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ASSESSING LANDSCAPE SENSITIVITY BASED ON FRAGMENTATION CAUSED BY THE ARTIFICIAL BARRIERS IN HUNGARY

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Abstract
Artificial barriers significantly disturb the landscape unit. Roads split the contiguous landscape units, thus basically modifying their ecological characters. The more artificial barriers are constructed in the landscape, the more fragmented it is. Therefore, the contiguous landscape unit is divided into two or more patches, weakening resilience and stability of ecological systems. During decrease in patch size, the stability reduces until the patch size is at its minimum viable or effective population size. In current study analysing the degree of fragmentation caused by artificial barriers in meso-scale landscape units (meso-regions) we can get an overall picture about changes in their stability and sensitivity. The major aims of this study is to investigate the fragmentation of landscape units caused by three types of artificial barriers (roads, railways and settlements) in micro-regions, and to measure the degree of fragmentation and its spatial-temporal (1990, 2011 and future scenario to 2027) changes using mathematical/statistical analysis and landscape metrics (Number of Patches, Division, Landscape Splitting Index and Effective Mesh Size). By calculating landscape fragmentation metrics, the micro-regions are identified, which must be protected with high priority in the future. In the planning processes, type and position of artificial barriers could be more properly determined by calculation of these landscape metrics.

Keywords: landscape fragmentation, sensitivity, stability, artificial barriers, landscape metrics

INTRODUCTION

Landscape pattern embedded in the matrix is formed by patches and corridors (Forman and Godron, 1986; Formann, 1995). Ecological barriers as linear elements delimit landscape patches of similar ecological characters. Barriers can be categorized into natural (e.g. river -corridor) and artificial ones from the viewpoint of living being (Kerényi, 2007).

Artificial barriers (e.g. roads, railways, settlements) can significantly disturb the landscape unit. Roads and railways split the contiguous landscape units, thus basically modifying their ecological characters (Forman and Alexander, 1995; Trombulak and Frissell, 2000; Forman et al., 2003). They can result completely isolated patches, altering the ecological interactions between natural habitats (Harris 1984; Sauders et al., 1991; Forman, 1995).

Due to fragmentation the ecological stability deteriorates and the natural material and energy flow can be affected (Csorba 2005; Moser et al., 2007). Owing to the transport infrastructure (e.g. roads, railways) high concentration of pollutants is also emitted into the atmosphere, yielding change in micro-climate (Saunders et al., 1991; Reck and Kaule, 1993; Trombulak and Frissell, 2000; Spellerberg, 2002; Jaeger, 2002; Forman et al., 2003). The more than 20 m wide motorways exert significant influence on run-off and groundwater flow (Barta and Szatmári, 2010; Barta et al., 2011; Kun et al., 2012). Consequently, in the highly developed countries the fragmentation is considered as the most serious threat by which natural habitat is damaged (Jongman, 1995; Wascher and Jongman, 2000). The more artificial barriers are constructed in the landscape, the more fragmented it is. Therefore, the contiguous landscape unit is divided into two or more patches, weakening resilience and stability of ecological systems. During decrease in patch size, the stability reduces until the patch size is at its minimum viable or effective population size (size of isolated population which can survive with a given probability beyond a given period) (Gilpin and Soul, 1986). With the landscape fragmentation, the border length of landscape units increases, causing higher landscape sensitivity (Mas et al., 2010).

Analysing the degree of fragmentation caused by artificial barriers in meso-scale landscape units (meso-region) we can get an overall picture about changes in their stability and sensitivity. In the light of all this information, the major aims of this study can be summed up as follows: (1) to investigate the fragmentation of landscape units caused by artificial barriers in micro-regions, (2) to measure the degree of fragmentation and its spatial-temporal changes by mathematical/statistical analysis and landscape metrics.

DATA AND METHODS

The investigations of micro-regions were carried out on the whole territory of Hungary (Marosi and Somogyi, 1990 (*Fig. 1*).

Data

Change in the degree of fragmentation caused by artificial barriers was analysed based on time series data: between 1990 and 2010, future scenario was calculated to 2027.

Types of artificial barriers investigated in current study are the following:

- road network (motorways, highways, side roads)
- railway network
- borderline of inner-city area

During the fragmentation investigation, railways and roads were regarded as not only linear but average 2-dimensional elements (like 2-dimensional shape of settlements) (Fi et al., 2012; Megyeri, 1997) the average width of which are as follows:

- motorway = 26.6 m
- highway = 7 m
- side road = 3 m
- railway = 6.05 m

Similar to the settlements, these landscape elements, which cover an area determined by multiplying their width by length, represent "blind spot" for the natural wildlife. For example, 4.6 km^2 area of Danube-Tisza Interfluve is occupied by the M5 motorway between Budapest and Szeged (173 km) without entry and exit slip roads (173 km x 26.6 m). Therefore, the material and energy flow is the most modified in these areas, especially in their buffer zones.

- Data of 1990 as base year were originated from OTAB (1990) database on roads, railways and settlements.
- Data were available from GIS maps of Térkép Ltd. (1:100000) (Térkép Ltd., 2011) to evaluate the fragmentation in 2011.

For future scenario, county maps of the documentation „The long-term plans for development in Hungarian motorways and highways" (1222/2011.VI.29. governmental regulation) were applied (VI.29. governmental regulation). After the geo-referencing process, planned tracks on the maps until 2027 were digitized and finally digitized tracks were joined to the integrated network database (see below) (*Fig. 2*).

By comparing road network maps of databases established at different times, they proved not to be coherent; thereby most road sections that already existed in 1990 are not properly jointed to those in 2011. Besides, similar problem arose in the case of settlement networks, as well. All this can be explained with the absence of an integrated database containing the borderlines of inner-city areas in 1990 and 2011. During comparison of different databases, elimination of spatial inaccuracy is not easy. If we compare the sizes and locations of settlements in the studied period, territorial expansions can not always be attributed to urban sprawl.

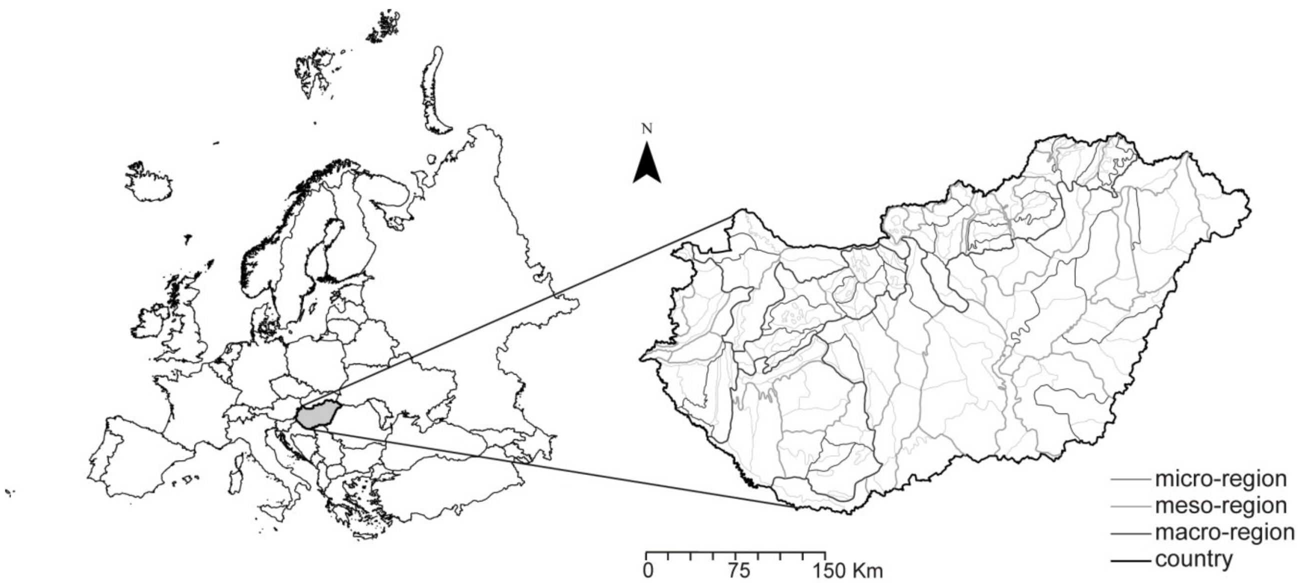

Fig. 1 Micro-regions of Hungary according to landscape delimitation in 1990

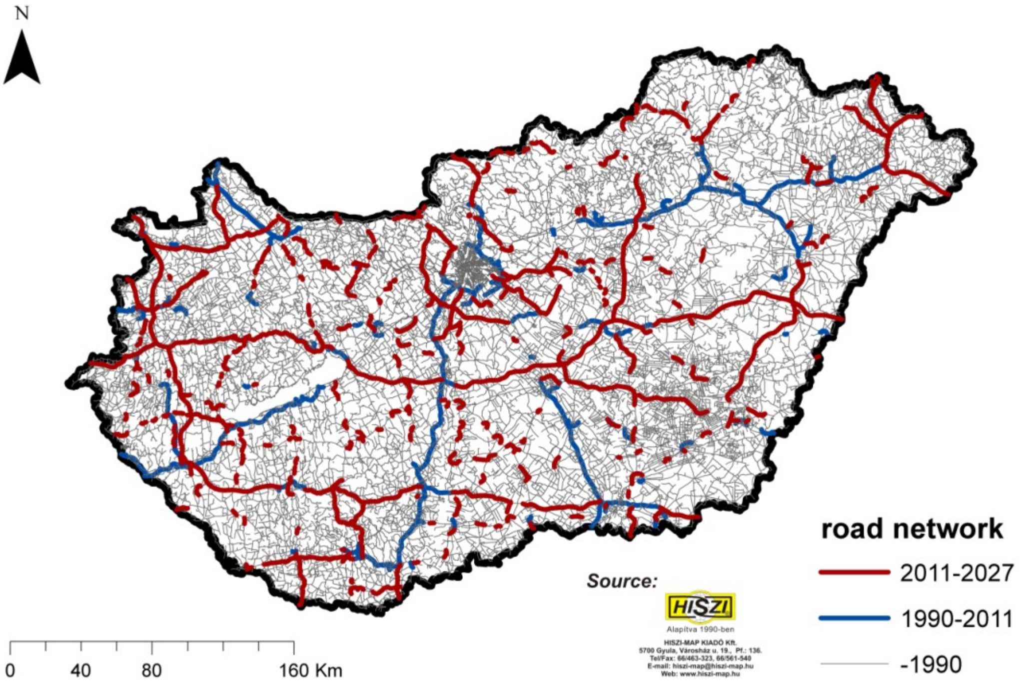

Fig. 2 Map on the expansion of road network between 1990 and 2027 based on the integrated road network database

These spatial errors may exert positive or negative influence on the fragmentation. In order to eliminate content inaccuracies an integrated road network database (based on network in 2011) was created in which the tables of attributes indicate road sections constructed prior to 1990 and between 1990 and 2011, respectively. With the help of this method, the error threshold has to be calculated exclusively in the case of settlements. During the tests, this value is 24.63 ha, which was counted as the average of size differences of settlements in two different basic databases.

Methods

The degree of fragmentation caused by artificial barriers can be measured in terms of various landscape metrics (McGarigal and Marks, 1995; Riitters et al., 1995; Haines-Young and Chopping, 1996; Hargis et al., 1998; Jaeger, 2000). Jaeger (2002) compared twenty-two landscape metrics to each other in order to find the most suitable one for fragmentation measurement. *Effective Mesh Size$_{CUT}$* (Mesh$_{CUT}$) proved to be the most adequate index. In addition, we counted three more metrics (*Number of patches, Division, Landscape splitting index*), which indicate the degree of fragmentation in different units. In each case, the metrics were calculated at class level; thus the patches and the classes are landscape units fragmented by artificial barriers as well as medium-scale landscape ecology units (~ micro-regions), respectively.

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Definition of landscape metrics indicating fragmentation:

- *Number of Patches* (NP): expresses the number of landscape units fragmented by artificial barriers. *Unit: pieces* (McGarigal and Marks, 1995).

- *Division* (D): is defined as probability that two randomly chosen living beings can not meet in the study area. *Unit: %* (Jaeger, 2000).

$$D = 1 - \sum_{i=1}^{n} \left(\frac{A_i}{A_t} \right)^2$$

where n: number of patches, Ai: size of n patches, At: total area of the region.

- *Landscape Splitting Index* (S): is determined as the number of patches one gets when dividing the total landscape into patches of equal size in such a way that this new configuration leads to the same degree of landscape division as obtained for the observed cumulative area distribution. *Unit: piece* (Jaeger, 2000).

$$S = \frac{A_t^2}{\sum_{n=1}^{n} A_i^2}$$

where n: number of patches, Ai: size of n patches, At: total area of the region.

- *Effective Mesh Size* (MeshCUT): denotes the size of patches when the landscape is divided into S areas (each of the same size) with the same degree of landscape division as obtained for the observed cumulative area distribution. Unit: ha or km^2

$$Mesh_{CUT} = \frac{A_t}{S} = \frac{1}{A_t}\sum_{i=1}^{n} A_i^2$$

where n: number of patches, Ai: size of n patches, At: total area of the region.

With the help of GIS data of Térkép Ltd. (2011) and OTAB (1990), maps of Coordination Center for Transport Development, these landscape metrics for each micro-region were calculated with respect to the railway, road network and settlements as artificial barriers for the year of 1990, 2011 and 2027.

Temporal changes in the fragmentation were also investigated in order to gain information on changes in landscape stability, sensitivity as well as potential landscape conditions in 2027 based on "The long-term plan and future development program of highway and motorway network" (1222/2011., VI.29. governmental regulation). In the case of change in MeshCUT index between 1990 and 2011 as well as probable further changes by the artificial barriers constructed in the micro-region until 2027, these landscape units can be supposed to have already modified material and energy flows after establishment of the artificial barriers *(Fig. 3)*. In contrast, in the future the examined parameters will not more change, thereby generating landscape balance (van Andel and Aronson, 2006).

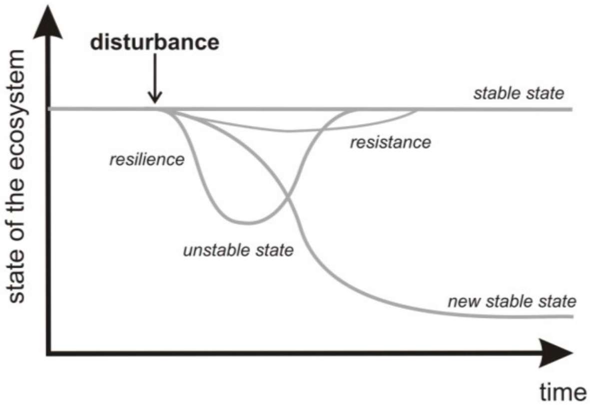

Fig. 3 Potential ecosystem responses to disturbance (e.g. construction of artificial barriers) (van Andel and Aronson, 2006)

RESULTS AND DISCUSSION

In order to get information on the sensitivity and the stability of landscape and its borders, temporal and spatial changes in fragmentation caused by artificial barriers (roads, railways, settlement) between 1990 and 2011 were determined calculating different landscape metrics. Moreover, the effect of motorway and highway networks to be constructed until 2027 on the landscape was studied. The micro-regions were examined which can be negatively affected by artificial barriers, reducing their stability and increasing their sensitivity.

Changes in the artificial barriers between 1990 and 2011

Almost 79% of the road network built between 1990 and 2011 is motorway (*Table 1*), which covers the largest area of landscape compared to other two barrier types. Furthermore, the entry and exit slip roads delimit landscape patches that have no ecological connectivity (~ residual patches) with each other or matrix (*Fig. 4*).

Table 1 Changes in the length of the road network between 1990 and 2011

	Sum length of track (km) 1990	Sum length of track (km) 2011	Change (km)
Motorway	953.99	3042.88	+2088.89
Highway	6791.79	7234.60	+442.81
Side road	53420.78	53535.45	+114.67
Sum:	61166.34	63812.93	+2646.37

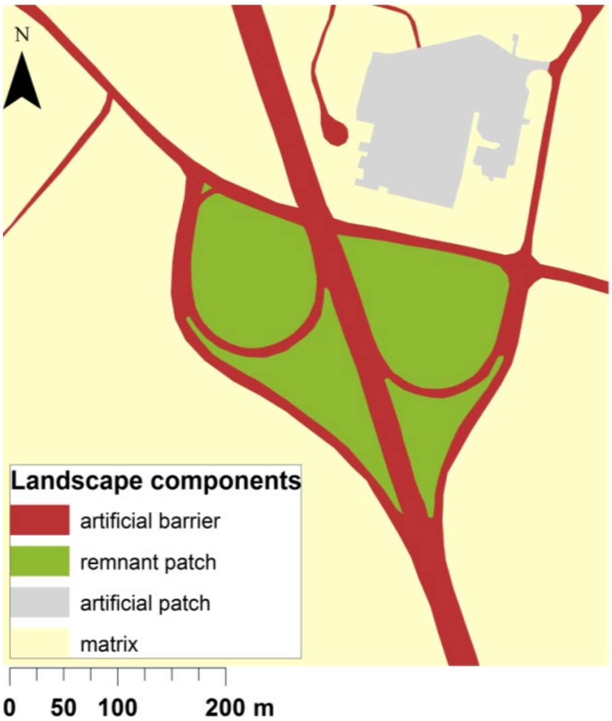

Fig. 4 Landscape components close to Kiskunfélegyháza after the construction of entry and exit slip roads at the M5 motorway

Beside motorways, mostly highway bypasses were constructed around the settlements in the study period. These bypasses (*Fig. 5*) are regarded to have the most significant fragmentation since their shapes can be not only straight but curved (their characters are similar to the entry and exit slip roads of motorways). Connecting to an existing road (with both start and end points), they are constructed mainly outside borderline of the inner-city area. Therefore, they are more likely to delimit a part of the landscape than a long straight road.

At the time of study period (1990-2011) Hungarian railway network are not extended by new tracks, whereas the existing ones are modernized as well as new stations are also built (Development of railway tracks, 2011). Therefore, this type of artificial barriers has not made the landscape more fragmented. Despite the fact that railway transport was liquidated in some sections, these sections can act as artificial barriers.

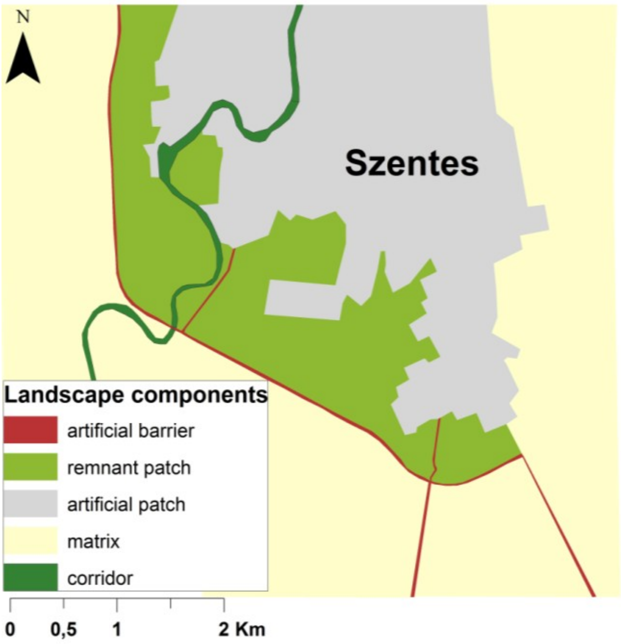

Fig. 5 Landscape components after the construction of bypass in Szentes

With regard to the error threshold, in the study period the most intensive territorial expansion was registered in the following Hungarian settlements (in descending order): Miskolc, Érd, Debrecen, Győr and Tiszaújváros. In addition, it was 12 cities in Hungary that exceeded 10 km^2 in the study period.

Change in fragmentation of micro-regions due to artificial barriers between 1990 and 2011

S, D, $Mesh_{CUT}$ metrics, except for NP, have been developed over the past decades (Jaeger, 2000; Moser et al., 2007), providing additional information on fragmentation and sensitivity of landscape compared to conventional metrics (Jaeger, 2002).

NP is the most common index of fragmentation. In the years 1990-2011, change in NP index was not determined in the case of 105 micro-regions, whereas this index increased in the case of 92 micro-regions. In terms of this index, fragmentation is the most considerable in the following micro-regions (in descending order): Pest Plain (+99) (*Fig. 6, No. 1*), Tolnai Sárköz (+66) (*Fig. 6, No. 2*) Middle Mezőföld (+64) (*Fig. 6, No. 3*), Sajó-Hernád Plain (+52) (*Fig. 6, No. 4*), South Baranya Hill (+45) (*Fig. 6, No. 5*).

After the establishment of a new linear element in transport network, this element can cross the existing ones in the landscape, cutting a patch out of the original landscape unit. NP unambiguously indicates this degree of fragmentation but can not give more information on characters of fragmentation and its adverse effects. As there has no been change in number of equal-sized patches defined with same probability, this index reflects no fragmentation in the case of 54 micro-regions (*Fig. 6*).

As far as S index is concerned, the five most fragmented micro-regions are: Győr-Tata Terrace Land (+12.33) (*Fig. 6, No. 6*), Middle Nyírség (+9.4) (*Fig. 6, No. 7*), Sajó-Hernád Plain (+9.01) (*Fig. 6, No. 4*), South Baranya Hill (+8.82) (*Fig. 6, No. 5*), Moson Plain (+8.12) (*Fig. 6, No. 8*). Consequently, results of the S index are partially congruent with those of NP index since Sajó-Hernád Plain and South Baranya Hill are the most fragmented micro-regions in terms of both metrics.

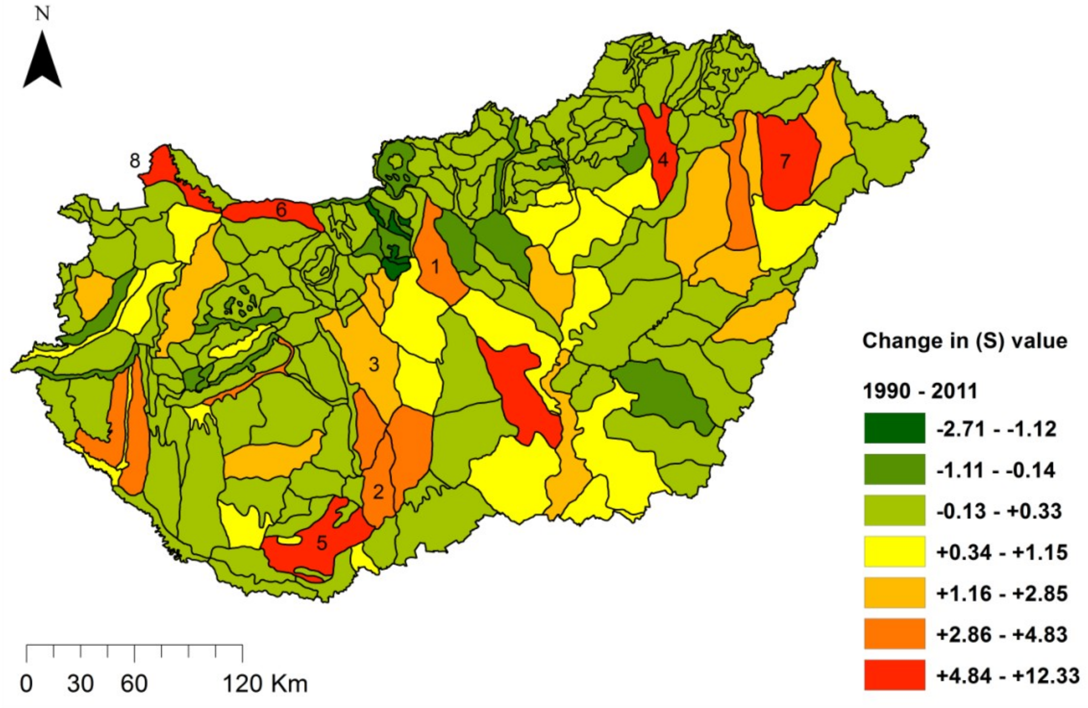

Fig.6 Change in Landscape Splitting Index (S) within micro-regions between 1990 and 2011 (based on fragmentation due to the artificial barriers)

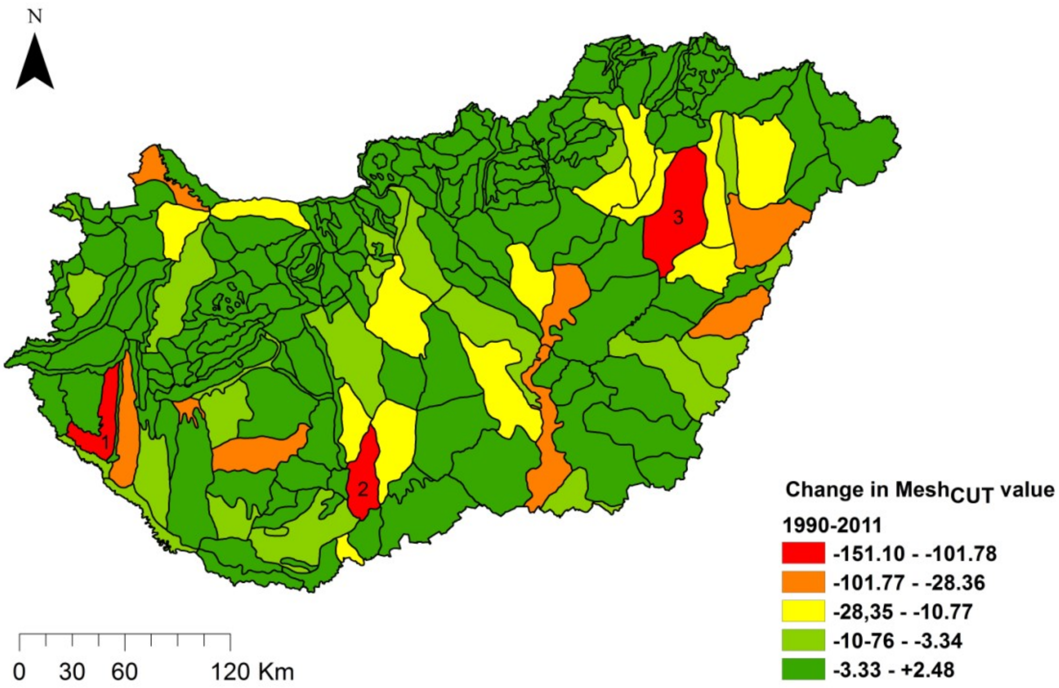

Fig. 7 Change in $Mesh_{CUT}$ index within micro-regions between 1990 and 2011 (based on fragmentation due to the artificial barriers)

The degree of fragmentation can be presented according to a specific example: In Győr-Tata Terrace Land (*Fig. 6, No. 6*), NP index was 11.74 and 24.07 in 1990 as well as 2011, respectively. Therefore, nearly twofold increase in this value indicates very severe fragmentation caused by artificial barriers in this micro-region. In other words, due to nearly 10 km long M1 motorway section bypassing Győr and urban sprawl of some cities (Győr, Tata, Komárom), this micro-region needs to be subdivided into twice as many equal-sized patches in order that two living beings can meet within the study area.

Change in $Mesh_{CUT}$ index during study period can be seen in the Fig. 7 with special regard to error threshold, no change in $Mesh_{CUT}$ can be noticed in the case of 54 micro-regions.

Considering effectively usable habitat, Egerszeg-Letenye Hill (*Fig. 7, No. 1*) can be considered to have the most unfavourable conditions (*Table 2*). $Mesh_{CUT}$ index reveals that this micro-region's total area of 645.02 km^2 decreased by 155.93 km^2. Owing to the highway 74, which cuts the micro-regions into two pieces in the north-eastern, and a section of the M7 motorway between Nagykanizsa and Letenye, NP, S and D metrics have increased from 18 to 45, from 2.56 to 7.15 as well as from 61 to 86, respectively. Therefore, the degree of fragmentation caused by artificial barriers is so serious here that the transport network development should be avoided in the future. If it is not possible, then road designers have to pay more attention to the ecological corridors of suitable quality and wide (ecoducts), which in optimal case facilitate faunal and floral migration between artificial objects.

$Mesh_{CUT}$ index demonstrates that the territory of more two micro-regions has decreased by 100 km^2 (*Table 2*). Landscape elements fragmenting micro-region Tolna Sárköz (*Fig. 7, No. 2*) are the followings: the M9 and M6 motorways cut this micro-region into two pieces in the east-west as well as the north-south direction, respectively.

Landscape elements fragmenting micro-region Hortobágy (*Fig. 7, No. 3*) are the following: a section of the M3 motorway between Polgár and Hajdúnánás (55 km); the highway 35 towards Hajdúböszörmény connecting to the motorway in the middle of the micro-region; a bypass situated in the eastern part of settlement Polgár (*Fig. 8*).

Table 2 Landscape metrics of the three most fragmented micro-regions between 1990 and 2011

Name of the micro-region	**Change in NP (Pcs.)**	**Change in S (Pcs.)**	**Change in D (%)**	**Change in $Mesh_{CUT}$ (km^2)**
Egerszeg-Letenye Hill *(Fig7. , No. 1)*	+27	+4.59	+25.08	-155.1
Tolnai-Sárköz *(Fig7. , No. 2)*	+62	+3.83	21.24	-133.74
Hortobágy *(Fig7. , No. 3)*	+19	+1.54	6.15	-101.78

Nevertheless, increase in the $Mesh_{CUT}$ index can also be observed in the case of 24 micro-regions. The maximum and average of this increase are 247.79 km^2 as well as 75.23 km^2, respectively. The first cause of increase in this index is the territorial expansion of settlements as a result of which they have reached the road network, in some case they have spread beyond it. Therefore, the NP and $Mesh_{CUT}$ metrics have decreased and increased, respectively owing to the modified shape of habitats. The second and third causes of increase in the $Mesh_{CUT}$ index are decrease in size of some settlements between

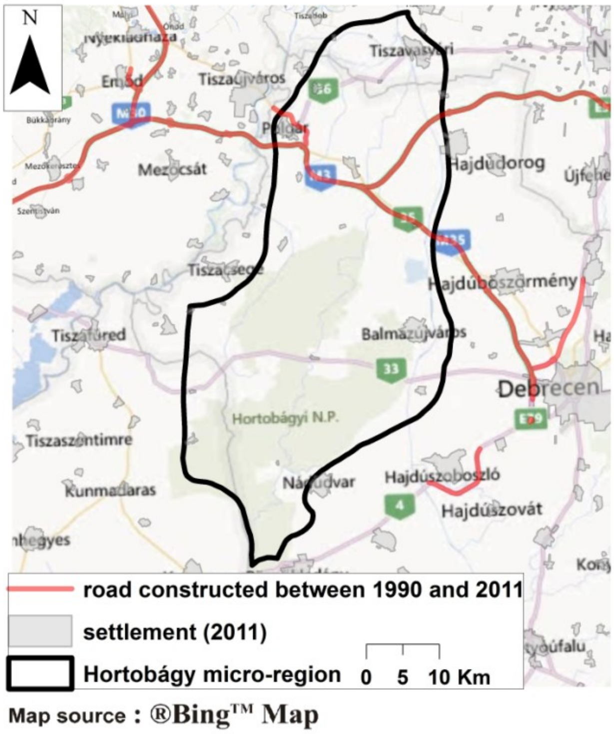

Fig. 8 New roads causing fragmentation in Hortobágy micro-region

1991 and 2011 as well as synergy of the first and second cases, respectively. It is unambiguous that reduction of the road and railways network is not responsible for the above-mentioned in the study period.

Consequently, further detailed studies are needed in the case of the concerned micro-regions in order to identify causes of this phenomenon.

Change in fragmentation of traditionally defined micro-regions due to artificial barrier between 2011 and 2027

If the long-term road development plan is fully implemented, 490.48 km more motorways (18.53%) and 2706.52 km more highways are to be constructed from 2011 till 2027. However, the plans have not included the construction of side roads (Table 3).

According to the scenario to 2027, NP index will not increased, thus the fragmentation caused by artificial barriers can not be predicted in the case of 67 micro-regions. Based on S index, fragmentation can not be assessed in 82 micro-regions, thus number of equal-sized patches, in such a way that this new configuration interprets to the same value of probability, will not increase. The following five micro-regions are likely to be the most fragmented in the future: Northeast Nyírség (+18.74) (*Fig. 9, No. 1*), Upper Kemeneshát (+10.09) (*Fig. 9, No. 2*), Bácska Loess Plain (+9.68) (*Fig. 9, No. 3*), Hatvan Plain (+7.87) (*Fig. 9, No. 4*), Szolnok Túr Plain (+7.12) (*Fig. 9, No. 5*).

Table 3 Changes in the length of road network between 2011 and 2027

	Sum length of track (km) 2011	**Sum length of track (km) 2027**	**Change (km)**
Motorway	3042.88	3533.36	+ 490.48
Highway	7234.60	9941.12	+ 2706.52
Side road	53535.45	53535.45	0
Sum:	63812.93	67009.93	+2646.37

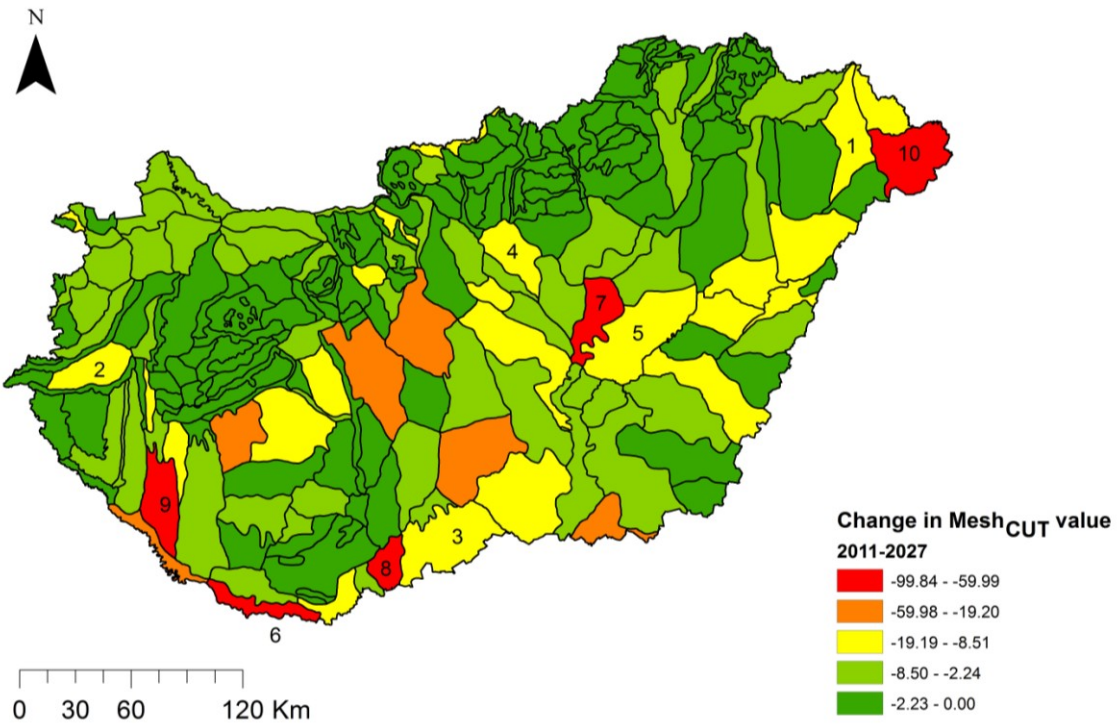

Fig. 9 Change in Mesh$_{CUT}$ index within micro-between 2011 and 2027 (based on the fragmentation due to artificial barriers)

Table 4 Landscape metrics of the five most fragmented micro-regions between 2011 and 2027

Name of the micro-region	Change in NP (Pcs.)	Change in S (Pcs.)	Change in D (%)	Change in $Mesh_{CUT}$ (km^2)
Dráva Plain *(Fig 9., No. 6)*	+2	+1.56	+24.42	-99.84
Szolnok Floodplain *(Fig 9., No. 7)*	+12	+5.26	+14.43	-86.23
Mohács Island *(Fig 9., No. 8)*	+3	+1.47	+24.45	-85.41
Western-Inner-Somogy *(Fig 9., No. 9)*	+9	+2.77	+10.01	-75.58
Szatmári Plain (*Fig 9., No. 10)*	+7	+7.07	+5.81	-59.99

After implementation of the long-term road development plan, $Mesh_{CUT}$ index of 101 micro-regions remain unchanged. In this aspect, Dráva Plain (*Fig. 9, No. 6*) can be regarded as the most disadvantageous micro-region in the future (*Fig. 9*) since its total area (433.27 km^2) will decrease by mostly 100 km^2 (99.84 km^2) due to a highway to be constructed from Sárvár to south border. This micro-region will be divided into two pieces in the north-south direction by new highway. Therefore, D index will increase from 46.43 % to 70.85 %.

In the case of three micro-regions, the $Mesh_{CUT}$ index decreased by more than 100 km^2 over the period 1990-2011, whereas in 2027 based on scenarios lesser decrease can be predicted. However, the non-negligible fact is that four more micro-regions are supposed to suffer a reduction of more than 50 km^2 (*Table 4*).

In the future, we have to lay greater emphasis on landscape ecological study of these micro-regions if all the planned roads are built. As far as the sensitivity of micro-regions is concerned, the most optimal would be if road designers took notice of not only the location of conservation areas under "Natura 2000" but reduction of landscape fragmentation for living beings based on calculation in current study. Consequently, more detailed landscape studies are necessary in the concerned micro-regions.

The sensitivity and stability of micro-regions fragmented by artificial barriers

In accordance with above-mentioned, it is obvious how the landscape fragmentation was changed by artificial barriers in a historical period (1990-2011) and how it will be modified in the future (2011-2027) after long-term road plan implementation.

So as to evaluate the sensitivity and stability of landscapes, two time-periods (1990-2027) were merged and analysed together. Four groups of the micro-regions can be differentiated based on their $Mesh_{CUT}$ metrics (*Table 5, Fig. 10*):

1. *Sensitive, mostly endangered, unstable micro-regions* the fragmentation of which has changed in both periods.
2. *Potentially sensitive micro-regions* the fragmentation of which did not change in the past, but they can be divided into smaller units due to the road development plans in the future.
3. *Potentially more stable micro-regions* the fragmentation of which changed in the past, but they are assumed to have no further fragmentation after the road development implementation.
4. *Stable micro-regions with minor sensitivity* the fragmentation of which did not change in the past and they are expected to have no fragmentation in the future.

Table 5 Classification of micro-regions in Hungary according to their sensitivity and stability

	Group 1	Group 2	Group 3	Group 4
Number of micro-regions (Pcs.)	129	15	46	40
Sum Area (km^2)	67588.8	5229.08	14381.8	5826.31
Sum Area (%)	72.66	5.62	15.46	6.26

1: In general, more than half of the micro-regions (129 of 230) have been divided into smaller units by artificial barriers in both study periods; they are most susceptible to external effects. Habitats are shrinking due to landscape elements built relatively quickly; the different landscape damaging processes (e.g. new road constructions) have not completed yet, resulting more and more sensitive and unstable landscape. Nonetheless, owing to data shortage the urban sprawl, which perhaps can reduce natural habitats, has not involved in current study.

2: 15 micro-regions were not fragmented by artificial barriers in the past, but they will be influenced in term of the road development plans up to 2027. Average value and maximal decrease of the $Mesh_{CUT}$ index are 3.3 km^2 as well as 11.7 km^2, respectively.

3: 46 micro-regions are supposed to be more stable in the future since they are likely not to been fragmented (from optimistic aspect, if further road network expansion is not planned and there is be no urban growth).

4: 40 micro-regions can be considered to be in the most optimal conditions as they will not be divided into smaller units from 1990 to 2027. As a matter of fact, this is an optimistic viewpoint if no more road networks were planned and the urban sprawl was not more intense in the future. Based on the test methods and data, these landscapes are in most stable conditions and are the least sensitive.

This classification addresses that the units in groups „1", and „2" must be protected with high priority. It is greatly recommended to minimize fragmentation in these micro-regions during the practical landscape planning.

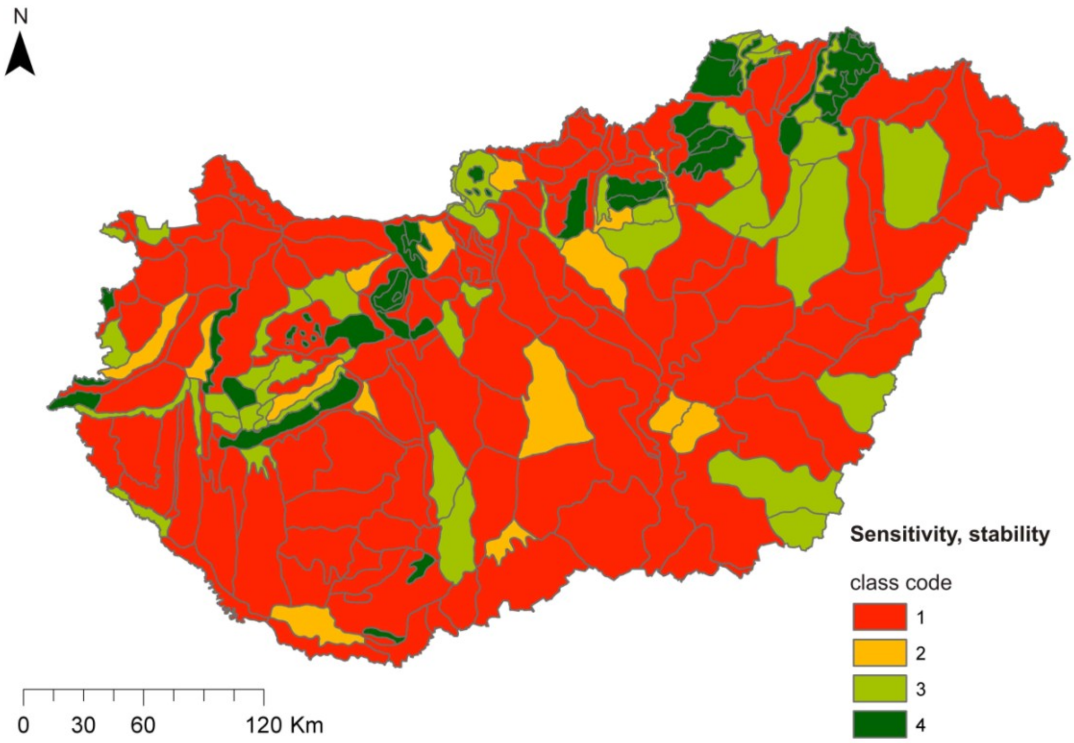

Fig. 10 Classification of micro-regions based on their sensitivity and stability to artificial barriers using data of 1990, 2011 and 2027

The landscape instability could be more effectively mitigated if not only the „Natura 2000” areas were prioritized, but the above-mentioned landscape metrics were also taken into account during the road development planning.

In the planning processes, type and position of artificial barriers could be more properly determined using the presented landscape metrics. Moreover, suggestions could also be made about micro-regions the balance of which can not tolerate more external effects (Girvetz et al., 2008; Jaeger et al., 2007; Fu et al., 2010). To realize all this, however, further analysis and various data are required.

Besides, the classification also calls for tasks to raise the stability and reduce the sensitivity in the case of micro-regions in groups „3” and „4”. More ecological corridors suitable for “green belts” should be designed so as to achieve these goals.

CONCLUSIONS

The landscape is known to be a system in which the external effects can trigger instability and induce changes. The landscape sensitivity is interpreted as a rapid response to external effects, reflecting the conditional instability of the landscape system. The more artificial barriers are constructed, the greater fragmentation is, and thereby causing decrease in effective territory.

As a matter of fact, there are a lot more artificial barriers in the landscape beyond examined ones, but present study aimed to investigate the artificial barriers, which can be rapidly constructed and have a most negative impact on the landscape. Natural barriers could also be examined via the applied methods but artificial ones take more effect on landscape sensitivity thank to their “sudden” devastating impact in contrast to “slowly appearance” of natural ones.

In this study, the spatial and temporal changes in fragmentation caused by artificial barriers were analysed so as to estimate the sensitivity and stability of the ecosystem and landscape units. The artificial barriers (e.g. roads, railways, settlements) can lead to extensive landscape modification. The contiguous landscape units are divided by roads and railways, thereby resulting profoundly transformation in their ecological processes. The ecological instability arises in the fragmented subunits and material and energy flow is modified owing to fragmentation. Moreover, the contiguous landscape unit is divided into two or more patches, changing its ecological stability.

Different landscape metrics were calculated and together evaluated to determine the degree of fragmentation caused by artificial barriers (NP, D, S, $Mesh_{CUT}$ metrics). By comparing the degree of fragmentation in 1990 and in 2011, comprehensive view on the changes of landscape sensitivity are available now, whereas by involving data of long-term road development plan (up to 2027) into our research some scenarios can be demonstrated, as well.

The presented examples also clearly show that study of the numbers and extension of artificial barriers, the NP index has not provided enough information on fragmentation. If data from more periods are available, it is preferable to apply together three metrics (D, S, $Mesh_{CUT}$ index), which express the degree of fragmentation by different units, thus providing more information on temporal change in landscape sensitivity and stability.

Using $Mesh_{CUT}$ index, traditionally defined landscape units were categorized into four groups according to their sensitivity and stability based on data between 1990 and 2011, as well as between 2011 and 2027. Group 1 represents landscapes that are characterized by more sensitivity and a gradual loss in habitat stability due to the expansion of the artificial barriers. Some landscape units (Group 2) may only be sensitive in the future, others (Group 3) may be heading for a more stable future and there are some landscapes (Group 4) that were not and will not be affected by fragmentation caused by the artificial barriers.

The advantage of the applied method is that landscape metrics are considerable help in choosing the location of artificial barriers. Furthermore, it would be relevant to give some suggestion about landscape units the balance of which can not tolerate more such barriers. (Girvetz et al., 2008; Jaeger et al., 2007; Fu et al., 2010) To realize all this, however, further analysis (Kevei-Bárány, 2010) and various data are needed, for example land cover maps (Mucsi et al., 2007; Szilassi and Bata, 2012), national ecological network data (Tóth 2006), field measurement data (habitat mapping) (Czúcz et al., 2008), monitoring data on effectiveness of wildlife crossings using ecoducts (Hardy et al., 2003).

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