the following land use patches:

forest → scrub forest → meadow/grassland → fallow → ploughland →
vineyard/plantation → built-up areas

These categories can also be separated well according to the land use patch type of the CORINE. Naturally, no such (complete) patch series spectrum is found in most of the landscapes or landscape fractions. Most areas consists of only 2-4 patch types, such as:

forest → scrub forest → meadow/grassland → fallow

scrub forest → meadow/grassland → fallow → vineyard

fallow → ploughland → built-up areas

In our opinion, ecology-based landscape planning should increase the consideration these kinds of landscape patterns. The patch series where members are the most similar (thus they are the smallest barrier against migration) can be easily marked on detailed landscape maps.

The method can be the practical application of the landscape structure concept (McGarigal & Cushman, 2005). Instead of using increasing number of general landscape indices:

„We would better served by quantifying the local landscape pattern across space as it may be experienced by the organisms of interest, given their perceptual abilities.“

(McGarigal & Cushman, 2005)

„We advocate the expansion of the paradigm to include a gradient-based concept of landscape structure that subsumes the patch-mosaic model as a special case. The gradient approach we advocate allows for a more realistic representation of landscape heterogeneity by not presupposing discrete structures, facilitates multivariate representations of heterogeneity compatible with advanced statistical and modelling techniques used in other disciplines, and provides a flexible framework for accommodating organism-centred analyses.“ (McGarigal & Cushman, 2005)

According to the authors, the moving-window analysis of FRAGSTATS software is appropriate for such analyses.

Determination of patch gradient is very similar to the McGarigal & Cushman (2005) method. It provides valuable background information for planning to achieve protection of species and ecosystems. It is obvious that these patch pattern gradients “generally” provide less useful alternatives for species. But if the aim of nature protection is to enable a species or species group to broaden their narrow or endangered habitat, this method can be helpful. There is also a chance that one could use patch gradient maps to create strategic goals for nature protection.

3.6 Landscape patches and built-up areas, traffic infrastructure

Serious ecological consequences from road construction are obvious, so when investments have reached the social threshold, the public often tries to force decision makers to find the most environmentally friendly alternatives (Lodé, 2000).

The harmful effects of busy roads have been studied since the rise of mass adoption of motorized transportation (Clarke, 1930). Beck (1956) called roads ecological infection canal (“Infektionkanal”). In the 1970s it was proven with efficient experiments that roads act as ecological barriers (Mader, 1979). Seven hundred and forty-two ground-beetles (*Abax ater*) were marked near a not-too-busy upland road in Germany and only two beetles were able to cross it. The rest of beetles turned back from the edge of the concrete. They were not killed by the cars, but the strange surface and open space prevented the movement of the animals. Mader also proved that only a few ground beetles surmounted a moderately busy road wider than 2.5 m. Less than 10% of spiders and small mammals overcome the road barrier (Mader, 1984).

Other authors reported similar results with regard to the habitat fragmenting of roads and urban areas (Forman, 1997, Harris, 1984; Schreiber 1988; Tóthmérész et al., 2011). Indeed, one study analysed the effects of landscape fragmentation on the function of the entire food chain (Polis et al., 2004).

Despite the vast number of animals that are killed along the roads (Erritzoe et al. 2003, Forman, 1997; Langgermach et al., 2006; van der Zande et al., 1980; Voss & Opdam, 1993), the ecological balance is not impacted to the extent that one might suspect. Even in the cases of busy roads, the reduction of the ecological diversity and population stability can be proven clearly only in the 200-500 m wide roadside zone (Farina, 1998; Forman & Alexander, 1998).

There are few studies that demonstrate that the fragmenting effects of the built-up areas play important roles in ecological fragmentation and the habitat shrinkage (Mühlenberg & Slowik, 1997; Paddison, 2001). Settlement ecology examines settlements rather than living creatures settling in unique habitats or being crowded from them, and it considers how the settlements surround the special habitats, how sensitive ecotopes are isolated, or how the settlements impede species movement. Settlements are less permeable than a road. A narrower village is a wider physical barrier than a highway with 3x3 lanes. However, comparing the strength of the ecological barriers it is not certain that the migration-preventing effect of a small village is more significant than a highway enclosed within a fence.

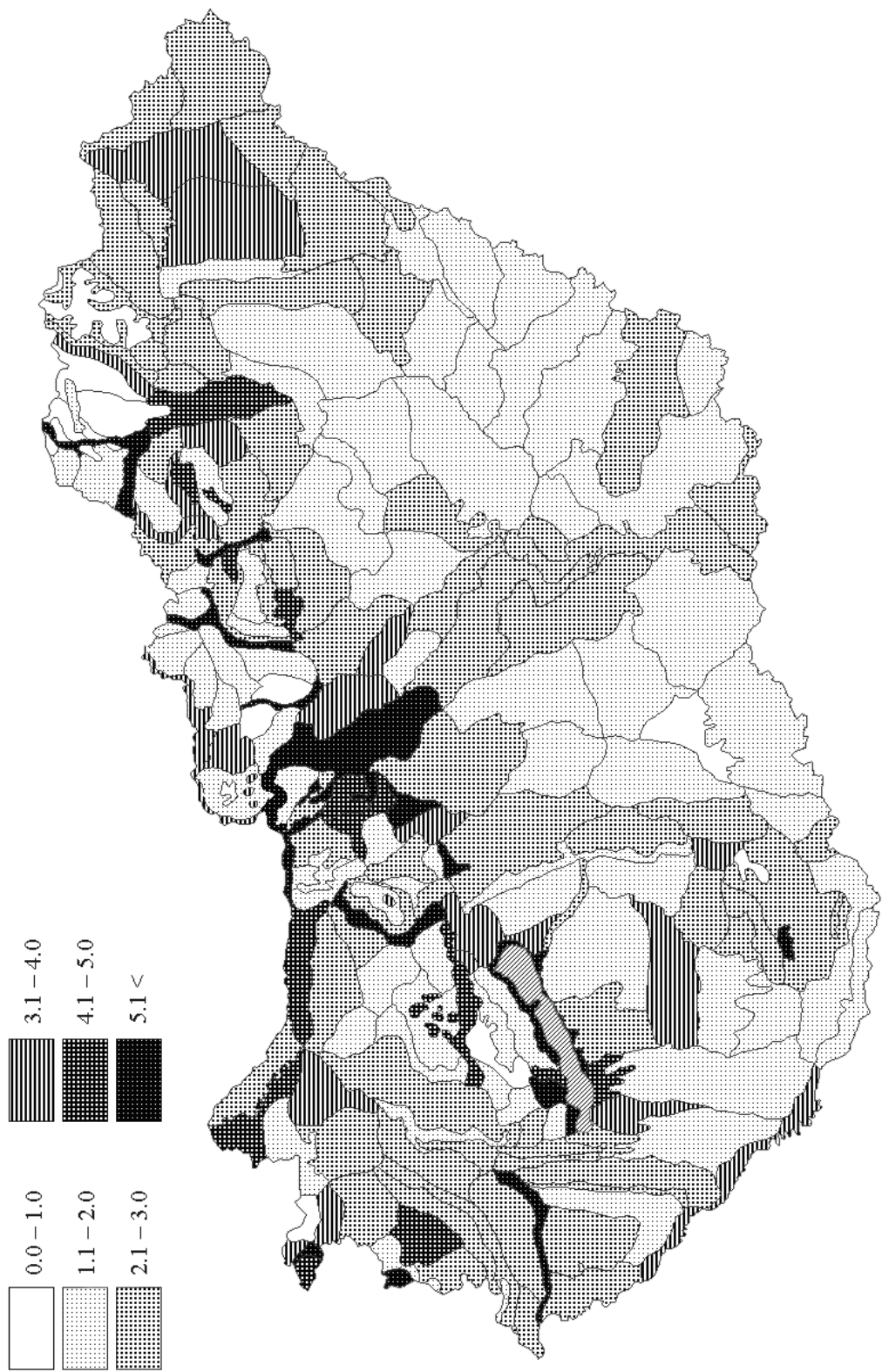


Fig. 1. Weighted and summarized data for the fragmentation effect of settlements and traffic infrastructure in Hungary (modified data km/km²)

Regarding biodiversity, a settlement landscape can exceed natural species richness. Although ecosystems are certainly less diverse along roads, species diversity of roadside weed vegetation is generally very small.

The degree of ecological fragmentation of landscapes is a useful index for landscape protection and planning. An index was determined using the 1:250 000 scale maps of the Cartographia Road Atlas of Hungary (Csorba, 2008). Based on the Cadastral of Microregions of Hungary, the boundaries of the microregions were drawn into the maps, and then within those fixed boundaries the greatest diameter of small settlements and the length of roads and railways were measured. In the case of large settlements the extent of inner parts and traffic intensities of the roads were considered. In the case of railways, whether railway lines are single- or double-tracked was considered. Results were modified using weighting, where the locations of protected natural areas compared to locations of settlements and then roads and railways were incorporated. The agglomeration processes of large settlements were also considered as they may too restrict the ecological gates and corridors along the migration routes of plant and animal species. Values of the fragmentation index were mapped in km/km² for the 230 microregions of Hungary, but in the present study the values distorted by weighting were presented (Fig. 1). In 23 microregions, the fragmentation index is higher than 5. The strongest ecological barriers are found in microregions in valleys and small basins within mountain regions of medium height and their environs.

4. Landscape metrics in practice

The results and the methods of landscape metric research are incorporated into practical applications relatively slowly (Jongman, 1995, Marsh, 1997). The two most significant uses are represented through the following examples.

The Forestry Commission of Scotland and Scottish Natural Heritage planned afforestation sites using BEETLE (an ESRI ArcView module) that examines landscape pattern in terms of a given species' needs. The Commission attempted to ensure landscape connectivity in the new system of forest fragments and in newly planted forest patches (Stone, 2007). In the programme (Cairngorms Forest and Woodland Framework - CFWF, 1999) an attempt to increase the habitat of corn bunting (*Miliaria calandra*) using landscape ecology principles was undertaken with the help of the local land-owners. The owners were encouraged to plant forests in the designated sites to build up the ecological system of the Scottish Highlands. The programme was not successful since the timeframe was short and the interest of local land owners was often not oriented toward afforestation. However, two separated forest patch in the Beinn Eighe National Nature Reserve were planted with 20 ha of forest. Drawing the lesson from the failure of the CFWF program, the Forest Commission elaborated a support system for owners who planted forests. They were not told where to plant forest, but they planted where they wanted to plant. Then the connectivity was tested using BEETLE model. The rate of the support depended on whether doing so would improve the connectivity of the plantation. During 5 months 1.6 million pounds were distributed to create 400 ha of new forest and 41 landscape ecological corridors that made a total area of 8500 ha more functional (Stone, 2007). Considering money as motivation, and the use owner's own ideas, it succeeded in improving the environment in terms for nature conservation; this is what all decision-maker should notice.

The second example is practical use of MESH index elaborated by Jaeger (2000). The German Federal Environment Agency made recommendations to reduce fragmentation based on the effective mesh density (m_{eff}). Accordingly, large habitat patches must be conserved or increased, and by 2015 the ratios of the area with the certain 2002 mesh density values (m_{eff}) must be reduced: 1.9% of patches had areas less than 10 km², 2.4% ranged from 10-20 km² areas, and 2.8% were 20-35 km² areas (Penn-Bressel, 2005). Limiting construction of roads, preventing territorial expansion of cities, encouraging in-fill developments, and long-term regional development plans were necessary tools. The effective mesh size as an indicator of the ecological condition of the cantons (Jaeger et al., 2008) was also used in the Swiss Monitoring System of Sustainable Development (MONET).

The effective mesh size is a popular metric not just in Europe but has also been used in the USA: in California, m_{eff} as the index of fragmentation (Jaeger et al., 2008) is used for the optimization of transport lines and in nature conservation and landscape protection decisions. This is explained by the modified transport rules: nature conservation must be considered during planning (Safe, Accountable, Flexible, Efficient Transportation Equity Act [SAFETEA-LU]). Accordingly, the possible effects of transportation line construction on habitats and methods to reduction these impacts must be identified before the construction of the transport lines. CALTRANS (California Department of Transportation) entrusted the research crew with effect analysis and thus the m_{eff} index came to the front (Girvetz et al., 2008; Thorne et al., 2009).

5. Acknowledgment

This paper was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences (bo_391_09) and the Meridian Foundation.

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Perspectives on Nature Conservation - Patterns, Pressures and Prospects

Edited by Prof. John Tiefenbacher

ISBN 978-953-51-0033-1

Hard cover, 270 pages

Publisher InTech

Published online 29, February, 2012

Published in print edition February, 2012

Perspectives on Nature Conservation demonstrates the diversity of information and viewpoints that are critical for appreciating the gaps and weaknesses in local, regional and hemispheric ecologies, and also for understanding the limitations and barriers to accomplishing critical nature conservation projects. The book is organized to emphasize the linkages between the geographic foci of conservation projects and the biological substances that we conceptualize as "nature", through original research. The reader moves through perspectives of diminishing spatial scales, from smaller to larger landscapes or larger portions of the Earth, to learn that the range of factors that promote or prevent conservation through the application of scholarship and academic concepts change with the space in question. The book reflects disciplinary diversity and a co-mingling of science and social science to promote understanding of the patterns of, pressures on and prospects for conservation.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Péter Csorba and Szilárd Szabó (2012). The Application of Landscape Indices in Landscape Ecology, Perspectives on Nature Conservation - Patterns, Pressures and Prospects, Prof. John Tiefenbacher (Ed.), ISBN: 978-953-51-0033-1, InTech, Available from: <http://www.intechopen.com/books/perspectives-on-nature-conservation-patterns-pressures-and-prospects/the-application-of-landscape-indices-in-landscape-ecology>

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