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Mathematical-statistical investigations of the meso scale landscape units' border

Theses of Ph. D. Dissertation

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1. Introduction

In Hungary the issue of landscape borders has been dealt with since the early years of the XX. century. Several approaches have become known for defining landscapes units but mainly practical reasons related to planning, developing and function necessitate distinctly defining the territory and boundaries of a landscape. The landscape is a basic term in geography, which also accounts for a more precise definition and delimitation.

The characteristics of a landscape is formed by several landscape shaping factors, landscapes are integrated systems. Drawing a borderline between landscapes may be easy, but a real separation and delimitation is far more problematic. Delimiting a landscape is made difficult by the fact that the borders of each landscape shaping factor - the botanical factor, the soil science factor and the relief factor - more or less differ from each other, and sometimes even one of the factors cannot be separated clearly, take the botanical one.

Besides, a sufficient integration of the natural and social factors and their effects is also an important point in the delimitation process. One of my research aims was to produce an objective, meso-scale delimitation which, by giving clear unit borders, could be used as a guideline in further, regional researches. I applied the objective multiresolution segmentation for delimitation. I validated my results with the available landscape divisions and with the suggestions for delimitations which were applied field measurement too (Marosi - Somogyi szerk. 1990, Ladányi 2010, Deák 2010, Molnár et al. 2008, Mücher et al. 2010).

Another interpretation of landscape borders suggests that no „rigid" borderline exists between different landscapes. Botanical and soil patterns as well as relief patterns may differ from each other in a great extent, there are some „similar" entities covering different pieces of surface. In addition, each landscape shaping factor is changing continuously, at different speed in time, forming no „rigid" border. Therefore, border of landscape, as landscapes are being integrated units, cannot be separated by drawing a line around. This statement brought me to the idea to interpret landscape borders using the fuzzy „soft sets" method.

Any landscape unit created by the landscape shaping factors could radically be overwritten by human activities in a split second. Besides delimitation it is also important to measure the ecological stability of landscape units and to examine the vulnerability of their borders.

So one of my aims was to analyze the landscape fragmentation caused by human activities to get a general view about how sensitive landscape borders are and to measure their sensitivity to human activities. My research focused on the fragmentation of landscape units caused by artificial barriers in micro-regions, intending to measure fragmentation and its spatial-temporal changes by making mathematical/statistical analysis and calculating landscape metrics.

2. Research methods and materials

In each case, I made my research on the entire territory of Hungary using maps and databases covering the whole territory of the country (accuracy of results was determined by these data). I included the following main natural factors into my research: lithology, relief (slope), soil, vegetation and water management, and the human activities as a separate factor was also involved (hemeroby levels).

To get comparable data from different sources, the landscape shaping factors were classified into the same number of classes when it was possible. I developed ~nine categories from the used data and converted each to numeric format by calculating the homogeneity values.

2.1. Interpreting landscape borders

As indicated before there are two ways to identify and interpret landscape borders:

2.1.1. Delimitation of landscapes units by objective segmentation

In practice (e.g.: landscape planning) the borders of landscape unit (regardless of the content of the landscape unit) are handled as “rigid” lines. However, there is a need to identify borders based on a scientific basis. If several factors are involved to identify the positions of the border, the processes of integration and delimitation are expected to be repeatable. It is useful that the delimitation process will be objective and describable using mathematical/statistical relations.

Different kinds of methods can be applied for creating an objective delimitation. In my dissertation the multiresolution segmentation was applied.

2.1.2. Analysis of landscape units using fuzzy logic

Entities and types of landscape shaping factors have spatial differences, their borders cannot be drawn with a “rigid” line, and speed of change also varies, so it is advisable to treat the borders as ecotones.

Applying the methods of fuzzy theory seems a relevant method, as being mathematically definable. For the analyses in my dissertation I employed this fuzzy logic using the homogeneity values calculated for each micro-region using the landscape shaping factor categories. The reason for using homogeneity values was that the fuzzy analyses require numeric input data and I was able to exclude the problems of ranking and weighting the factors.

The calculations of fuzzy sets defined and classified as:

a) Core Zones: The areas with a homogeneity value higher than 70% belong to the set of homogenous landscape cores (these appear on the result map with a value of 0),

b) Border Zones: the areas with a homogeneity value lower than 30% belong to the set of border zones (these appear on the result map with a value of 1),

c) Transitional Zones: the areas with a homogeneity value different with a homogeneity score between 30% and 70% are given a new value that indicates the percentage in which they belong to one or the other of the sets.

2.2. Landscape and landscape border sensitivity analysis

Analyzing the level of fragmentation caused by artificial barriers in meso-scale landscape units we can get an overall picture about changes in their stability and sensitivity of their borders. I confined in my research to the issues of road and railway network and settlements as artificial barriers for fragmentation measurements.

Changes in the state of fragmentation has been observed between the years 1990 and 2010, and calculated the assumed changes for the year 2027. The road network (highways, main roads, national roads), the railway network and the administrative areas of the settlements have been involved as artificial barriers. In fragmentation examinations railways and all road types have been handled as 2D objects in the calculations.

Maps of the road and railway network and settlements have been taken from „OTAB" database for the base year 1990, and from the geoinformatical database of „Térkép" Co. for the year 2011. For future forecasts the county maps of the documentation „The long-term plans for improvements in Hungarian motorways and expressways" from a government site *(www.kkk.gov.hu)* has been used. I georeferenced these maps for future state then I digitalized the tracks lines of planned roads. These track lines have been used for the future state of fragmentation.

Besides the *"Effective Mesh Size" (Mesh)* landscape metric, I have made calculations for three more landscape metrics: the *"Number of Patches" (NP)*, *"Division"(D)* and *"Landscape Splitting Index"(S)*, which express the degrees of fragmentation in different units. The values have been calculated on class level: patches were the fragmented landscape units and meso-scale units were the classes.

3. Results and conclusions

3.1. Interpreting landscape borders

3.1.1. Results of the multiresolution segmentation method

1. Making comparisons by different landscape metrics show that the degree of naturalness is higher in the segmented landscape units (SLU) than in the traditionally defined landscape units (TLU, Marosi - Somogyi eds. 1990). 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).

2. According to the interpretations of Mas et al. (2010) the sensitivity of the shape of the segmented landscape units is higher, e.g., in terms of the external human impacts, then the earlier delimited traditionally defined landscape units.

3. Looking at the three types of orografic category (plain, hill, mountain) the results of the comparison (Fig.1) indicate that segmented landscape units better fit to the categories of the used source data. 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.

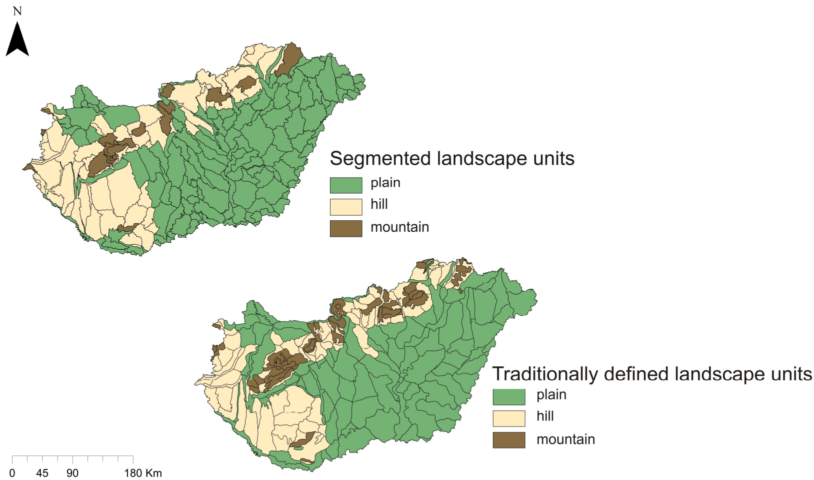

Fig.1.: The TLU and the SLU in plain-hill-mountain regions

3.1.2. Results of the applied fuzzy logic

4. The applied fuzzy logic proved adequate method for interpreting the landscape unit using the six landscape shaping factors in the calculations, considerable inhomogenous areas (~ecotones) were clearly determined. This means that these areas or zones should be considered, where the drawing of borders of landscape units is uncertain. On the other hand, the fuzzy membership function also enabled to identify zones in which these factors show a high homogeneity; these areas should be seen as the „core zones" of a landscape unit (Fig. 2).

5. This „soft" border developed by the fuzzy logic marks a special zone in which the borders of the landscape units are not static, make pulsations for a shorter period of time. However in the long period, these borders never cross this special zone. These findings coincide with those of Méri-Körmöczi et al. (2010). The results agree the prior observations that the width of the ecotones between different types of landscapes - depending on the scale - might range from some dozens of meters to hundreds of kilometers (Bastian O. 1997, Forman R. T. T. 1995). In Hungary the applied methods show values from a couple of 100 meters to 3-5 kilometers.

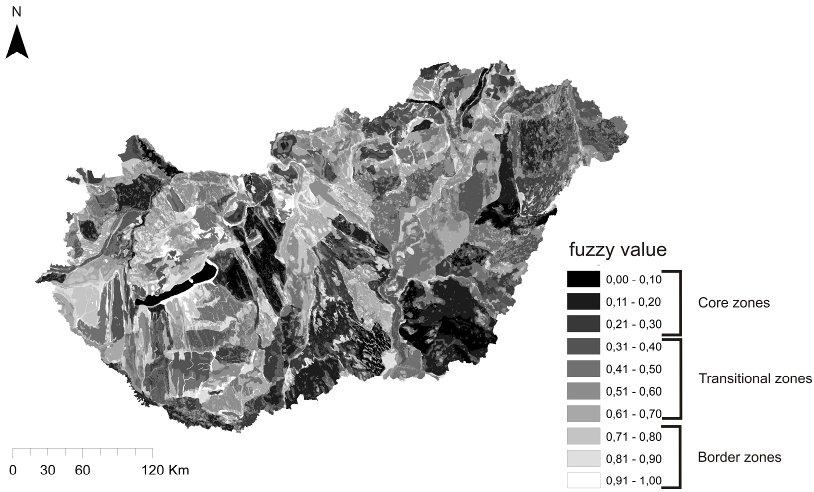

Fig. 2.: Fuzzy result map of Hungary using the six landscape shaping factors

3.1.3. Validation: comparative analysis of the multiresolution segmentation and the fuzzy logic

In my research the "classical" validation methods such as using area-based measures or location-based measures such as field survey mapping (Clinton et al. 2010, Möller et al. 2007, Shi et al. 2007, Johansen et al. 2010) could not be completed. 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 the segmented landscape units.

I used three different methods for the validation of segmented landscape units in order to be able to compare my objective delimitation using multiresolution segmentation against the suggested modifications and delimitations of other researchers at meso-scale level (Ladányi 2010, Deák 2010, Molnár et al. 2008).

6. Both the Landscape Typology and Map (LANMAP) and the segmented landscape units (SLU) were produced by objective segmentation. In possession of relevant data and method descriptions they are repeatable expecting similar outcomes. When creating the segmented landscape units, I used more landscape shaping factors at higher spatial resolutions. This resulted smaller landscape units with more complex shape, and each unit are containing areas with larger homogeneity. 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.

7. The comparative analysis with the help of the applied fuzzy membership function enabled me to achieve a new, better fitting and more useful division of landscapes especially in border- and in core zones using the multiresolution segmentation. The fuzzy logic was also legitimated as being a reliable method in determining the place and the size of ecotones.

8. Regional comparative analyses allow to make the statement that the objective multiresolution segmentation is applicable for landscape delimitation at meso-scale level (~micro-region level), because the segmented landscape units show similarities with those created by more complex ecological researches. The results confirm that segmented units have been defined correctly and support the idea of supervising and correcting the borders of traditionally defined landscapes units as already encouraged by other researchers too (Ladányi 2010, Molnár et al. 2008, Deák 2010).

3.2. Changes in landscape fragmentation

9. Involving documentations about long-term plans for upgrading the Hungarian highway and major roads network (up to year 2027) into my research, I got some information about the predictable future as well. If the long-term plan of improving road network will be build in Hungary, the "*Effective Mash Size$_{CUT}$*" of 101 micro-region_remains unchanged. However the non-negligible fact is, that 4 micro-regions are expected to suffer a reduction of more than 50 km^2 in "*Effective Mash Size$_{CUT}$*" value (Table 1). In these micro-regions if all planned roads will be built, extra attention should have to be paid for protection of natural resources. Considering the sensitivity of any micro-regions, in planning process the best solution would be to involve other factors besides the „Natura 2000" areas.

Table 1.: Results of landscape metrics of the top 5 fragmented micro-regions between 2011 and 2027

Name of micro-region	Change in NP (pcs.)	Change in S (pcs.)	Change in D (%)	Change in Mesh$_{CUT}$ (km^2)
Dráva-sík	+2	+1,56	+24,42	-99,84
Szolnoki-ártér	+12	+5,26	+14,43	-86,23
Mohácsi - sziget	+3	+1,47	+24,45	-85,41
Nyugat-Belső-Somogy	+9	+2,77	+10,01	-75,58
Szatmári-sík	+7	+7,07	+5,81	-59,99

10. The analysis of the *"Effective Mash Size$_{CUT}$"* values in two time-periods (1990-2011, 2011-2027) 4 groups of micro-regions could be separated according to their sensitivity and stability (Table 2).

a, sensitive, mostly endangered, unstable micro-regions – the fragmentation of these units changes in both time-period,

b, micro-regions that will potentially be sensitive in the future – the fragmentation of these units didn't change in the past, but according to the road improvement plans they would be fragmented and divided into smaller units.

c, micro-regions that will potentially be more stable in the future – they were fragmented in the past, but according to the road improvement plans they are assumed to have no further fragmentation.

d, stable micro-regions with minor sensitivity – their fragmentation didn't change in the past and according to the road improvement plans they are expected to have no fragmentation in the future.

This classification warns that in landscape protection the units in groups **„a"**, and **„b"** must be handled with high priority. It is highly recommended to minimize fragmentation during planning process in these micro-regions. Such kind of deterioration in stability could also be eased if not only the „Natura 2000" areas were prioritized, but the above mentioned landscape metrics were also calculated.

On the other hand, the classification also calls attention to micro-regions in groups **„c”** and **„d”** where the main task is to raise their stability and reduce their sensitivity. To achieve these goals wildlife („green”) corridors, ecoducts should be designed.

Table 2.: „Sensitivity-stability” grouping of landscapes in Hungary

	Group „a”	**Group „b”**	**Group „c”**	**Group „d”**
No. of micro-regions	129	15	46	40
Total area (km^2)	67588,8	5229,08	14381,8	5826,31
Total area (%)	72,66	5,62	15,46	6,26

11. In planning the road tracks the positions of „artificial barriers” could be determined in more favourable of the vulnerable landscapes by using the presented landscape metrics. Suggestions could also be made about micro-regions the balance of which would not tolerate more anthropogenic interventions (Girvetz et al. 2008, Jaeger et al. 2007, Fu et al. 2010). Further analysis and different kinds of data are needed. To achieve this however, further analyses (Keveiné Bárány 2010) in landscape ecology should be made by involving various data (e.g., land cover maps – Mucsi et al. 2007, Szilassi – Bata 2012; national ecological network data - Tóth 2006; or field measurement data: e.g., habitat mapping - Czúcz et al 2008, measurement of the useness of ecoducts - Hardy et al. 2003)

12. Using two methods for calculating the *"Effective Mesh Size"* clearly proved that the construction of new artificial barriers made the fragmented units even more sensitive. In Hungary the rail- and road networks are so dense that the borders of the micro-regions are the same as the borders of fragmented landscape patches. Exceptions make 9 micro-regions regarding to the first time period (1990-2011), and 12 micro landscapes regarding to the second (2011-2027). By these micro-regions the differences between the applied methods are not to be neglected as far as the habitat area and the degree of freedom for living creatures is concerned.

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