LANDSCAPE UNITS FOR HUNGARY USING MULTIRESOLUTION SEGMENTATION OF GEO-DATA AND FUZZY ANALYSIS

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Abstract: The result of the study is an objective delimitation of landscape units by combining mathematical-statistical multi-objective segmentation methods and digital maps using geo-statistics and a variable number of shaping factors. The starting point is the important scientific replication problem of traditional or subjective landscape units developed during recent decades (e.g., for Germany and Hungary) via the bordering of landscapes into macro-, meso- and micro-regions. Subjective and objective segmentation methods were compared using quality indicators. The study is based on fuzzy indicator maps of the shaping factors of the soil, lithology, potential natural vegetation, soil water management, hemeroby and slope. A multiresolution segmentation analysis was applied to Hungary to delimit the borders of the meso-scalic landscape units. The complex results were analysed and compared with two traditional Hungarian landscape delimitations and with the results of the European-wide Landscape Classification (LANMAP). The results of the regional comparative analysis first show that the multiresolution segmentation method is applicable at the micro-region scale level and additionally demonstrate that the segmented landscape units offer a landscape unit system for Hungary that is an alternative to the traditionally defined landscape units, which are scientifically validated to only a minor extent and are related to few past applications in territorial or landscape planning. The applied multiresolution segmentation methodology combined with fuzzy set methods and based on multiple layers of geodata is an acceptable and useful method to delimitate landscape units at various hierarchical levels.

Keywords: landscape borders; fuzzy sets; scale; landscape classification; geodata; indicators

1. INTRODUCTION

Delimiting the borders of areas, units or entities is a universal problem in the spatial and landscape sciences, particularly when addressing natural systems or socio-ecological systems. Administrative areas are commonly applied as units for the statistical analysis of municipal, regional or countrywide surveys, but the administrative borders of these areas are fixed by politics and are often changed throughout history. In contrast, landscape or natural borders and entities are seldom clear and distinct due to the transitional character of nature. Therefore, a landscape-based analysis should employ integrated units that require bordering ecotones; the ecotones represent zones and are not represented by simple lines on the map. An appropriate technique used to treat the ecotones as boundaries and apply them to distinct units such as objects (e.g., objects of decision-making) without treating the ecotones as unique pathes is the fuzzy logic approach rather than traditional Boolean logic techniques (Ji, 2002; Arnot & Fisher, 2007; Chong et al., 2010; Mezősi & Bata, 2011, Digiovinazzo et al., 2011). Fuzzy logic techniques can be combined with spatial metrics, as shown by McGarigal & Marks (1995) or Herzog et al., (2001).

However, planners prefer to use well-defined and accurate borders for analytic units in diverse investigations (e.g., in spatial and landscape planning, impact assessment, climate change predictions and other applications). Decomposition of a landscape hierarchical structure via multi-scale analysis is an important component of landscape

analysis, and O'Neill et al., (1986) recommended the use of three hierarchical levels for landscape units as a minimum in analytical studies (Haase, 1976, 1991; Drăgut & Blaschke, 2006).

In landscape ecology two main scientific approaches are applied to solve delineation problems: (1) the traditional method that combines a belt of shaping factors into a subjective delimitation of the unit or border (subjective segmentation), and (2) mathematical methods of segmentation via repeatable scientific methods using geo-statistics and digital geo-data (objective segmentation).

(1) The traditional belt method characterises the landscape based on landscape-shaping factors arranged hierarchically in micro-, meso- or macro-regions. Most landscape classifications available in Europe have been developed using these methods. The borders are generated by visually overlaying the borders of the constituent or shaping factors (i.e., geology, relief, soil, vegetation, climate, fauna and water household), which may be weighted. The delimitation process is performed by scientists, but it is not repeatable due to the subjective nature and the artistic drawing of the borders. The method by which the basic data are used for delimitation is generally unclear. The first examples using the traditional belt characterisation were applied approximately 100 years ago in Hungary using geomorphology in which the landform was used as the dominant character. Most of the later landscape or natural classifications were developed using geo-ecological and natural factors (Pécsi & Somogyi, 1967, Neef, 1967, Haase, 1976, 1991).

In Hungary, natural factors have been predominantly applied for the delimitation of landscape units. Thus, it is understandable that the drawn borders of landscapes closely follow the borders of geo-morphological units, for example (Pécsi, 1970). In the 1960's, Pécsi & Somogyi (1967) used scientific indicators to delineate the landscape in macro-, meso- and micro-regions, but this delimitation was based on traditional methods with shaping factors of indeterminate quality (Fig. 1). The technique of drawing borders was also defined according to the Russian school of landscape ecology (Isachenco, 1953; Preobrazensky, 1966; Solntcev, 1981) in which different regional types or characteristics of regions were classified using basic orography, soil, flora, geology, geomorphology and land use information as data for bordering. This classification logic resulted in manageable units. In this article, this technique will be referred to as the Traditionally-defined Landscape Units (TLU). The TLU has been widely applied, but the included parameters are not clearly defined, and several

modifications have been proposed to the borders for a subset of the landscape units (Ladányi et al., 2010; Ladányi et al., 2011; Deák & Bárány-Kevei, 2006; Molnár et al., 2008; Mezősi & Bata, 2011).

The Pécsi & Somogyi (1967) map (TLU) is used in this study as a basis of comparison.
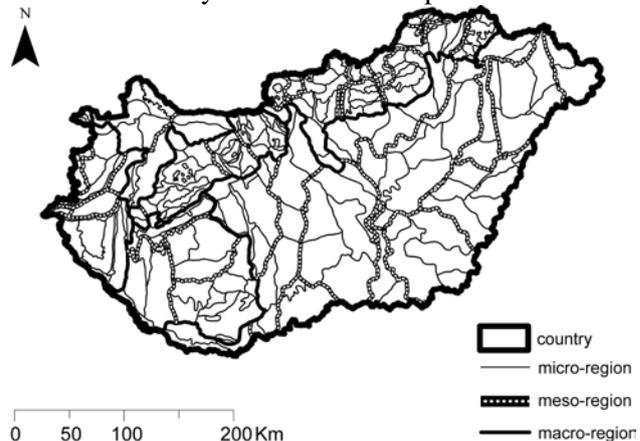

Figure 1. Landscape levels in Hungary as traditionally defined (Pécsi & Somogyi, 1967).

Other approaches have used landscape units as integrative units (Leser, 1997; Forman & Godron, 1986; Bastian, 2001), but land use was seldom integrated in general (Grabaum & Meyer, 1998). Several concurrent landscape classifications based on traditional methods have been developed for Hungary using combined data from fieldwork and various shaping factors, e.g., those of Molnár et al., (2008) (Vegetation-based Landscape Units-VLU) or Ladányi et al., (2010) (soil- and land-use-dominated landscape units).

(2) Image segmentation (i.e., multiresolution segmentation) enables the researcher to address a number of spatial factors in an integrative manner and treats landscapes as a complex system. Image segmentation methods were first developed in the 1970s (Haralick, 1973; Haralick & Shapiro, 1985). The segmentation approach was designed to analyse remotely-sensed (spectral) data (Burnett & Blaschke, 2003; Haralick & Shapiro, 1985; Ryherd & Woodcock, 1996; Baatz & Schäpe, 2000; Bock et al., 2005, Boutin et al., 2008; Lucas et al., 2011), but the method is also applicable to vector data (Mücher at al., 2010; Renetzeder et al., 2010). Several new segmentation algorithms and applications have been tested in geo-science applications in recent years, but per-pixel analyses are often criticised, as Blaschke & Strobl (2001) and Burnett & Blaschke (2003) have noted in detail. Object-based image analysis is useful to extend the landscape analysis beyond the pixel classifications and takes into account the sizes, shapes and positions of the objects

(Blaschke & Strobl, 2001; Drăgut & Blashke, 2006).

Several studies have clarified that multiresolution segmentation is an acceptable method for the delimitation of spatial units. This method allows the boundary calculations to be repeated in a transparent manner (Blaschke & Strobl, 2001; Mücher et al., 2010). Multiresolution segmentation was used by the European Landscape Character Assessment Initiative (Wascher, 2005) for the European Landscape Typology and Map (LANMAP). However, in the LANMAP application, only four shaping factors (climate, relief, lithology and land cover) were used at the large-scale and 1-km² spatial resolution. In the case of Hungary, the results of LANMAP are not fully comparable with the TLU of Pécsi & Somogyi (1967). The units of LANMAP also differ in the methodologically applied delimitation, the data sources, the scale of application and the nomenclature.

As detailed in the following sections, the objective of this paper is to present a method for determining spatial units by combining mathematical-statistical multi-objective segmentation with GIS methods. The authors briefly describe the Hungarian landscape delimitation systems, the data and methods applied, and the fuzzy maps of shaping factors calculated by the authors. Next, a segmentation analysis (a new map of landscape units) is presented for Hungary. The resulting Segmented Landscape Units (SLU) are analysed and compared with two traditional Hungarian landscape delimitations and with the LANMAP results (for which it is generally difficult to verify the quality of the segmentation map borders). The results are validated in three Hungarian regions to compare the subjective and objective classification results of diverse author groups.

2. STUDY SITES

Hungary is located in centre of the Carpathian Basin in Europe and has an area of approximately 93.000 km² (Fig. 2). During this research, each analysis was carried out throughout the entire country. Thus, for clarity in presenting the results, in certain cases (in the regional comparative analyses), only three typical smaller study sites (1-3) were shown. These study sites are located in the southern portion of the Great Hungarian Plain.

1. *The Kiskunság Loessy Ridge micro-region:*
The Kiskunság Loessy Ridge micro-region is a typical alluvial plain landscape covered by loess and sands and is located in the Danube-Tisza Interfluve in the Great Hungarian Plain (Dövényi, 2010).

2. *The Illancs micro-region:*
The eastern side of the Illancs micro-region is covered by a sand layer 20-30 m deep, and the southern edge is covered by loess (Dövényi, 2010).
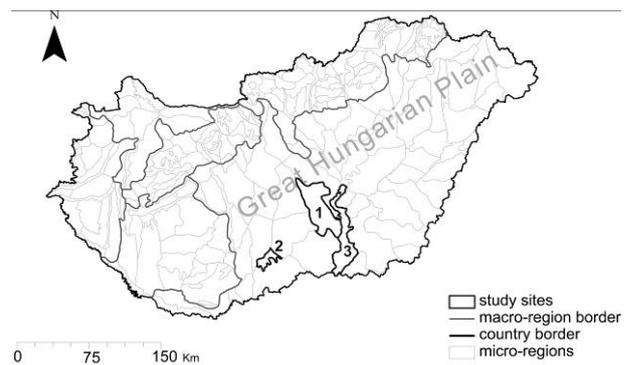

Figure 2. Regional study sites in Hungary

3. *The South Tisza valley micro-region*
This micro-region is located in the southern portion of the flood plain of Tisza River. The surface forms are active or historic waterways, including abandoned channels. Aeolian accumulation forms (e.g., sand dunes and sand sheets) are also typical geo-morphological forms of this micro-region.

3. DATA AND METHODS

3.1. Data

In the analysis, the landscape shaping factors of soil, lithology, potential natural vegetation, soil water management, hemeroby and the slope (relief) taken from different digital databases were applied at a regional scale of 1:100.000. The soil (1), lithology (2) and soil water management (4) data were available from the AGROTOPO spatial soil information system (Agrotopographical Database, 1991), and the potential vegetation map of Hungary was used for the vegetation (3) data (Zólyomi, 1989). The slope (6) was calculated from the SRTM (Shuttle Topography Mission) Digital Elevation Model (van Zyl, 2001), and human impacts were included in the study via the creation of a hemeroby map for Hungary (5) (Table 1).

Hemeroby is an integrated measure of the anthropogenic influence on landscapes or habitats (Naveh & Liebermann, 1984; Zechmeister & Moser, 2001). The hemerobic state was introduced by Jalas (1955) and modified by several authors (e.g., Bastian & Schreiber, 1994; Blume & Sukopp, 1976; Kowarik, 1988; Sukopp, 1969). The Corine Land Cover classes (European Environment Agency, 2000) were classified into seven levels of hemerobic state and adapted for Hungary by Csorba & Szabó (2009).

To obtain comparable data from different sources, the landscape shaping factors were classified into the same number of classes whenever

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possible. The soil (1), lithology (2) and soil water management (4) datasets include nine classes. The potential natural vegetation (3) classification contains ten classes because it was not possible to merge classes in this case. The ahemerobe class does not appear (Csorba & Szabó, 2009) in Hungary, and therefore six hemeroby classes (5) were used in the analysis. The slope (6) was classified into nine classes using the natural breaks of its histogram. This geostatistical method identifies the class breaks that best group similar values of slope and maximise the differences between identified classes (Jenks, 1967). An overview of all classes and parameters is given in table 1.

In the case of the three regional study sites, the detailed modifications of the TLU (Ladányi et al., 2010; Ladányi et al., 2011; Deák & Bárány-Kevei, 2006) formed the basis for the regional comparison analysis. The complex comparative analysis used the TLU (Pécsi & Somogyi 1967), the Vegetation-based Landscape Units (VLU) of Molnár et al., 2008, the European Landscape Typology and the Map (LANMAP) of the European Landscape Character Assessment Initiative (Wascher, 2005).

Table 1. Parameters of data categories and data sources for the digital input layers used in research

Landscape shaping factor	Source	Number of basic categories
soil	AGROTOPO	31
lithology	AGROTOPO	9
natural vegetation	potential vegetation map of Hungary	22
soil water management	AGROTOPO	9
hemeroby	Corine Land Cover map	28
slope	SRTM Digital Elevation Model	-

3.2. Applied methods

3.2.1 Multiresolution segmentation

Multiresolution segmentation is an optimisation procedure that minimises the average heterogeneity and maximises the respective homogeneity in the resulting unit for a given number of image objects from the layers. The method addresses the problem of integrating different data in a given rule set by handling the six input layers, the scale setting and the definition of compactness for the resulting map (eCognition Developer 8.7 - Trimble, 2011).

The Segmentation is sensitive to the scale parameter. For heterogeneous data, the resulting objects for a given Scale parameter will be smaller than those from more homogeneous data. To avoid affecting the emergent units in the segmentation process, the shape parameter was set to 0.1, and the compactness parameter was set to 0.5. These settings assure that 'natural' boundaries follow the obvious borders in the landscape for the resulting segments and avoid both fractal shapes and artificially compressed objects. Scale parameter settings between 50 and 300 were experimentally applied, resulting in different sizes for the calculated units (Table 2). Thus, in this investigation, an iterative approach was applied to find the optimal setting to obtain the same number of landscape units as in the TLU.

Table 2. Experimental segmentation results for the SLU using different Scale parameter settings

Scale parameter	Number of segmented units	Max area (km^2)	Mean area (km^2)	Min area (km^2)
300	41	7263.83	2168.12	17.4
270	44	7263.83	2113.48	17.4
250	56	6994.48	1660.55	17.18
210	78	4950.4	1192.13	17.18
190	92	4950.4	1010.71	13.16
150	131	3612.39	709.81	13.16
130	174	3365.22	534.4	10.47
120	201	3365,22	462,6	10,47
115	230	2593.62	404.27	7.48
110	260	2593.62	356.26	7.48
70	548	1188.32	166.03	7.48
50	1067	1008.34	87.14	2.54

A scale of 115 results were produced that were comparable to the landscape units for the TLU with the same number of landscape units (230). To further compare the TLU and the SLU, the landscape metrics were calculated using FRAGSTATS software (McGarigal & Marks, 1995, Szabó et al., 2012). The Largest patch (LP), Smallest patch (SP), Number of patches (NP), Mean patch size (MPS), and Mean fractal dimension (MFRACT) metrics were measured to indicate naturalness (Herzog et al., 2001; Zebisch et al., 2004; Wrbka et al., 2004; Winter & Fischer, 2010). The Fractal dimension index reflects the shape complexity across a range of spatial scales (patch sizes). Similar to the Mean shape index, it overcomes one of the major limitations of the straight perimeter-area ratio as a measure of shape complexity (McGarigal & Marks, 1995).

The metrics used to indicate sensitivity are the Sum of border length, the Per unit length of borders, the Core area index (CAI) and the Mean shape index (MSI) (Mas et al., 2010). The Core area index represents the area in the patch greater than the specified depth-of-edge distance (2 km in this case) from the perimeter. The Shape index corrects for the size problem of the perimeter-area ratio index by adjusting for a square standard and, as a result, is the simplest and perhaps most straightforward measurement of the overall shape complexity (McGarigal &Marks, 1995).

The TLU is the result of a subjective segmentation process. In that segmentation, the integration logic is different for the plain and the hill regions. For example, in the plain region (0.0 – 200.0 m), the borders of the soil or the "natural" vegetation are used to determine the borders of the micro- or meso-regions; in hilly (200.1 – 500.0 m) and mountainous (>500.0 m) regions, the geological, orographic, and land use maps were used instead (in that order). Therefore, the TLU and the SLU were compared in these categories to demonstrate the differences between the results of the objective and subjective segmentation processes.

3.2.2. Fuzzy map of Hungary using six landscape shaping factors.

Mezősi & Bata (2011) used the fuzzy logic method to define the borders of the landscape units. In accordance with this fuzzy logic method, the landscapes are considered in sets of "soft" boundaries of the landscape shaping factors (McBratney & Odeh, 1997; Arnot & Fisher, (2007).

The fuzzy analyses require unified numerical input data for each landscape shaping factor, therefore the homogeneity values of the landscape shaping factors for each landscape unit (micro-region) were calculated. Thus, in the preparation of the rough input data (Table 1), the value of homogeneity was measured using the percentages of the soil (1), lithology (2), potential vegetation (3), soil water management (4), hemeroby (5) and slope (6) categories within the micro-region. The resulting figures provide the basis for fuzzy analysis. Additionally, for comparative analysis, this fuzzy result map was used to show the differences between the borders of the TLU and the borders of the new SLU.

The calculation in this study uses the fuzzy sets defined and classified as (Fig. 3.):
- Landscape Core Zones: The areas with a homogeneity value higher than 70% belong to the set of homogenous landscape cores (these areas appear on the result map with a value of 0),
- Border Zones: The areas with a

homogeneity value lower than 30% belong to the set of border zones (these areas appear on the result map with a value of 1),
- Transitional Zones: The areas with a variable homogeneity value between 30% and 70% are given a new value that indicates the percentage by which they belong to one or the other sets.
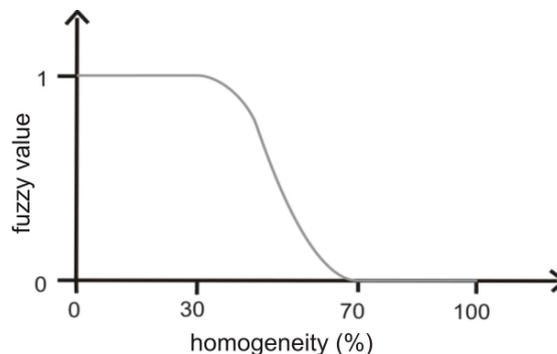

Figure 3. The applied fuzzy membership function

This rule set was applied individually for each of the six landscape shaping factors, and subsequently, the average calculation was applied for integration in the fuzzy set operation (Mezősi & Bata 2011).

4. RESULTS

4.1. Segmentation Analysis

In this study, the segmentation process was based on the thematic data layers (shaping factors) (Table 1): soil (1), lithology (2), potential natural vegetation (3), soil water management (4), hemeroby (5) and slope (6). Each thematic layer was aggregated to a 100-m spatial resolution. The data were transformed into raster files, and the procedure handled these layers simultaneously (similar to a spectral image with six bands) by applying the mutual best-fitting rule.

During the segmentation process, the same number of SLU units (230) was created, similar to the TLU (230). In the case of SLU, the LP is 2593.62 km^2, and the SP is 7.48 km^2. The difference between the LP and SP is 2586.14 km^2. In case of the TLU, the difference is 1817.7 km^2 (the LP is 1829.15 km^2, and the SP is 11.45 km^2). The value of the MFRACT metric is increased, and the value of the MPS index is decreased in the segmentation. This result means that the degree of naturalness is higher in the SLU than in the TLU because the SLU displays more complex, fragmented, and natural borders than the TLU. These results are in agreement with the results of Herzog et al., (2001) and Renetzeder et al., (2010).

Table 3. Calculated metrics for comparison of the TLU and SLU in terms of naturalness and sensitivity

Metric	TLU	SLU
To indicate naturalness:		
Number of patches (landscape units)	230	230
Largest patch (km^2)	1829.15	2593.62
Smallest patch (km^2)	11.45	7.48
Mean patch size (km^2)	404.35	404.26
Mean fractal dimension	1.184	1.216
To indicate sensitivity:		
Sum of border length (km)	13428.28	33752.00
Per unit length of borders (km)	58.38	146.75
Core area index (%), using 2 km edge	30.05	37.39
Mean shape index	1.72	2.31

In the case of the TLU, the sum of the border length is 13428.28 km, and this value is 33752.00 km for the SLU. However, the difference between the Per unit length of borders is not large (88.37 km/unit). The calculated CAI for the SLU is 37.39% CAI (%), and for TLU, this value is 30.05%. Using the same value of the edge (2 km), the SLU is characterised by larger core areas, but 19 landscape units have no core area; these units are smaller than the value of the edge (2 km), and the shapes of the units are more fragmented. The MSI of the SLU is 2.31, much higher than that of the TLU (1.72). Therefore, according to the interpretation of Mas et al., (2010), the sensitivity of the shape of the SLU segmented units is higher, e.g., in terms of the external human impacts.

In the following, the number of units and the average heterogeneity of the TLU and SLU have been aggregated to the plain, hill and mountain classes due to the high importance of these landforms for the delimitation of the landscape borders of the TLU (Table 4). The number of SLU units in the plains class is higher (145) than that of the TLU (97), and there are 66 SLU units for the hilly class and 19 to 45 for the mountainous class. A lower average homogeneity was calculated for the SLU for plains and mountainous units, but hilly units displayed the same average homogeneity (Fig. 4).

Table 4. Number of units and average heterogeneity of the TLU and SLU landscape units aggregated for plain-hill-mountain classes.

		Number of units	Percent of Hungary	Average heterogeneity
TLU	Plain	97	63.4	3.5
	Hill	88	28.0	3.3
	Moun-tain	45	8.6	3.8
SLU	Plain	145	61.9	2.3
	Hill	66	32.0	3.3
	Moun-tain	19	6.1	3.5

4.2. Comparative analyses

In this study, a classical segmentation validation similar to that that used for remote-sensing data would ideally be segmented into patches that could be validated using area-based measures or location-based measures such as field survey mapping (Marignani et al., 2008; Mathieu et al., 2007; Jacquin et al., 2008; Clinton et al., 2010; Möller et al., 2007; Shi et al., 2007; Johansen et al., 2010).
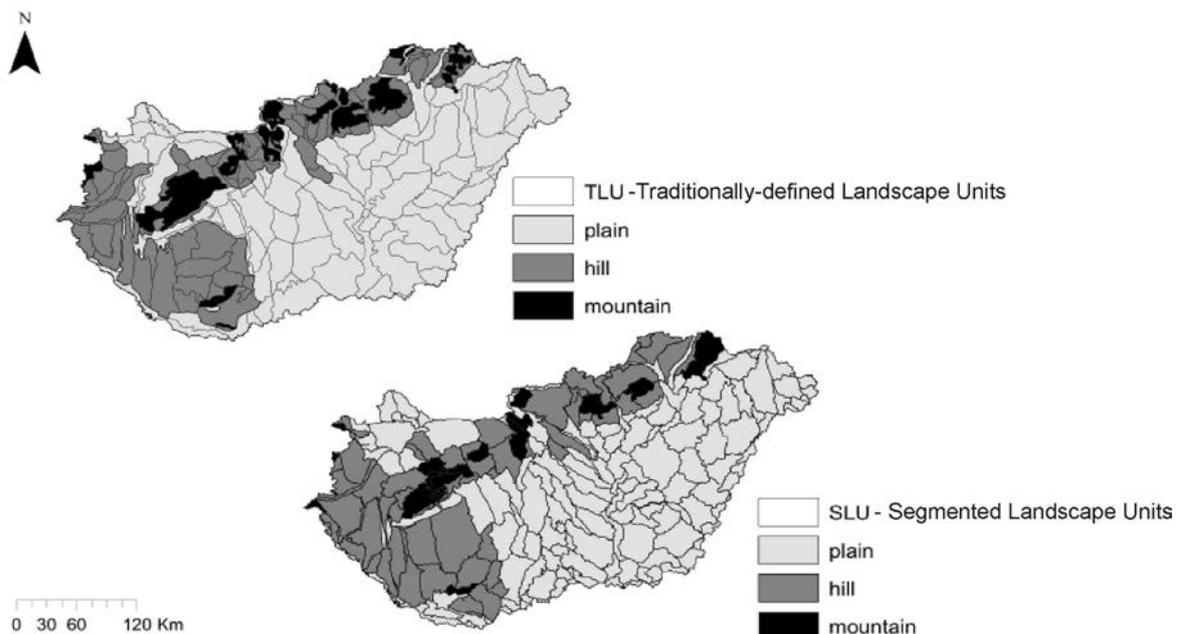

Figure 4. The TLU and the SLU in plain-hill-mountain regions.

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The key problem is that no delimitation system of landscape units exists that is widely accepted by the geo-scientific community in Hungary, which means that no basic reference units or data exist to validate a new segmentation system such as the SLU. Previous research has resulted in modifications to the TLU borders, and new subjective segmentation systems have been proposed (Ladányi et al., 2010; Deák & Bárány-Kevei, 2006; Molnár et al., 2008; Mezősi & Bata, 2011). The applied methodology results in a new fundamental landscape unit system for Hungary. Nevertheless, different analyses were applied to compare the different delimitations of the landscape units in a complex manner.

Table 5. The proportions (%) of the overlapping borders at 1-km resolution

	TLU (%)	VLU (%)	LANMAP (%)	SLU (%)
TLU (%)	_	35.12	31.19	34.00
VLU (%)	40.72	_	33.14	66,33
LANMAP (%)	28.02	25.68	_	30.25
SLU (%)	33.33	33.27	33.01	_

4.2.1 Complex comparative analyses

The fuzzy analyses show that the average width of the border zone is 1 km in Hungary therefore to compare the borders of the different delimited landscape units, the borders were converted into raster lines of 1-km spatial resolution. This method aids in contrasting the borders because vector-based borders can only intersect, whereas raster formatting of borders can create overlap. The table 5 is not a symmetric matrix; because the various landscape delimitations have different lengths therefore the ratio to each other cannot be equal. As Table 5 shows that the borders of the TLU overlap within 40.72% with the borders of the VLU; however, the converse value is only 35.12%. The borders of LANMAP are equal to 33.14% of the VLU. The SLU shows a best match with the VLU with 66.33% overlap of all borders. According to these results, the borders of the SLU are located nearest to the borders of VLU as a result of a subjective segmentation and complex field research.

4.2.2. Comparative analyses via application of fuzzy logic

The applied fuzzy logic for the TLU and SLU is shown in figure 5. For the TLU, only 30.51% of Hungary belongs to the class of landscape cores whereas 41.92% belongs to the class of transitional zones (in several units of the entire micro-region).

Only 27.58% belongs to the border zones. In the SLU, the border zone (fuzzy value: 0.31-0.70) is smaller than of the TLU (21.37% of Hungary).

This fuzzy analysis has clarified and justified the proposition that new and better fitting landscape delimitation methods should be identified as proposed by the SLU, particularly in the border zones and in the core zones.
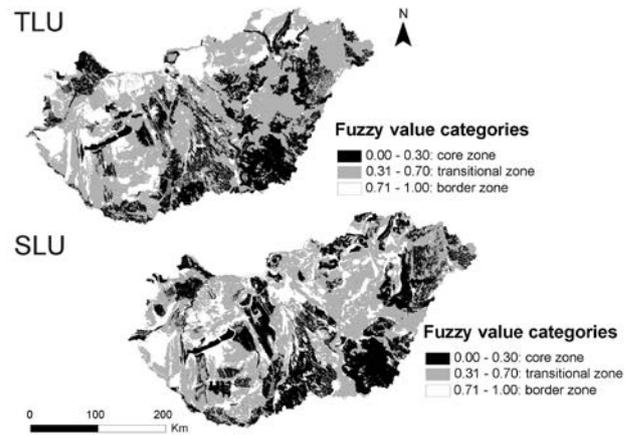

Figure 5. Landscape core-, transitional - and border zones as results of applied fuzzy logic classes for the TLU and SLU of Hungary

4.2.3. Regional comparative analysis

Three typical landscape units (see Fig. 2 and Figs. 7-9) in the Carpathian Basin SLU were compared in detail with the TLU and additional field investigations.
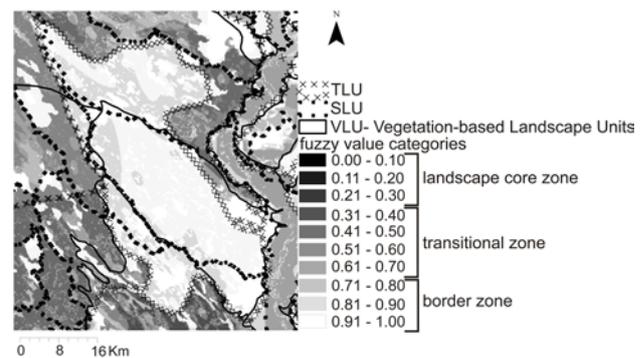

Figure 6. Comparison of the different landscape delimitations of the Kiskunság Loessy Ridge micro-region

a) Kiskunság Loessy Ridge micro-region

In the south-eastern portion of the Kiskunság Loessy Ridge micro-region (Fig. 6), the borders consist of ecotones with a width of approximately 4-8 km. This ecotone region belongs to the class of Border zones (fuzzy value: 0.71-1.00) in the fuzzy analysis (see Section 3.2.2.). The map also shows that the borders in the TLU are well located whereas

the borders of SLU are nearly overlaid. For the multiresolution segmentation and fuzzy analysis, the SLU results in smaller and more homogenous units. The SLU unit in the centre of the map is quite similar to the border of the VLU regions. The average distance between the VLU and SLU is 2.75 km, the largest distance is 10 km, and the smallest distance is less than 1 km. These results strongly support the SLU, and in this area, it is clear that the borders of the TLU should be modified and that multiresolution segmentation processing is a good choice for creating new landscape delimitations.

b) Illancs micro-region

By considering the surface lithology and land use and applying the fieldwork of the Illancs micro-region, Ladányi et al., 2010 recently refined the borders of the TLU. In this micro-region, the NW and SE borders can be interpreted with fuzzy logic as ecotones with an average width of 3-5 km at the NW border (Fig. 7). Several parts of the SLU are located near the Illancs areas defined by Ladányi et al. (2010) with an average distance of less than 1 km. Comparing the borders of SLU with the fuzzy result, it is obvious that the borders of the SLU were moved northwards in the segmentation process.

The results of the SLU are quite similar to those modifications of the complex landscape in an ecological analysis carried out by Ladányi et al. (2010). Thus, the multiresolution segmentation process is appropriate for landscape delimitation in this micro-region.
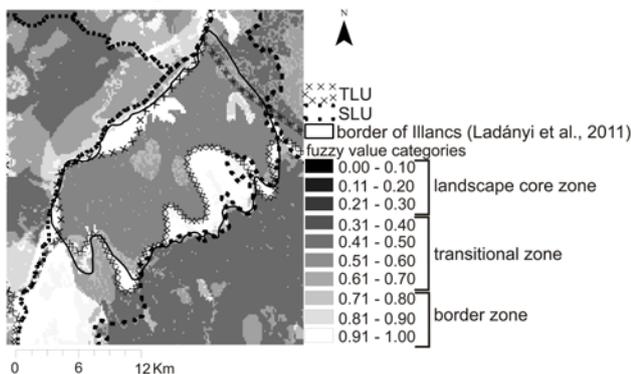

Figure 7. Comparison of the different landscape delimitations for the Illancs micro-region

c. South Tisza valley micro-region

In the area of the South Tisza valley, micro-region modification of the landscape borders was suggested by complex landscape ecological analysis (using soil and vegetation factors and habitat maps created by fieldwork) (Deák & Bárány-Kevei, 2006).

The fuzzy analysis clearly shows that this region belongs primarily to the transitional zones (fuzzy value: 0.31-0.70) in which new landscape

delimitation is helpful to clarify the differences in the shaping factors (Fig. 8). Both the fuzzy and complex landscape ecological analyses show that in this region, the SLU is delimited into a larger number of landscape units compared with that of the TLU. Several borders of the SLU are similar to the proposed modifications of the landscape ecological analysis. The difference between them is less than 1.5 km, an acceptable rate at a Scale of 1:100.000. In this plain and river region, more numerous and smaller landscape units should be delimited. Thus, the SLU results in adequate delimitations.
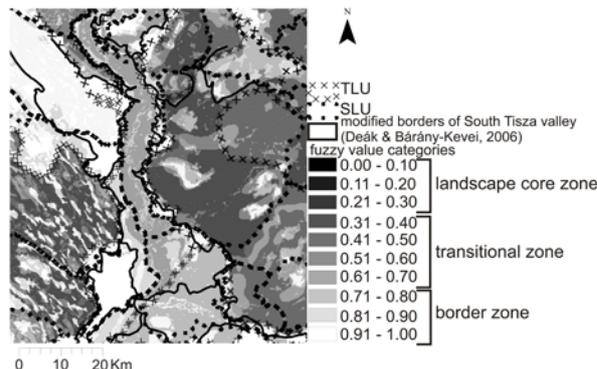

Figure 8. Comparison of the different landscape delimitations in the South Tisza valley micro-region

5. DISCUSSIONS

In Hungary, the TLU delimitation of landscape units developed by Pécsi & Somogyi (1967) is still in use after a 50-year history of criticism in terms of its subjective character. The selection of adequate factors for delimitation of this map and the decision-tree approach applied to integrate the step-by-step factors in the delimitation has created major problems. The application of the TLU also means that the factors are significantly weighted according to empirical knowledge only (Haase, 1976, Marks, 1979). The TLU exhibits a further weakness in that the indicators/parameters used are mostly of a nominal data type; therefore, the scope of the executable statistical operations for verification is rather limited.

All of these observations have stimulated the authors to develop new landscape delimitations for Hungary that handle the above-mentioned problems using basic mathematical and statistical computations. If such tasks of landscape planning, land development, spatial arrangements of land uses or protection of selected habitats must be performed, then an accurate and meaningful delimitation of landscapes is also essential, as are the associated margins of error. Certain delimitation problems of landscapes at the micro-scale were discussed in the 1980s (Mosimann, 1984; Forman & Godron, 1986;

Leser, 1997). At the macro-scale, delineation was carried out by traditional overlay via subjective segmentation methods until the early 2000s, and modern statistical methods were seldom applied as developed for LANMAP for the European scale (Wascher, 2005). However, at the meso-scale, the above-mentioned problems are obvious, and a relevant methodological solution was not available.

Two main solutions exist to delimit the borders using subjective or objective segmentation methods. In the following, the authors review the differences for Hungary (Fig. 9).

The Traditionally-defined Landscape Units (TLU) and the Vegetation-based Landscape Units (VLU) are the results of subjective segmentation processes. The LANMAP map and the Segmented Landscape Units (SLU) created in this study are both calculated using objective segmentation methods. In this analysis, the authors have defined new landscape units (SLU) using objective segmentation (multiresolution segmentation) and methodological steps that do not contain subjective or non-repeatable settings or weighting factors such as those used in the TLU (Pécsi & Somogyi, 1967).
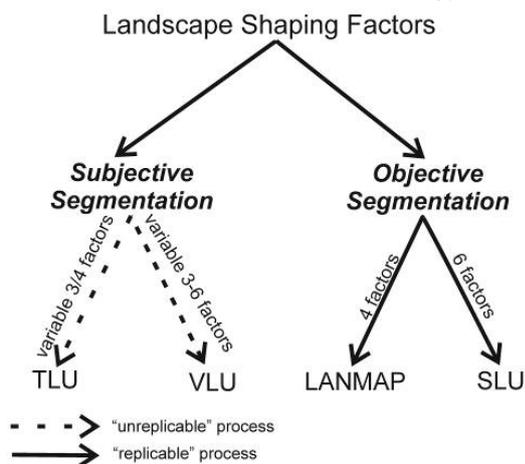

Figure 9. Methods used to delimitate the different Hungarian landscape units.

In the segmentation process, classified factors with quantifiable geo-information data were taken into consideration. Thus, other factors that incorporate the social sciences, ethnography, and cultural sciences are not included although they may be important in other applications (e.g., regional planning). The aim of our study was to delimit the regional landscape areas using these neutral (unweighted) units. The new SLUs have patterns and ecological parameters similar to those of the TLU (Number of patches, Mean patch size, Mean fractal dimension, and Core area index (Table 3). The applied method for delimiting the SLU uses more detailed data than the LANMAP (Mücher et al., 2010), and additional parameters in much smaller territorial units were included in the segmentation process.

If the delimitation process was carried out through a subjective segmentation, e.g. the knowledge of botanists from the different landscape types (VLU) significantly enhanced the quality of the segmentation. The TLU and VLU use similar parameters and techniques. In both methods, subjective segmentation was combined with fieldwork, and the delimitation processes are not repeatable. From the four delimitations compared in this work, the TLU used the fewest shaping factors. The delimitations of the LANMAP units and SLU are the result of objective segmentation; therefore, both applied methods that are replicable. Compared with the LANMAP units, the SLU integrates a higher number of landscape-shaping factors by applying a much higher spatial resolution, which results in SLU units that are more homogeneous (Table 6).

Table 6. General comparative analysis of four landscape delimitations of Hungary

	TLU	VLU	LANMAP	SLU
Number of units	230	109	160	230
Information density	1: 100.000	1: 200.000	1: 1.000.000	1: 100. 000
Number of used landscape shaping factor	3-4	3-6	4	6
Fieldwork applied?	Yes	Yes	No	No
Delimitation process is repeatable?	No	No	Yes	Yes

6. CONCLUSIONS

As described by the example of Hungary, the delimitation of landscape units was prepared using subjective segmentation, which does not provide the ability to repeat or control the resulting map TLU (Pécsi & Somogyi, 1967). To create a repeatable and scientifically well-described delimitation, an objective segmentation methodology based on multiresolution segmentation was adopted in this study from remote-sensing applications on the data integration problem for landscape delimitation problems.

In an earlier example, multiresolution segmentation (as a method) was used by the European Landscape Character Assessment Initiative on a large scale (Wascher, 2005) for the European Landscape Typology and Map (LANMAP). The aim of our study was to further develop this idea by applying more accurate

landscape shaping factors and a better spatial data resolution at the meso-scale.

In this study, a "classical segmentation validation" could not be elaborated upon because no generally accepted basis data for the validation are available for the new SLU. Thus, the borders of the SLU were compared in a stepwise analysis. A complex comparative analysis showed that the locations of the borders of the SLU are similar to the borders of the VLU, with an overlap area of 66.33%. Thus, the applied multiresolution segmentation is well suited to serve as a new landscape unit system for Hungary. At the same time, the SLU can avoid costly fieldwork needed to delimit the landscape units if sufficient and good quality data are available for multiresolution segmentation. In comparison with the LANMAP units, the SLU used additional landscape shaping factors and a higher spatial resolution.

The regional comparative analyses showed that in three regions, the applied multiresolution segmentation method is highly applicable at the micro-region scale level to delimit landscape units. These analyses also demonstrated that the SLU offers a new landscape unit system for Hungary. The multiresolution segmentation methodology combined with fuzzy set methods and based on multiple layers of geo-data is useful and objective for delimiting landscape units at various hierarchical levels, e.g., in landscape or territorial planning.

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