SIMILARITY ASSESSMENT OF NATURAL LANDSCAPES BASED ON TAXONOMIC DISTANCE

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Abstract. The degree of similarity/dissimilarity between landscapes is important information for landscape classification, potential assessment and evaluation. In geographical assessments, similarity in landscape functioning and visual attributes is commonly analysed by using landscape factors (e.g., relief, water balance and soil fertility), land use and built-up area. In this study the similarity and dissimilarity of Hungarian landscape units were investigated to reveal the appropriateness and uncertainty of the current delimitation methods. Nine indicators for 230 landscape units, delineated by the traditional methods, were integrated into a data matrix. Dissimilarity coefficients were calculated for each unit to determine the Euclidean distance between all indicators. Dissimilarity analysis was performed by multidimensional scaling using Kruskal's stress test and hierarchical clustering. The applied method enabled a more objective determination of taxonomic distance. Based on the results, the similarity and dissimilarity of landscapes could be evaluated by more accurate and quantitative datasets. Several neighbouring landscape units should require increased attention in spatial planning because these landscapes differ from each other: they belong to different clusters based on the investigated indicators, though they are adjacent.

Keywords: *similarity analysis, multidimensional scaling, taxonomic distance, ecology*

Introduction

Several approaches for landscape interpretation exist (e.g., based on functionality and spatial patterns) that significantly influence the primary determining factors of the landscape and their relations (Bastian and Schreiber, 1999). An obvious approach is to consider landscapes as relatively homogenous units. In many countries, natural factors (e.g., lithology, relief, soil and hydrology) were evaluated, and the results were used later as landscape units (Mosimann, 1984; Naveh and Liebermann, 1984; Haase, 1989). Landscape units are determined by natural factors that are influenced by human impact, contributing to a complex landscape system (Mezősi et al., 2013).

The integrated regional units of landscapes can be evaluated according to two main approaches:

- In the first approach, homogenous landscape units are the basis of the evaluation, and the complex units can be created using clustering or segmentation methods. For example, homogenous vegetation, pedological or relief units can be separated and integrated (Bölöni et al., 2011; Miklos, 2012; Divíšek et al., 2014; Bata et al., 2014). A similar method is based on overlaying (e.g., multiplying) separate homogenous units (e.g., soil, climate and relief), and the resulting spatial units are considered "homogenous" units (e.g., LANMAP – Wascher,

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2005; Mücher et al., 2010). The resulting spatial units cannot be considered integrative; however, they can reflect landscape system features. Their acceptance as integrated units depends on the interpretation of the landscape definition.

- According to the second approach, landscape units are considered inherently integrated units (with all their hierarchical levels), but there are significant differences in the involvement of natural and human parameters. According to this interpretation, ecotopes, considering mostly natural factors and higher-level hierarchical elements, are similar; however, the degree of similarity decreases with increasing scale (Mosimann, 1984; Naveh and Liebermann, 1984; Haase, 1989; Blaschke and Strobl, 2003; Jongman, 2003; Bastian et al., 2006).

The degree of similarity between landscapes is important data for landscape classification, landscape potential assessment and landscape evaluation. Similarity is dependent on the scale of the regional units and the applied hierarchical level because the level of complexity and the resulting problems in the assessments increase with decreasing scale.

This study addresses the following questions of the landscape classification problem:

- Is the landscape unit delimitation that is currently used appropriate? Do the landscape units differ from each other? Which units would belong to other hierarchical units or cluster groups based on dissimilarity?
- According to the theoretical approach, what are the effectiveness and accuracy of the different methods for the determination of spatial units?

According to the mathematical definition of similarity, two objects are similar if one can be transformed into the other by mathematical operations (e.g., rotations, zooming or reflections). The rate of similarity can be determined by several methods (e.g., cosine similarity and correlation-based similarity) depending on the attribute structure of the given database. The parameters in this study are primarily nominal, and the classical mathematical operations are not appropriate. Thus, taxonomic distances were used for the evaluation of the relationships between landscape units (*Fig. 1*). This method has been successfully used for similarity analysis in other fields of physical geography, e.g., in the determination, relationship assessment and mapping of pedological classes based on environmental variables (WRB, 2006; Minasny and McBratney, 2007) or in the clustering of tropical dry forests based on environmental parameters (Muenchow et al., 2013). The application of multidimensional scaling (MDS) in geosciences has a 40-year history, mostly in the field of human geography (Rushton and Golledge, 1972).

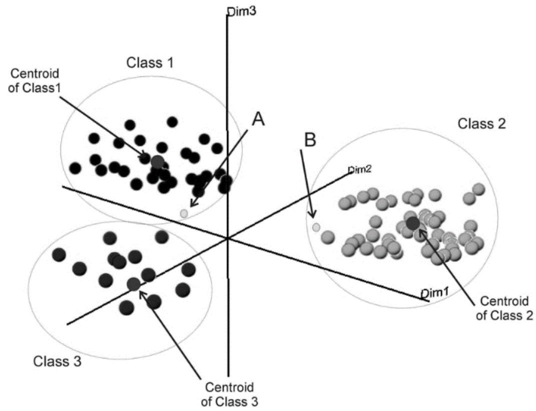

Figure 1. *A 3D visualisation of the landscape units forming three classes/clusters, based on the taxonomic distance method. Points A and B refer to outlier landscape units (in edge position), belonging to another class/cluster*

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Material and Methods

Taxonomic distance and the applied data

This study is based on the taxonomic distance between the landscapes in an n-dimensional space. The number of dimensions depends on how many independent parameters describe the similarity of the landscapes (Kruskal and Wish, 1978; Hastie et al., 2001). The application of this method in landscape similarity assessments is difficult because landscape units are described primarily by nominal or interval data; furthermore, several parameters are considered for the determination of similarity. Taxonomic distance measurement using the Euclidean distance method requires numeric datasets, and the high number of applied parameters results in a multidimensional environment that is difficult to interpret. Thus, the initial datasets were converted to numeric type, and using the multidimensional scaling method (MDS), the resulting datasets were reduced to a 3D environment.

For the similarity analysis of the landscape units, the features of the landscape units, described in the Inventory of Landscape units in Hungary, were applied (Marosi and Somogyi, 1990, and the second, improved edition by Dövényi, 2010), in which the landscape units were considered integrated units. Their delineation was primarily based on natural environmental factors (geomorphology, geology, climate, hydrology, vegetation and soil), but social factors (land use, geographical situation, cultivated crops, special landscape character and other socio-economic parameters in the second edition) were also considered (*Fig. 2*).

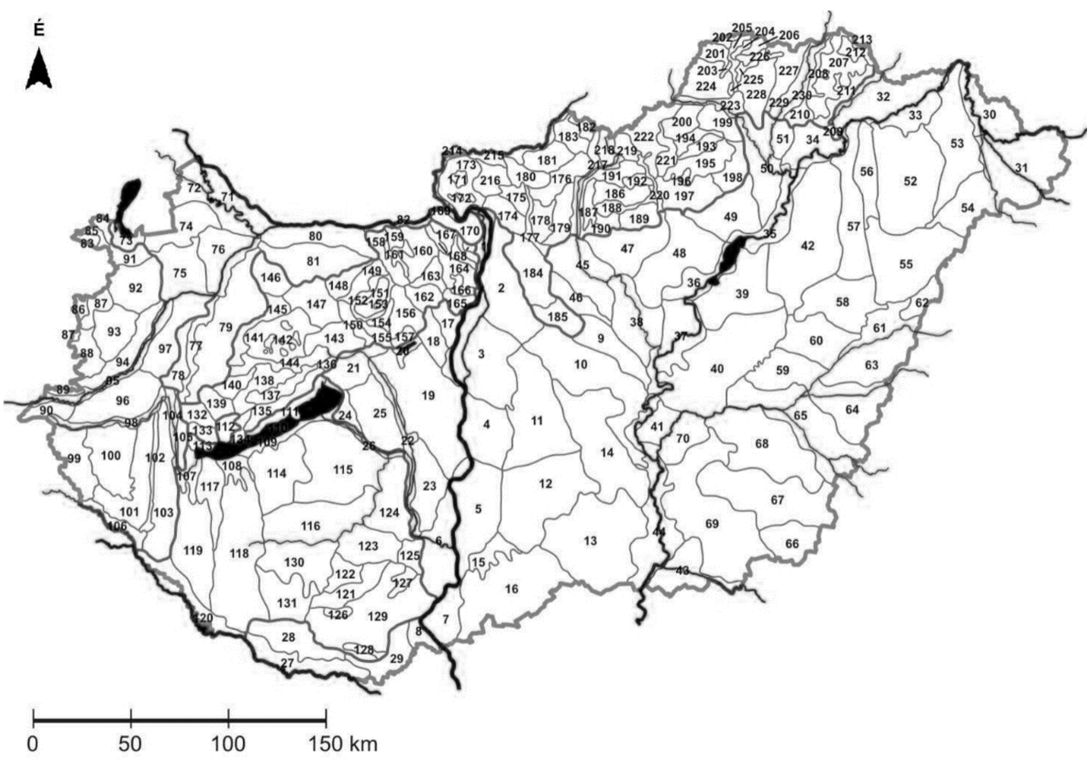

Figure 2. *Landscape units in Hungary based on Marosi and Somogyi (1990) and the second, improved edition by Dövényi (2010). The list of landscape units, indicated by the numbers, is available online at http://www.geo.u-szeged.hu/english/sites/www.geo.u-szeged.hu.english/files/kistajlista.docx*

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Nine parameters for 230 landscape units (primarily 100-500 km^2 in area) were investigated by calculating the average values for each unit. The detailed description of the applied parameters can be found in *Table 1*. Several data sources have more recent versions available (e.g., CORINE Landcover Database), but temporal consistency was considered important during the analyses.

Table 1.*The parameters applied during the analysis*

Parameter	Data source	Scale	Calculation of the parameters
relief	SRTM (2000)	90 x 90 m	area weighted average of the elevation (m) for each landscape unit
soil	AGROTOPO (1991)	1:100 000	area weighted average of the topsoil thickness (cm) for each landscape unit
climate	meteorological dataset (OMSZ 1961-1990)	100 x 100 m	1961-1990 average PaDI (Pálfai 2004, Pálfai és Herceg 2011) area weighted average of PaDI for each landscape unit $\mathrm{PaDI} = [\sum_{i=Apr}^{Aug} \mathrm{Ti} \quad /5*100]/\sum_{i=Oct}^{Sept} \mathrm{Pi}*\mathrm{wi}$ Ti – monthly average temperature, °C Pi – monthly precipitation, mm wi – weighting factor
ratio of built-up areas	CORINE (1990)	1:100 000	ratio of built-up areas (%) (CLC111, CLC112, CLC121, CLC122, CLC123, CLC124, CLC131, CLC132, CLC133, CLC141, and CLC142) for each landscape unit
ratio of forest cover	CORINE (1990)	1:100 000	ratio of forest cover (%) (CLC311, CLC312, and CLC313) for each landscape unit
ratio of vineyards	CORINE (1990)	1:100 000	ratio of vineyards (%) (CLC221) for each landscape unit
vegetation	MODIS EVI	250 x 250 m	area weighted average of the Enhanced Vegetation Index (EVI) in July between 2000 and 2010 for each landscape unit
fragmentation	road and railway network 1990-ben (OTAB 1990)	1:100 000	effective mesh size for each landscape unit (Jaeger 2000) $EffectiveMesh = \frac{A_t}{S} = \frac{1}{A_t}\sum_{i=1}^{n} A_i^2$ n – number of patches A_i – size of the patch i A_t – size of the entire area
hemeroby	CORINE (1990)	1:100 000	area weighted average of the hemeroby index (Csorba and Szabó 2009) for each landscape unit

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Methods

In the assessment, a combined methodology was used (*Fig. 3*) to allocate the outlier landscape units in the existing classes (see *Fig. 1*), which thus require a reconsideration of their class membership. Using the dataset of the parameters correlation analysis, principal component analysis and multidimensional scaling (MDS) were performed to quantify the similarity of the landscape units. MATLAB was used for the calculations.

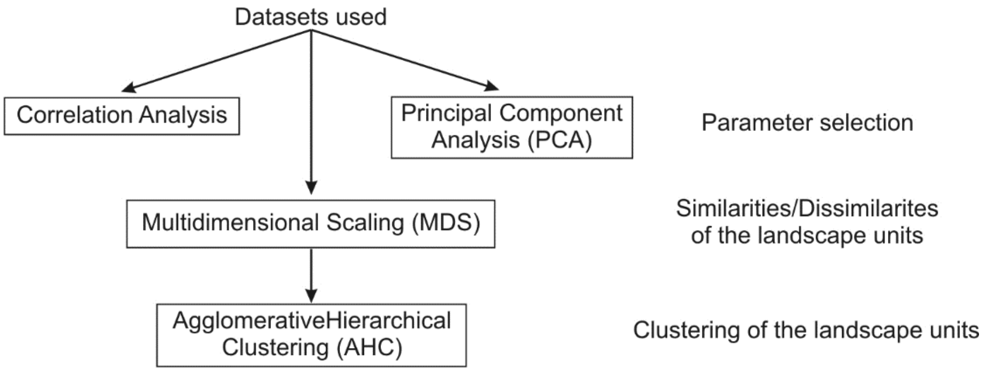

Figure 3. *Flowchart of the methods applied for the similarity assessment of the landscapes*

The correlation analysis was conducted to determine whether there were strong relationships among parameters. If such variables exist, one of the variables has to be removed from the MDS analysis because the axes of the dimensions representing these parameters are very similar, which influences the results. Based on the resulting correlation matrix, the key factors among the selected parameters in the landscape can be determined.

Principal component analysis (PCA) was used for the determination of the relationship between the applied factors based on Pearson's correlation matrix. The PCA method is mostly used for data reduction and data structure assessments. PCA uses an orthogonal transformation to convert a set of possibly correlated variables into a set of uncorrelated variables (F_1… F_n). The number of the resulting principal components is less than or equal to the number of original variables. The first principal component has the largest possible variance. Because the first few principal components describe a significant amount of the variance, dimension reduction is possible. If the calculated eigenvector of a principal component is less than 1, it is not considered in the evaluation. The cumulative percentage is the accumulated share of variation explained up to the last component (Joliffe, 2002).

Multidimensional scaling (MDS) refers to a class of techniques that uses proximities among any type of objects as input (Kruskal and Wish, 1978). According to Carroll et al. (2005), MDS is a family of models and methods for representing stimuli or other objects as points in multidimensional space based on proximity (e.g., similarity or dissimilarity) data. This method relies on the principle that distances (usually, but not necessarily, Euclidean) in that space are related via a simple (usually linear or monotonic) function of the proximities (Marcussen, 2014)

For multidimensional scaling, a data matrix was established considering the factors for each of the 230 landscape units. Based on this data set, a dissimilarity matrix ($\Delta\delta_{ij}$) was

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computed, where the dissimilarity coefficient (δ_{ij}) refers to the dissimilarity between i and j landscape units. Dissimilarity (distance) was calculated using Euclidean distance measures:

$$\text{Euclidean distance} = \sqrt{\sum_{t=1}^{p}(x_{it} - x_{jt})^2}$$

where x_{it} denotes the ith row and x_{jt} the jth column of the x_t data matrix (Hout et al., 2013; Rushton and Golledge, 1972).

Using MDS, multidimensional datasets can be reduced to 2 or 3 dimensions. During the analysis, the x, y and z co-ordinates of each landscape unit were computed; thus, the units could be visualised in a three-dimensional space. The location of the points and the distances between them describe the dissimilarity/similarity of the landscape units. Two approaches were considered during the evaluation. In version A, only natural factors were involved in the calculations, whereas in version B, both natural and anthropogenic factors were considered. Similarity was evaluated based on the taxonomic distances from the cluster centroids.

Kruskal's stress test (Kruskal, 1964) was used to measure the goodness of fit (S) before and after the dimension reduction (the difference between the original and the computed Euclidean distances).

The results of the test were described as excellent ($S<0.05$), good ($0.05<S<0.1$), medium ($0.1<S<0.15$), or poor ($0.15<S<0.2$). If $S>0.2$, the given number of dimensions is not acceptable due to the high variance (Kruskal, 1964; Kruskal and Wish, 1978).

Agglomerative Hierarchical Clustering (AHC) identifies clusters based on the dissimilarity matrix data of the landscape units. The AHC, as an iterative classification method, results in a hierarchical structure of the input datasets based on a bottom-up approach. In the AHC algorithm, the aggregation criterion is based on variance (Rolet and Seguin, 1986) using the Ward formulation (Ward, 1963), which ensures that at each step of the clustering, the overall heterogeneity is minimised, and the separation between classes is maximised. Using the AHC method, landscape units were clustered into 4 groups.

Results

According to the correlation matrix of the investigated parameters (*Table 2*), a strong positive relationship between the relief and forest cover (0.86) and a strong negative correlation between forest cover and hemeroby (-0.78) were identified. Avoiding duplications, the forest cover and hemeroby parameters were excluded from further investigations because they are partially involved in the vegetation, built-up areas and fragmentation parameters. The reason for this exclusion was confirmed by the results of the principal component analysis.

The principal component analysis based on all (9) parameters resulted in two main dominant variables (F1-F2). F1, the most dominant factor involved the relief, soil, forest cover, vegetation and hemeroby parameters, with relief as the most important factor. F2 involved built-up areas, referring to the anthropogenic effects. F3, F4 and F5 included fragmentation, vineyards and climate factors, respectively. These variables corresponded to the factor for which the squared cosine is the largest. The eigenvalues of F4-F9 were less than 1 (*Fig. 3*); thus, they were not considered.

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Table 2. *Correlation matrix of the investigated parameters (Pearson correlation, n=230)*

Parameters	1	2	3	4	5	6	7	8	9
1 relief	1	-0.523	-0.431	0.677	0.860	-0.177	-0.008	-0.228	-0.711
2 soil		1	0.259	-0.203	-0.527	0.026	-0.073	0.014	0.691
3 climate			1	-0.492	-0.411	0.173	0.014	0.078	0.305
4 vegetation				1	0.769	-0.342	-0.051	-0.281	-0.458
5 ratio of forest cover					1	-0.290	-0.009	-0.140	-0.785
6 ratio of built-up areas						1	0.058	-0.237	-0.105
7 ratio of vineyards							1	-0.125	0.122
8 fragmentation								1	-0.015
9 hemeroby									1

Based on the results of the correlation and principal component analyses, 7 parameters were applied in the investigation of landscape similarity. In version A, natural factors (relief, soil, climate and vegetation) were included in the calculations, and the resulting 0.002 value of Kruskal's stress test indicates an excellent fit. In version B, both natural (relief, soil, climate and vegetation) and anthropogenic factors (ratio of built-up areas, ratio of vineyards and fragmentation) were included in the calculations, and the resulting 0.01 value of Kruskal's stress test also indicates an excellent fit. In both versions, four clusters were separated using the AHC method.

The clusters and their centroids (centroid landscape units) in version A were visualised in 3D in *Figure 4*, demonstrating the dense point cloud and the clusters. The calculated distances were shown in *Table 3*. Based on the results, 101, 33, 93 and 3 elements were clustered into Clusters 1, 2, 3 and 4, respectively.

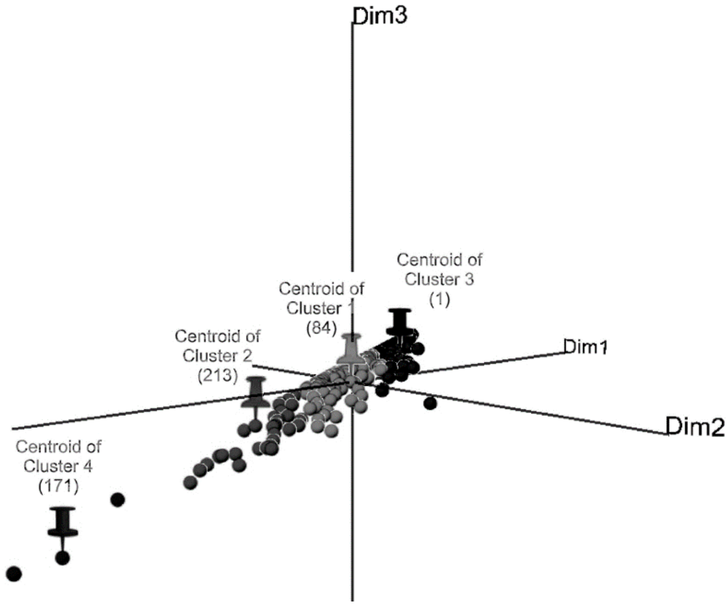

Figure 4. *Clusters in version A and their centroids in 3D space*

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Table 3. *Distances between cluster centroids in 3D space in version A*

	Cluster 1 (84)	Cluster 2 (213)	Cluster 3 (1)	Cluster 4 (171)
Cluster 1 (84)	0	146.75	82.77	443.24
Cluster 2 (213)		0	229.33	298.33
Cluster 3 (1)			0	525.93
Cluster 4 (171)				0

The taxonomic distances from the cluster centroids were the basis of the determination of similarity; however, the definition of the boundaries for outliers in the clusters was not straightforward. The statistical analysis of the distances from the cluster centroids (excluding points of Cluster 4) indicated a frequency limit at 70% of the distances; thus, this value was applied as a criterion for similarity. Using this criterion, 25 landscape units were selected for which the revision of the grouping might be necessary (*Fig. 5*).

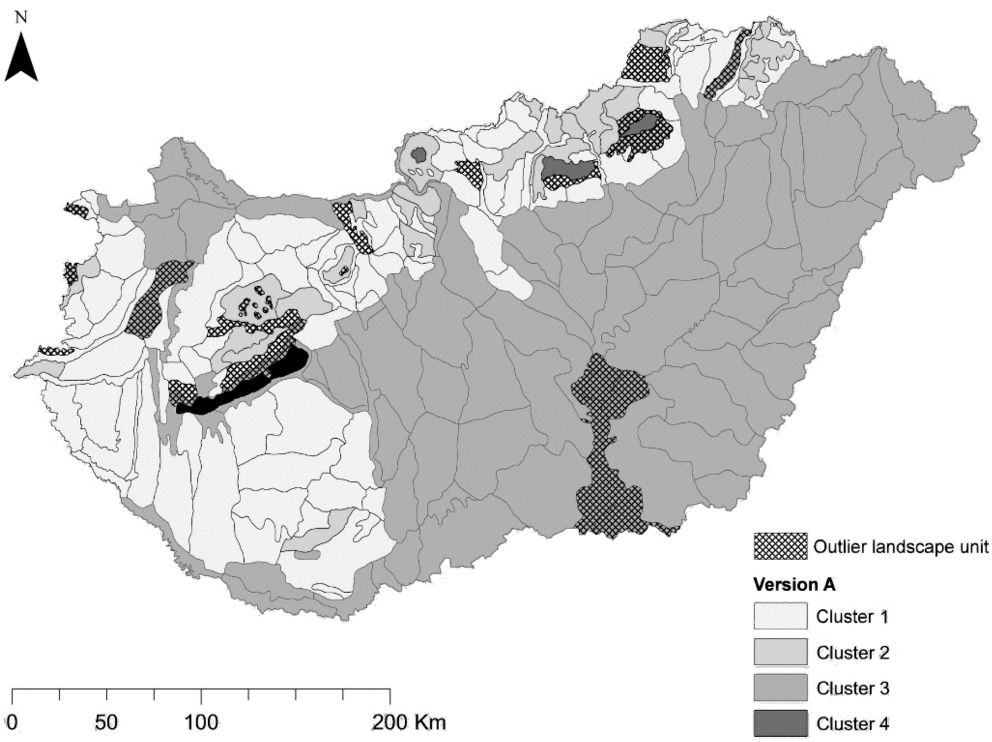

Figure 5. *Clusters in version A and outlier landscape units*

In version A, Cluster 1 was defined by medium relief and significant topsoil-thickness; Cluster 2 was characterised by high relief and high EVI averages indicating high forest cover; the lowest relief was observed in Cluster 3; and the landscape units of Cluster 4 were defined by the smallest topsoil thickness, highest relief and high EVI averages, also indicating high forest cover.

The version B analysis had similar results. The clusters and their centroids were visualised in 3D in *Figure 6*, and the calculated distances between them were given in

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Table 4. According to the results, 101, 36, 88 and 5 elements were clustered into Clusters 1, 2, 3 and 4, respectively. In this version, 25 landscape units were selected for which the revision of the grouping might be necessary (*Fig. 7*).

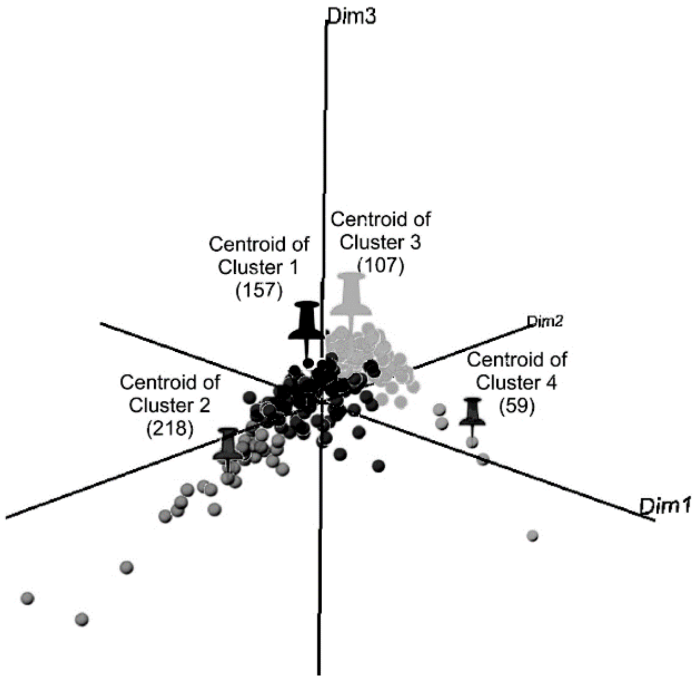

Figure 6. *Clusters in version B and their centroids in 3D space*

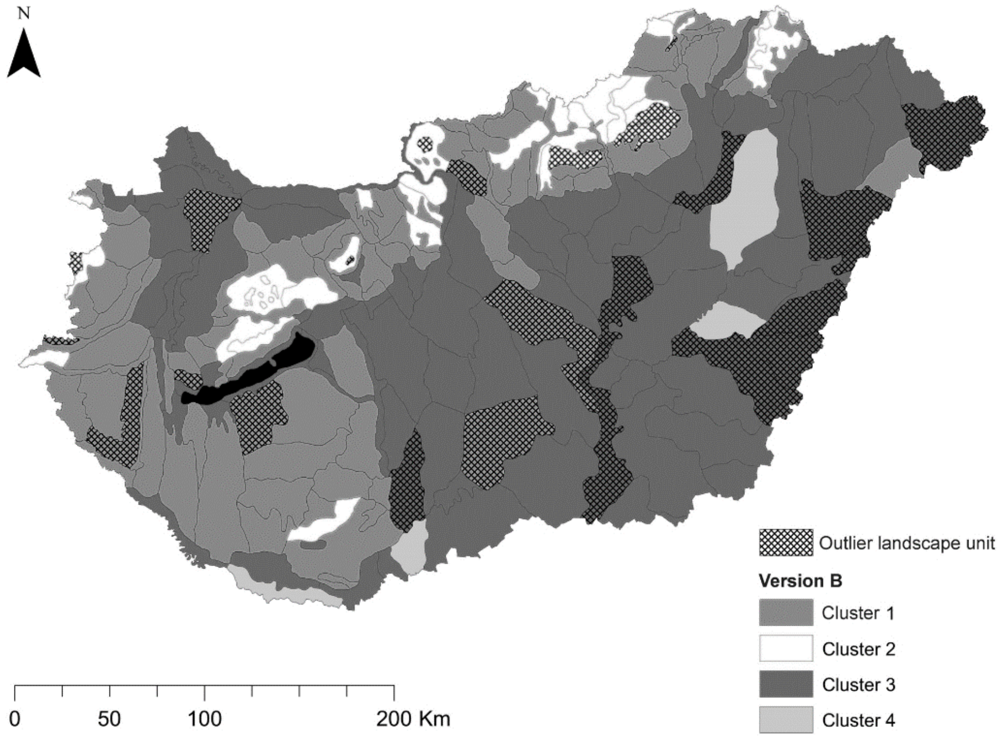

Figure 7. *Clusters in version B and the outlier landscape units*

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Table 4. *Distances between cluster centroids in 3D space in version B*

	Cluster 1 (157)	Cluster 2 (218)	Cluster 3 (107)	Cluster 4 (59)
Cluster 1 (157)	0	172.10	81.45	294.45
Cluster 2 (218)		0	250.45	413.97
Cluster 3 (107)			0	283.77
Cluster 4 (59)				0

In version B, Cluster 1 was defined by medium relief and relatively high averages of built-up areas and vineyard cover; the highest relief was characteristic of the landscape units of Cluster 2; Clusters 3 and 4 were similarly characterised by low relief, high topsoil thickness, and a higher ratio of built-up areas, but cluster 4 was separated due to low fragmentation (higher effective mesh size). These areas were located along rivers without substantial linear infrastructure.

The A and B assessments defined outlier landscape units (marked with stripes in *Figures 5 and 7*); furthermore, certain landscape units were assigned to different clusters in the two different approaches. In these cases, further assessment of the linkages with the neighbouring landscape units should be considered.

Table 5 presents examples where taxonomic distances may reveal the dissimilarity of neighbouring landscapes or confirm that they should be merged based on their similarity. In several cases, clear answers cannot be obtained. For example, among the lowland landscapes, units 7 and 8 (Mohács Island and Mohács Terrace Plain) are relatively close, based on their taxonomic distance; thus, they might be merged according to version A.

Table 5. *Taxonomic distances (based on MDS) between selected landscape units*

Version A			Version B		
unit IDs	clusters	taxonomic distance	unit IDs	clusters	taxonomic distance
7-8	3-3	**4**	7-8	**4-3**	**139**
226-227	1-1	**18**	226-227	1-1	23
226-223	1-1	80	226-223	1-1	96
227-223	1-1	61	227-223	1-1	74
194-195	2-2	**16**	194-195	2-2	**16**
194-193	2-4	**274**	194-193	2-2	**245**
195-193	2-4	**262**	195-193	2-2	**256**

The consideration of more parameters in version B resulted in higher taxonomic distances between them and their placement into different clusters, confirming the opposite result (they cannot be combined). Among the hilly landscapes, similar results occur. In the case of the neighbouring landscape units 223, 226, and 227 (Sajó Valley, Rakaca Valley, and Eastern Cserehát), 226 and 227 can be combined based on the results of both versions of the analysis. However, the two units are both at greater distances to the neighbouring landscape unit, 223, in the same cluster, indicating their dissimilarity.

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To analyse the mountainous landscapes, the landscape units of the Bükk Mountains are used as an example. Landscape units 194 and 195 (Northern and Southern Bükk) are characterised by low taxonomic distances and belong to the same clusters; thus, they can be merged. However, both units differ from the neighbouring unit, 193 (Bükk Plateau); thus, their separation is reasonable (they belong to different clusters in version A).

The results confirm the revised landscape unit classification in the new Hungarian National Atlas (publication is expected in 2016), where simplification of the previous classification and the mitigation of political influence were the basis of the reconsideration of the landscape units.

Discussion and conclusion

European landscapes and those of the Carpathian Basin are characterised by high diversity. The preservation of the mosaic character has become important and is increasingly a target of many countries in Europe (e.g., European Landscape Convention). In this study, the similarity of the landscape units was assessed. The focus of the assessment was not to highlight the similarity of landscapes but to develop a quantitative basis for landscape assessment.

In geoscientific studies, at least three different landscape concepts exist (focusing on the formation, the functions or the land use of the landscape), but these concepts are not clearly distinct approaches. Within these concepts, different factors describe the system; thus, the assessments integrate different parameters. Whether the land use or visual character of the landscape can be properly characterised based on traditional genetic or functional parameters is still under debate. The higher the naturalness of a landscape unit, the more obvious the relationship between the genetic type and the landscape character (Brunce et al., 2007; Li and Wu, 2007; Csorba, 2008; Breuste et al., 2009)

In the case of most European landscapes, the knowledge of the genetic processes (e.g., a hilly landscape formed by aeolian processes) or the functional parameters does not provide useful information for practical assessment. Practical application requires data on land use (e.g., arable lands) or visual characteristics for planning and development purposes, which can be obtained by applying assessments of landscape character and landscape indicators (LCA, 2014).

In the optimal case, the land use and the landscape character fit the potential natural attributes of the landscape (Pietrzak, 2000; Tress et al., 2003; Li and Wu, 2007). This match between character and land use would support increased economic sustainability, because adapting to the inherent potential causes the least impact on the system and also requires the least effort to maintain the land use. Land use was adapted to the natural attributes of the landscape for centuries, but many attributes have been irreversibly altered, and social needs have extended far beyond the natural potential.

The methods applied in this study provided a more objective statistical comparison of landscapes. A wide range of possible indicators exists (in addition to those used in this assessment) but with special care of the correlations of the parameters, furthermore several different approaches (e.g., function or use) can also be considered in landscape assessment. The grouping of the applied indicators may also allow more focused similarity assessments.

Statistically correct clustering does not guarantee that the resulting groups are clearly interpretable in the landscape classification. The clustering of similar landscapes into different meso-level landscape units indicates failure. This problem refers back to the

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landscape concept. If landscapes are considered the integration of natural and social factors, their describing parameters depend on the concept and the type of the landscape. Therefore, the selection of parameters describing the system cannot be 'standardised' because the most relevant parameters have to be involved in the assessment (Naveh and Lieberman, 1984). The integration of social factors that are not easily measurable is important, as demonstrated by the Hortobágy 'Pusta' (UNESCO world heritage) in Hungary. This landscape, typifying the ancient image of the Carpathian Basin, cannot be correctly described only by natural parameters because the social influence and grazing have contributed significantly to its present character.

The calculations in this study were based on integrated units and their hierarchical system. Other approaches exist for the joint evaluation of different factors and parameters; for example, the LANMAP project, which overlays four basic maps (climate, relief, lithology and land use), with the resulting map consisting of homogenous polygons that can be integrated into a system and grouped regionally or hierarchically (Wascher, 2005; Mücher et al., 2010). These homogenous units are not realistic for Hungarian territories, and several landscape character types are not represented. Moreover, the results differ significantly from the traditional classification, possibly because of the parameters applied and the European scale data. However, the results facilitated further research using other types and greater numbers of parameters. Based on the findings of the ELCAI (European Landscape Character Assessment Initiative), several landscape assessments applying new approaches were initiated in Europe (Pedroli et al., 2007; Krzywinski et al., 2009; Küster, 2010).

The problem with the landscape approach, which applies integrated units, is that the integration of ecological units into landscape unit classification is not well defined in every case. Therefore, the present landscape classification methods are still based primarily on modern geomorphology or social and economic factors (Haase, 1989; Wrbka et al., 2004), but they do not reflect the integrated character of the landscapes.

Multidimensional scaling has many applications, from geophysics to mental mapping. The assessment of functional vegetation clusters and multi-parameter assessments in ecology and zoology has confirmed its application in landscape ecological assessments (Clarke, 1993; García-Abad et al., 2010; Muenchow et al., 2013).

Quantifiable similarity can likely be effectively used for other theoretical landscape research and for practical application in landscape planning and protection. Landscape similarity results can contribute to the estimation of the regional scale effects of global changes. For example, landscape units can be classified based on landscape similarity to examine the regional scale effects of global climate change, trends in mass tourism or land use homogenisation (e.g. afforestation).

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