LANDSCAPE ECOLOGICAL FRAGMENTATION OF THE SMALL LANDSCAPE UNITS (MICROREGIONS) OF HUNGARY BASED ON THE SETTLEMENT NETWORK AND TRAFFIC INFRASTRUCTURE

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Abstract

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Landscape geographical research has not dealt with the determination of the degree of ecological fragmentation of landscapes in Hungary yet. The degree of ecological fragmentation of landscapes is a useful index for landscape protection and planning. In this study that index was determined using the 1:250 000 scale maps of the Cartographia Road Atlas of Hungary. On the base of the Cadastral of Microregions of Hungary, the boundaries of the microregions were drawn into the maps, and then within those fixed boundaries the greatest diameter of small settlements and length of roads and railroads was measured. In the case of large settlements the extent of inner parts, traffic intensities of the roads was taken into account, while in the case of railroads it was taken into consideration whether railway lines are single or double tracked. Results were purified using a weighting, where the location of the protected natural areas compared to the situation of the given settlement, roads or railroads was taken into consideration. In the calculations it was taken into account as well that the agglomeration processes of the large settlements may restrict the ecological gates and corridors of the migration of plant and animal species. Values of the fragmentation index can be given in km/km^2 for the 230 microregions of Hungary, but in the present study the values distorted by weighting are presented in maps (Figs 1, 2, 3). It can be seen from the map (Fig. 3) that in 23 microregions the fragmentation index is higher than 5. Strongest ecological barriers can be found in microregions in valleys and small basins within mountain regions of medium height and in the environs of the lake Balaton and Budapest.

Key words: landscape fragmentation, ecological weighting of fragmented landscapes, settlement density map of Hungary, road and railway network density map of Hungary

Introduction

According to the unanimous opinion of ecologists most serious threat for the ecosystem of the Earth is fragmentation of habitats nowadays (Colligne, 1996; Farina, 1998; Forman, 1995; Hargis et al., 1998; Ingegnoli, 2003; Jongman, Brunce, 2000; Klopatek, Gardner, 1999 etc.). According to Reijnen et al. (1995), the most important reasons for strong fragmentation of habitats are building up and development of linear infrastructure.

Despite all landscape planning efforts extent of built up areas and surfaces used by traffic infrastructure is growing irresistibly (The European..., 2005). Its ratio is nearly 10% in Europe already. In some regions, for instance in the Benelux countries, northern Italy and in the Mediterranean seashores it reaches 15% of the total area. It is no surprise that one of the important aims of the sustainable development program based on environmental friendly principles is to decrease the demand for build up space from today's 129 ha per day (!) to 30 ha per day in Germany by 2020 (Perspectives for Deutschland, 2002).

There is an outstanding work of Jaeger (2002) among studies on landscape protection and planning consequences of habitat fragmentation. It is based on 14 deep interviews with engineers of nature protection, landscape planning and transportation. It deals mainly with practical issues of landscape fragmentation. Jaeger has established a model for fragmentation processes:

- perforation (Perforation)
- incision (Inzision)
- dissection (Durchschneidung)
- dissipation (Zerstückelung)
- shrinkage (Verkleinerung)
- attrition (Auslöschung)

According to Jaeger there is a strong connection between geometrical parameters of geographical landscape pattern and characteristics, which describes the functioning of the landscape. In his opinion the degree of landscape fragmentation should be described by three parameters for landscape planning and environmental impact assessment based on ecological fundaments.

1. Landscape division (Zerteilungsgrad), which shows at what probability will two randomly chosen sites fall into the same landscape patch.
2. Landscape splitting index (Zerstückelungsindex), which shows the number of patches with equivalent size the area has to be divided to so we get the same landscape division. That means, that highly fragmented landscapes should be divided into more pieces.
3. Mesh size (Maschenweite) shows the equal size of the patches used in the definition in the landscape splitting index. So a highly fragmented landscape has a small mesh size.

In the opinion of the author of the present paper determination of the degree of landscape fragmentation is a very important task of landscape ecology today, and modern landscape geography can provide fundamental data in this subject for ecology, practical landscape planning and landscape protection (Jongman, 1995).

Impacts of traffic infrastructure on migration of living creatures

Roads are artificial landscape elements, which form strikingly marked networks with strongly different characteristics from their environment. Their strong effect on living creatures originated mainly from that concrete surfaces are unnatural materials, which do not provide almost any biological benefits for plants and animals and they are not suitable places for nourishment, hiding or reproduction at all. The single benefit might be that concrete surfaces are warmer than their environment and, for this reason, reindeers and birds often use them as warming places. Anyhow this advantage cannot compensate plants and animals for the disadvantages. On the other hand roadsides are places of alimentation for birds of prey, which sit and wait on trees along roads because they take small rodents and amphibians as prey, which get onto the road erroneously and get frightened and confused. It can often be seen also that much feed is shed along the roads of crop transportation, consequently roads can act as abundant sources of feed as well. The additional water, which runs off the surface of the roads, could create more humid habitats along the roads but higher temperature result in higher ratio of evaporation loss of water. The accumulation of heavy metals of traffic origin and salt in the plants, which are consumed by the animals along the roads, is not a desirable result (Oelsen, Jain, 1994).

Strong fragmentation effect of the road system is originated from that it cannot be bypassed. Animals during their migrations sooner or later will face a strip of concrete. Crossing and isolation barrier effect have their ecological hazards as well. Spreading of some species of plants requires the help of animals, too. On the other hand vegetative spreading of plants by sprouts is hampered by the roads. Roads block spreading of plant species by the wind to a lower degree, but most populations consist of species of mixed types of spreading, consequently crossing the roads most populations bear some selection distortion. Plants and animals ensconce in a disturbed habitat have a competition advantage over those lived there before (Forman, 1997; Geertsema et al., 2002).

Most remarkable form of the harm of traffic to animals is the loss originated from that vehicles run down animals. A survey carried out in the Netherlands showed that 159 000 mammals and 653 000 of birds are run down annually, in the case of inferior species (amphibians, insects, butterflies) the number can easily reach several millions (Van der Zande et al., 1980). According to estimation (Forman, Alexander, 1998) the number of vertebrates perished on the roads in the USA reaches one million per a day (!). According to experts the number, which seems to be extremely high for the first sight usually does not mean danger for the ecological balance of the populations involved (Hodson, 1966; Forman, 1995). On the other hand population density of small mammals, birds and arthropods is significantly lower in a 100 200 m wide environment of busy roads. Habitat fragmentation usually increases the number of generalist species and decreases the number of specialist species (Farina, 1998). It is a general observation as well that individuals in overpopulated populations often try to cross newly built roads, which can be considered as a sign of malfunction of behavior.

In restriction of mobility of animals   in order of importance   width of the road, traffic density and material of the road play the most important role. Obviously the three factors are not independent, since one can rarely see a wide and busy dirt road for instance (Van der Sluis et al., 2004).

Ecological barrier role of roads was proved by interesting experiments in the 1970s. The study of Mader (1979) is cited most frequently. He marked 742 ground beetles (*Abax ater*) along a not very busy road in a mountains in Germany, and found that only two of them could cross the road from several hundred attempts. Others were frightened away by the concrete surface of the road. Thus they are not perished by the wheels of the vehicles but the unfamiliar material of the road acted as a barrier. Another project proved that hardly any ground beetles can cross a road wider than 2.5 m and only 10% of spiders and small mammals get through to the other side of the road (Mader, 1984).

Genetic erosion, which follows the fragmentation of the habitats, is a more serious danger than running down of animals (Opdam, 1991). The degree of the habitat fragmentation can be expressed by mesh size, which applies to the average extension of the areas fragmented by roads (Farina, 1998; Forman, 1995). If the size of the habitat fragmented by roads and railway lines is smaller than the size of a habitat, which is optimal for the normal functioning of the natural sized population of a given species, sooner or later it will lead to genetic erosion. Artificial barriers cause the formation of metapopulations (Forman, Alexander, 1998; Ingegnoli, 2003; Opdam et al., 1993; Vos, 1997).

There is relatively little knowledge on the minimal size of habitats where there are not irreversible disturbances in the behavior, feeding and especially the reproduction of the individuals of the populations (Bleuten, 1988); Hagenguth, 2000; McGarigal, Marks, 1995). Critical size of the habitat is considered to be 1 ha in the case of arthropods, 10 ha in the case of small mammals, and 100 ha in the case of birds (Blake, Karr, 1987; Lord, Norton, 1990). Minimal patch size of an C European alluvial softwood forest (*Salicetum albae-fragilis*) is estimated to be 30 40 ha. There are species, which are very sensitive to the size of their habitat, like birds that nestle in the inner parts of the forest patches (Farina, 1998).

Ecological consequences of habitat fragmentation caused by roads are so obvious that public feeling forces the decision makers to seek the most environmental friendly routes for the linear infrastructure. Passageways over or under motorways are usually parts of the plans nowadays, but there are serious doubts about the effectiveness of these objects (Lodé, 2000; Nieuwenhuizen, Van Apeldoorn, 1995; Schreiber, 1988). There is not a simple yes or no answer for the problem probably. In other words there are populations for which game passageways and ecotunnels mean the last straw, while for others they are not really effective solutions.

Habitat fragmentation effect of settlements

Less attention is paid in the literature to fragmentation effect of the building up, which obviously plays an important role in the ecological fragmentation of landscapes and in the shrinking of habitats (Reichholf, 1999; Mühlenberg, Slowik, 1997; Wagner, 1999). Studies on the ecology of the settlements deal mostly with plant and animal species which appear or disappear in the settlements, as special types of habitats, and pay less attention to how settlements encircle special habitats, how are sensitive ecotopes isolated, or in what ways are movements of animals blocked. Naturally settlements are much less permeable than the elements of linear infrastructure. The narrowest one-street village means an even wider physical obstacle than a 6 lane wide motorway. However, comparing the strength of their ecological barrier function it is not sure that a small village can block migration of plant and animal species more effectively than a motorway, defended by fences.

Populations bound to linear infrastructure and to settlements are different in another way as well: from the aspect of biodiversity, a settlement can be even richer in species than those habitats which had existed there before. Habitats along the elements of linear infrastructure are poor in species, biodiversity of vegetation along roads is usually very low (Bastian, Schreiber, 1994).

Basic data on the settlement and road network of Hungary

Hungary falls into the category of countries with medium density of settlement system and traffic infrastructure within Europe. Hungary's 3703 settlements represent several hundreds more patches in the ecological landscape structure, since many settlements consist of several, topographically isolated parts. There are 5 settlements in 100 km^2 in those regions where the settlement system is the densest; while in those areas, where the network is the sparsest this number is only 2 settlements per 100 km^2. About 12% of the area of the country is built up (area taken out of cultivation), which is near to the European average.

The total length of the road system in Hungary is 29 912 km, while the length of the railway lines is 7873 km. The latter one is the 5th densest network in Europe. In addition to the length of the roads there are several hundreds of kilometers in forests and roads on the dams, which have important impact also on the ecological landscape structure.

From the aspect of practical landscape protection and planning the degree of artificial fragmentation of an area, that is the density of linear infrastructure and built up, is a fundamental data. Dosch and Beckman published a map of that kind in 1999. The map describes the infrastructure of the whole Germany on the base of the density of roads, railway lines, waterways and high voltage electricity cables per km^2. Values scatter between 0.2 and 2.5, with high values in the west and southwest. The area of the former GDR is clearly distinguishable. Lowest values of density of infrastructure can be found in the northeast, in Meckleburg-Vorpommern.

Unfortunately even this German map does not reflect ecological, landscape-ecological aspects sufficiently either. Data of spatial fragmentation is not differentiated on the base of the traffic load of different roads, and does not take into account the topographic relationship between a given element of infrastructure and protected natural areas, etc. Obviously, determinant role of settlements is not taken into consideration at all in the map either.

In the opinion of the author of the present paper, an index of spatial fragmentation, which is more sufficient for the ecological landscape planning practice, would be a very useful tool at national, regional and settlement level, too.

For this reason using the 1 : 250 000 scale maps of the Cartographia Road Atlas of Hungary

- the total settlement, road and railway line density of the country was measured,
- data gained that way was weighted on the base of landscape ecological aspects,
- finally, it was presented according to the official microregion system of the country.

Weighting of data on the degree of fragmentation

Roads

The sections of roads outside the settlements were taken into account only, because a road that crosses a settlement does not strengthen the barrier function of a settlement to the migration of plants and animals significantly. On the other hand the scale did not make possible to take into account the complex barrier role, for instance, of a suburban area with a motorway, which is, however, not a frequent combination.

Unsurfaced roads were taken into consideration only if they cross patches of forests or protected areas. Strong ecological barrier role of the openings in the forests is proved by several studies (Forman, 1995; Harris, 1984; Ružičková, 2003).

The following system was elaborated:

- There is no index number for unsurfaced roads that cross forest.
- Index number is 3 for unsurfaced roads which cross protected areas (in the case of a protected forest the index number is 3 again).
- Index number is 2 for 3rd or 4th order approach roads where they run out of protected areas.
- Index number is 5 for 3rd or 4th order approach roads where they cross protected areas.
- In the case of roads for forestry purposes opened for public use temporarily (e.g., in the weekends) an index number of 1.5 or 2.5 seemed necessary (the latter one in the case of protected areas).
- Index number in the case of secondary roads was between 4.0 and 4.8 as a function of traffic density, which was determined using the map "Traffic volume on public roads" on the 87th page in the National Atlas of Hungary (Cartographia Ltd., 1999).
  The value of the index number is 4.0 under a traffic density of 1000 car units
  Index number is 4.2 where traffic density is between 1000–2000 car units
  Index number is 4.4 where traffic density is between 2000–5000 car units
  Index number is 4.6 where traffic density is between 5000–8000 car units
  Index number is 4.8 where traffic density is over 8000 car units per day.
- Index numbers for main roads, similarly to secondary ones, were between 4.0 and 4.8.
- In Hungary relatively few main roads and secondary roads cross protected areas. For those sections of main roads, index numbers between 8.0 and 8.8 were applied according to the before mentioned car unit categories.
- Motorways got an index number of 10. (In Hungary there are not any motorways that cross protected areas.)

Railway lines

- Index number in the case of double tracked main railway lines was 5. An index number of 6 was given in those cases where railway lines run in the immediate vicinity of a motorway, main road or secondary roads. (Immediate vicinity in this context means closer than 1 km.).

In those cases where traffic lines run so close it is reasonable to raise the index number, since in such places migration is strongly restricted by the synergic impact of a road and railway line. In habitats, not larger than several hundred meters in diameter, which are isolated that way usually cannot form an undisturbed core area; they are occupied mostly by a transitional ecotone zone.

- In the case of single tracked branch lines index number is 3, and it was raised to 4 in places, where railway lines run closer than 1 km to a motorway or main road or secondary road.
- Only a few railway lines crosses national parks. Since all of those ones are low traffic density branch lines, index numbers were not raised in those cases either.

Settlements

Settlements can be considered as permanent ecological barriers. Measuring the diameter of a settlement, we can get the width of the area which living creatures have to go round in the vicinity of a settlement. This index is quite suitable for small villages and towns. Later it was found that the larger the city is, the more significant the distorting effect of the index will be. In those landscapes where major part of the area of landscape is occupied by a big city and ecological barrier role of the roads and railway lines in the inner parts was not taken into account, just their greatest diameter was used as an index, so low results were calculated, which were far beyond the results for landscapes with tiny villages with dense traffic system. It is obvious that Budapest cannot get lower ecological fragmentation index than that of landscapes with small villages. However, total maximal diameter values of tiny villages in Dél-Dunántúl region (Southern Transdanubia) are not lower significantly than those values for big cities and their sparse settlement system in the Nagy Alföld (Great Hungarian Plain).

For this reason it was necessary to apply another index to express the real ecological effect of the settlements. In that index the size of the settlement have to be reflected. A clear solution could be to multiply the maximal diameter of the settlements with their circumferences. It is an interpretable result from ecological aspects, since it gives the length of the ecological border (ecotone), which forms a barrier for the migration of the plant and animal species. Unfortunately there are no data available on the length of circumferences of the inner parts of the settlements in Hungary. There are data on the extent of the peripheries and inner parts of the settlements, on the other hand. For this reason the multiplication of the size of the inner parts of the settlements, larger than 1 km^2, was used as another index together with the diameter.

There are 1664 settlements in Hungary, which have an inner part larger than 1 km^2. It is 45% of the total 3703 settlements in the database, which is a sufficient number, especially taking into account the fact that it represents 82.9% of the total built-up area.

On the other hand, those 2039 settlements, where the correction factor based on the area of the inner parts was not used, represent 17% of the total built-up area of our country. Those settlements, where correction index was not used, are usually tiny villages with 2-3, several hundred meters long streets. In their cases only the greatest diameter of the settlements was taken into consideration.

Keeping in mind the ecological barrier role, the following index numbers were used, because that way, values calculated for the effect of the road and railway line system were not distorted by the indexes for the impact of the settlements.

- The greatest diameter of settlements was multiplied by 6, which shows that the ecological barrier role of the settlements is considered to be similar to that of first order main roads, but it is deemed to be weaker isolator factor than a motorway. It means that, in the author's opinion, a one-street village is a weaker ecological barrier for the migration of plants and animals than a motorway. It seems to be an acceptable principle, since fences along motorways have very strong impact on migration of animals, but that impact is much weaker on plants.
- Index number is 8 in the case of settlements, where there is a protected area not further than 1 km from the settlement. In such cases the disturbing effect of the settlement on nature is obviously stronger.
- There was a special case, where one more aspect was to be taken into account. There are some tiny, but long villages in the valleys of hilly regions, where the extent of the inner parts is smaller than 1 km^2, however, the length of the villages reaches 2-3 km, and they act as strong ecological barriers. For this reason the index number of 6 for the maximal diameter was not enough to express their impact, so in those cases an index number of 7 was applied.
- An index number of 7 was applied in those cases also, where two 1.5-2 km long villages are growing together. A one kilometer gap between two 1.5-2 km long ecological barrier has a great importance from ecological aspect. There must be an at least 400 m wide gap left in such places according to the laws for landscape planning practice (Duhay, 2004). Therefore, it is a correction number, which expresses the threat of agglomeration. Since it would have been problematic to apply the suggested 400 m value in our 1 : 250 000 scale map, the correction value was applied in cases only, where the ecological corridor is narrower than 1 km between two settlements. (In the case of the agglomeration of the tiniest settlements, which have a maximal diameter of 500-1500 m that correction was not used.)
- In the case of settlements larger than 1 km^2 in area, one more parameter was added to the before mentioned ones. That index is based on the spatial extent of the settlement. After several experiments, an index number of 15 for the size of the inner parts of the settlements was proved to be sufficient. It means that built up of the inner parts of the settlements is considered to be a stronger fragmentation factor by 1/3 than the effect of motorways.

  Indexes are summarized in the following table.

T a b l e 1. Correctional index numbers for the weighting of the fragmentation effect of settlements and traffic infrastructure.

Land use type	Method	Criteria
Ssettlements	greatest diameter in km multiplied by 6	
	greatest diameter in km multiplied by 7	in the case of large agglomerating or very long one-street villages
	greatest diameter in km multiplied by 8	if it is within, or in the immediate vicinity of a protected area.
	area of the inner parts in km^2 multiplied by 15	only in the case of settlements, where the area of the inner parts is larger than 1 km^2
Rroads (section outside settlements)	road without a hardened surface in km	in sections, which cross forest patches
	road without a hardened surface in km multiplied by 3	sections which cross protected areas
	third or fourth order approach roads in km multiplied by 2	
	roads of forestry with a hardened surface in km multiplied by 1.5	opened for public use only temporarily (in the weekends e.g.)
	third or fourth order approach roads in km multiplied by 5	sections which cross protected areas
	roads of forestry with a hardened surface in km multiplied by 2.5	opened for public use only temporarily (in the weekends e.g.)
	secondary road in km multiplied by 4.0–4.8	as a function of traffic density
	secondary road in km multiplied by 8.0–8.8	in protected areas, as a function of traffic density
	main road in km multiplied by 4.0 -4.8	as a function of traffic density
	main road in km multiplied by 8.0 -8.8	in protected areas, as a function of traffic density
	motorways in km multiplied by 10	
Rrailway lines (outside settlements)	branch line in km multiplied by 3	
	branch line in km multiplied by 4	sections which run close to motorways or main roads
	trunk line in km multiplied by 5	
	trunk line in km multiplied by 6	sections which run close to motorways or main roads
	narrow gauge railway line in km multiplied by 1.5	
	narrow gauge railway line in km multiplied by 3	sections which run close to motorways or main roads

The system has not dealt with a settlement type and some special objects, undoubtedly. On one hand it was not possible to take into account the sparse (homestead) settlement system in the Nagy Alföld plain, on the other hand it was very difficult to share the area of the inner parts of settlements situated on borders of microregions. There was not any data available for the calculation of the fragmentation impact of opencast mines and airports.

In the case of the roads some not very important, special types were not taken into consideration as well. Such a type is traffic on dams for instance. Although, major part of roads on the top of the dams is closed for public traffic, there are some open sections as well. There can be remarkable differences in the intensities of traffic on the roads on dams. They can be strong barriers in periods of flood danger, while they can play almost negligible role in other seasons. It is an important problem from the aspect of ecology, since quality of connections among wetlands is a critical factor for the sufficient operation of the ecosystem (see: Emphasized importance of green corridors along rivers in European Nature Protection Network). The isolation of habitats on the embanked side of the dams and along the rivers is not weakened remarkably by connections through the dams, therefore the intensity of the traffic on the dam, makes no difference. It is possible; however, that traffic on the dams is a strong barrier for certain groups of living creatures.

The before mentioned lack of data and the scale of the map have not allowed to take into account the fragmentation impact of walking paths as well. Nevertheless, it is easy to understand that their ecological barrier role can be very strong in the environment of metropolitan agglomerations and popular recreation areas. This role of walking paths in that scale could not have been taken into consideration. In the opinion of the author, weighting system presented here is not too complicated, but differentiates properly, and reflects ecological and landscape ecological aspect. It can lead to some misunderstandings, undoubtedly, that result has not already been given in km/km^2 due the weighting, but they are values, which have been modified on the base of ecological considerations. Therefore, if there is a value of 3.5 for a microregion, it does not mean that the length of the ecological barriers due to settlements, roads and railway lines in that microregion is 3.5 km per one km^2 on the average. The raw values are lower, because the original kilometer values for each barrier types get an index number as a function of the strength of ecological barrier role. In other words there are distorted km/km^2 values, which should be called, more properly, landscape fragmentation indexes.

Fragmentation maps of the microregions of Hungary

There are three maps based on the results of the measurements, which are presented here (Figs 1, 2, and 3). Results are calculated for 230 microregions, which are elements of the official landscape hierarchy of Hungary described in the Cadastral of Microregions of Hungary (Marosi, Somogyi, 1990).

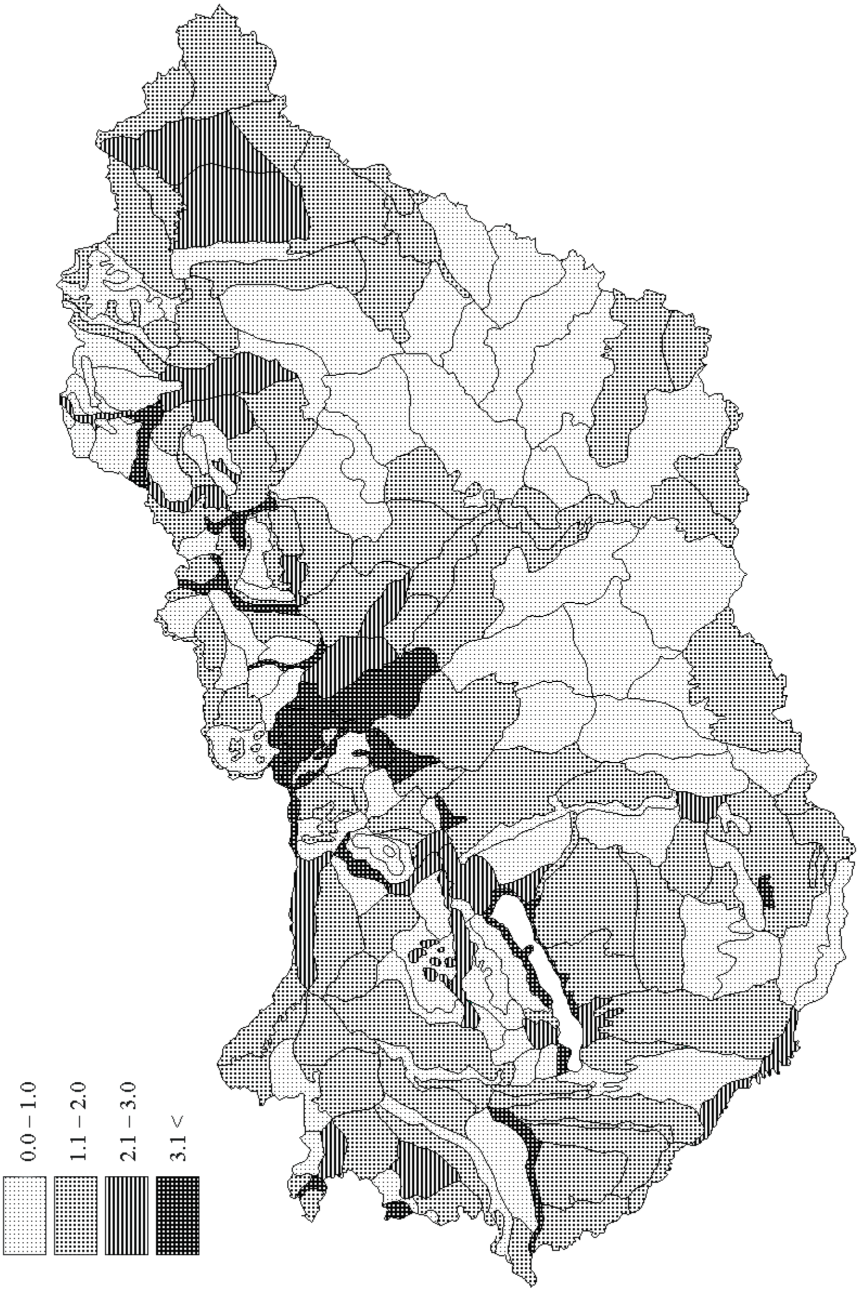

Fig. 1. The degree of fragmentation of microregions of Hungary by the settlement system (modified data km/km[2] – detailed explanation see the text).

The first map presents the degree of fragmentation of microregions of Hungary by the settlement system. Values are grouped into four categories on the base of before mentioned ecological, landscape-ecological considerations.

In the first category there are 89 microregions from the whole 230. Their total area is 39 300 km^2, which is 42% of the area of Hungary. There are two microregions in the mountains, where there are not any independent settlements at all, so the degree of fragmentation is practically zero. Microregions in the mountains and in the Nagy Alföld plain can be found in this category usually, while microregions in the foothills or hilly regions rarely fell into this category.

Only a bit more, 94 microregions fell into the second category, which is 42 640 km^2 on the total. Foothill microregions in Dunántúl (Transdanubia) region, north-eastern part of the Nagy Alföld plain and in Északi-középhegység (North Hungarian Mountains) can be found typically in this category (Fig. 1).

Fragmentation indexes of the settlements were higher than 2.1 in the case of 47 microregions. Strongest habitat fragmentation values were found in microregions on the southern bank of lake Balaton, and in the valley of river Danube north from Budapest. Almost every major valley, which separates the parts of the Északi-középhegység (North Hungarian Mountains) (the valley of Galga, Zagyva, Tarna, and Sajó), fell into that category.

The dense settlement network in the landscapes of the south-western part of the Dunántúl (Transdanubia) and the north-eastern part of the Nagy Alföld plain are known for geographers. Present study, however, has been completed for experts of landscape planning, landscape protection, landscape architecture, nature protection, for those, who not necessarily have geographical background but they are responsible for preparing plans on the protection of the environment, settlement development; situation analyses, and strategic plans.

Landscape ecological fragmentation of microregions on the base of the road and railway line system

Spatial pattern of the landscape fragmentation index based on the fragmentation impact of road and railway system is presented in the second map (Fig. 2). From the four intervals of the map compared to the first map, on the base of the number of microregions in the different categories, the first, lowest category is predominant, because from 230 microregions on the whole 120, that is more than half of them fell into that category. On 64% (59 980 km^2) of total area of our country landscape fragmentation effect of traffic infrastructure seems to be weak. In opposition to the dataset of the settlements, here is not any microregions, where could not be found any analyzable fragmentation effect, that is, even if there are not settlements in every microregions, roads or railway lines still cross landscapes without settlements also. Roads of forestry cause relatively strong landscape fragmentation in national parks in mountainous regions. It is remarkable, that some core areas in mountainous regions got the lowest index, while others show much higher fragmentation values. Higher results

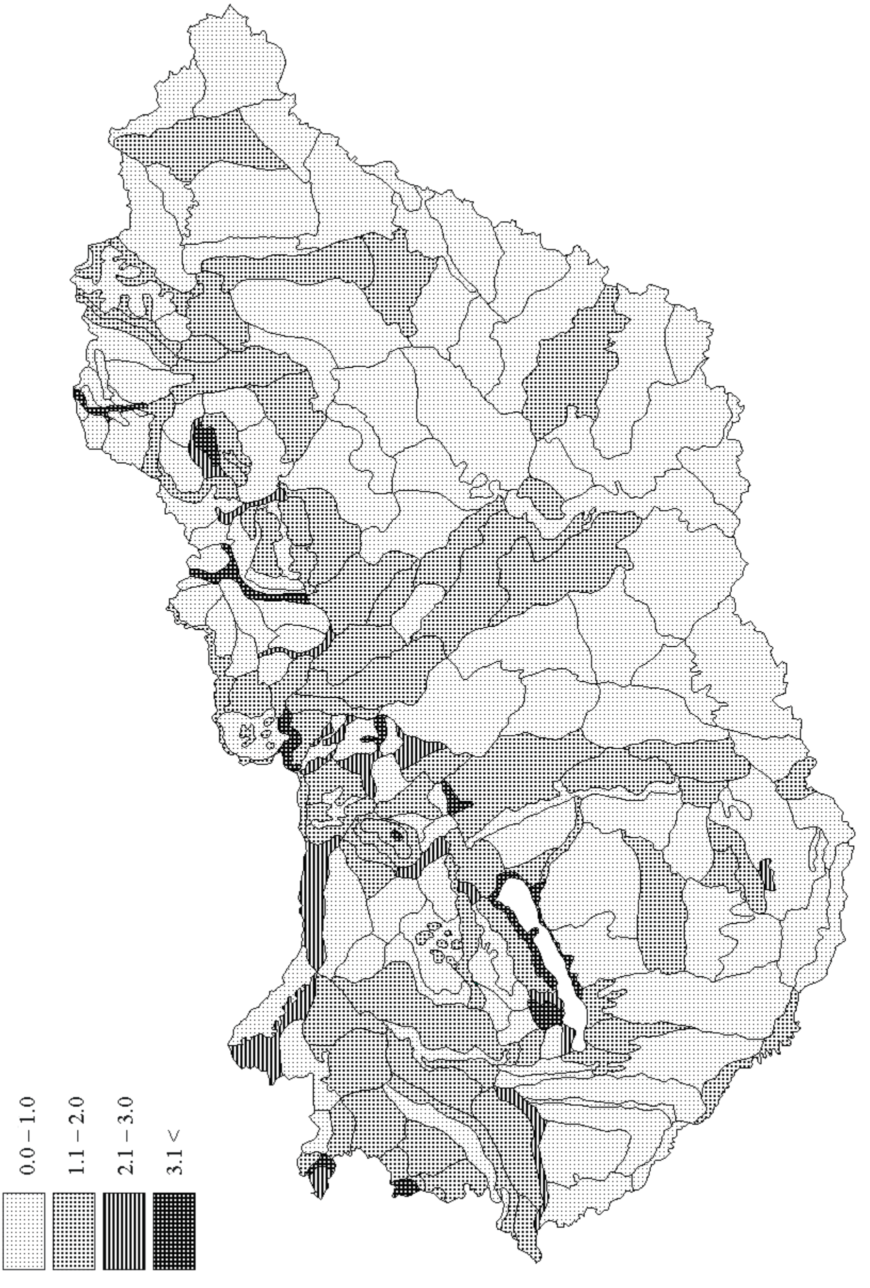

Fig. 2. The landscape fragmentation index based on the fragmentation impact of road and railway system is presented (modified data km/km^2 – detailed explanation see the text).

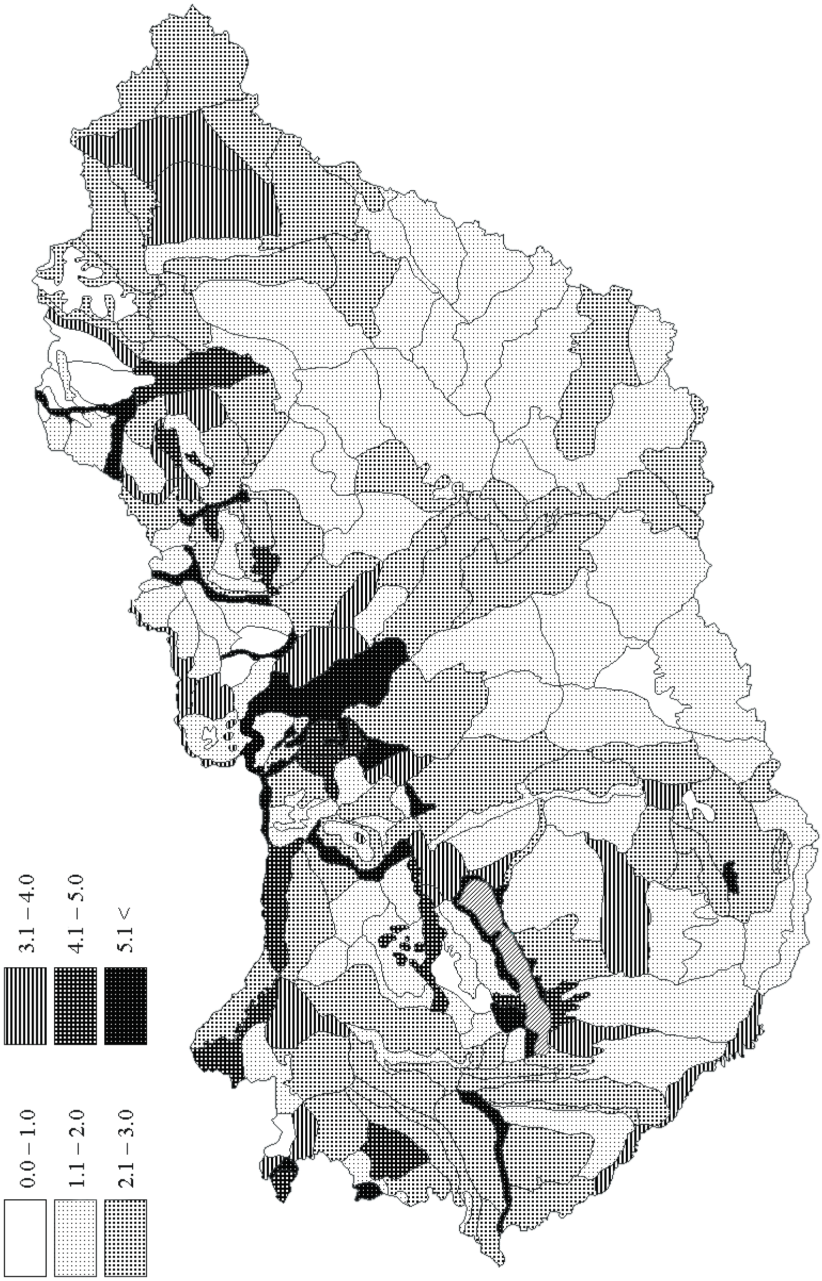

Fig. 3. Weighted and summarized data for the fragmentation effect of settlements and traffic infrastructure of Hungary (modified data km/km^2 – detailed explanation see the text).

have come out where there are many roads in the forests, which cross protected areas, consequently get high index numbers.

Medium level of fragmentation can be found in 82 microregions (1.1–2.0). In the spatial pattern of the microregions in that category the radial traffic infrastructure of Hungary is slightly traceable. Stronger fragmentation of microregions along the 4 motorways set out from Budapest, and the radial railway lines is clearly visible. Fragmentation indexes of the microregions in Észak-Dunántúl (Northern Transdanubia) are remarkably high (Fig. 2).

In the case of microregions at the lake Balaton, and valleys between mountains, the contrasts to neighbouring microregions are much stronger than in the case of the fragmentation impact of the settlements. There are high values for valleys between parts of the Északi-középhegység mountains, while microregions in their environment got only fragmentation indexes under 1. Obviously, alluviums in the valleys endangered by floods are not occupied by settlements, but for roads, which cross deep, wet lands on the top of embankments those areas mean no obstacle at all. These differences are clearly visible comparing the two maps (Figs 1, 2).

The agglomeration belt around the Hungarian capital is not very striking in the maps of habitat fragmentation caused by traffic infrastructure. The spatial pattern of microregions in the first two categories, which show the strongest fragmentation (> 2.1), is more uniform than in the case of landscape fragmentation caused by settlements.

Maps of summarized ecological microregion fragmentation indexes

Third map was completed using weighted and summarized data for the fragmentation effect of settlements and traffic infrastructure (Fig. 3).

There are six intervals in the map with the following distribution:

Fragmentation indexes	Number of microregions
0.0–1.0	16
1.1–2.0	77
2.1–3.0	73
3.1–4.0	25
4.1–5.0	15
5.0 <	23

Fragmentation indexes, which express the degree of complex ecological dissection, show a mosaic-like pattern, and there are strong differences in the indexes of the neighbouring microregions. In some cases there are significant differences in the indexes of the microregions within one microregion group or a mesoregion even in the Nagy Alföld plain. Nevertheless, strong scattering of the indexes between microregions within a group can usually be found in the mountainous regions and a bit less frequently in the hilly regions.

Complex fragmentation index of the microregions in Hungary is between 1.1 and 2.0 in one third of all cases, and almost the same number falls into the next category between 2.1 and 3.0. 19 from the 23 microregions, where fragmentation is the weakest, can be found in the Északi-középhegység Mts. Fragmentation indexes of the microregions in the two plains (Great and Little Plain) are usually under the averages of Hungary, but areas, where there are motorways and tiny villages, like in the north-east, indexes are close to the average.

Many passage valleys between parts of middle height mountain ranges or hills act as strong barriers for the migration of living creatures. Other types of landscapes overloaded with anthropogenic obstacles, are recreational landscapes on the banks of rivers and lakes (e.g. lakes Balaton or Velence). Recreation belt along river Tisza, on landscape level, has not such effect yet. Finally there are some densely built up small basins (Pécs, Sopron, Budaörs-Budakeszi, etc.), where the degree of fragmentation of the landscape by settlements, roads and railway lines has reached a critical value.

As a summarization it can be stated that compared to the national averages, which are the followings:

	Ecological barrier role of settlements (corrected km/km^2 values)	Ecological barrier role of roads and railway lines (corrected km/km^2 values)	Degree of landscape ecological fragmentation (corrected km/km^2 values)
Hungary	1.86	1.39	3.25

Nagy Alföld plain shows weak, while the Dunántúli-dombság (Transdanubian hills) show strong landscape ecological fragmentation. Values over the average occur in the southern Transdanubian macroregion, while all other macroregions are around or under the average, what reflects well the different spatial pattern of the settlement network of the macroregions.

MACROREGIONS	Landscape ecological fragmentation effect of the settlements	Landscape ecological fragmentation effect of roads and railway lines	Values of summarized ecological fragmentation
Nagy Alföld (Great Hungarian plain)	1.49	1.00	2.49
Kisalföld (Little plain)	1.85	1.36	3.21
Nyugat-magyarországi peremvidék (West-Hungarian borderland)	1.63	1.55	3.18
Dunántúli-dombság (Transdanubian hills)	2.69	1.57	4.26
Dunántúli-középhegység (Transdanubian Mts)	1.77	1.49	3.26
Északi-középhegység (North Hungarian Mts)	1.72	1.40	3.12

The author is convinced that maps presented here can provide a basis for landscape planning based on ecological aspects, despite problems with the weighting of raw values, results reflects well the real habitat fragmentation and migration.

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