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LANDSCAPE ECOLOGICAL FRAGMENTATION

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ABSTRACT

The degree of ecological fragmentation of landscapes is a useful index for landscape protection and planning. Strong fragmentation effect of the road system is originated from that the animals during their migrations sooner or later will face a strip of concrete. Up till now less attention is paid in the special 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. 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.

Also the two main data for the ecological fragmentation seems to be the greatest diameter of the settlements – the settlements functions as a barrier for the migration - and the density of the roads and railroads. In the case of large settlements the extent of their inner parts, in the case of the roads the traffic intensities was taken into account, while in the case of railroads it was taken into consideration whether railway lines are single or double tracked. Values of the fragmentation index can be given in km/km^2 for the 230 microregions of Hungary.

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.

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

The Great Hungarian Plain shows weak, while the 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.

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.

HABITAT FRAGMENTATION AND ROAD NETWORK

The 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. The main causes the fragmentation of habitats are building up and development of linear infrastructure.

Roads forms 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. 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. 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 by-passed. 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. Most remarkable form of the harm of traffic to animals is the loss originated from that vehicles run down animals. 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.

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 Central- 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).

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

In Hungary the settlement and traffic infrastructure density reaches a medium level 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.

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.

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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 Southern Transdanubia region are not lower significantly than those values for big cities and their sparse settlement system in the 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 is no data available on the length of circumferences of the inner parts of the settlements in Hungary. There is 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.

FRAGMENTATION MAPS OF HUNGARY (FIG. 1.)

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).

There are six intervals in the map (Fig. 1.) 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 Great Hungarian 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 North Hungarian 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, 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): 1.86
- Ecological barrier role of roads and railway lines (corrected km/km^2 values): 1.39
- Degree of landscape ecological fragmentation(corrected km/km^2 values): 3.25

The Great Hungarian plain shows weak, while the 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
Great Hungarian plain	1.49	1.00	2.49
Little plain	1.85	1.36	3.21
West-Hungarian borderland	1.63	1.55	3.18
Transdanubian hills	2.69	1.57	4.26
Transdanubian Mts	1.77	1.49	3.26
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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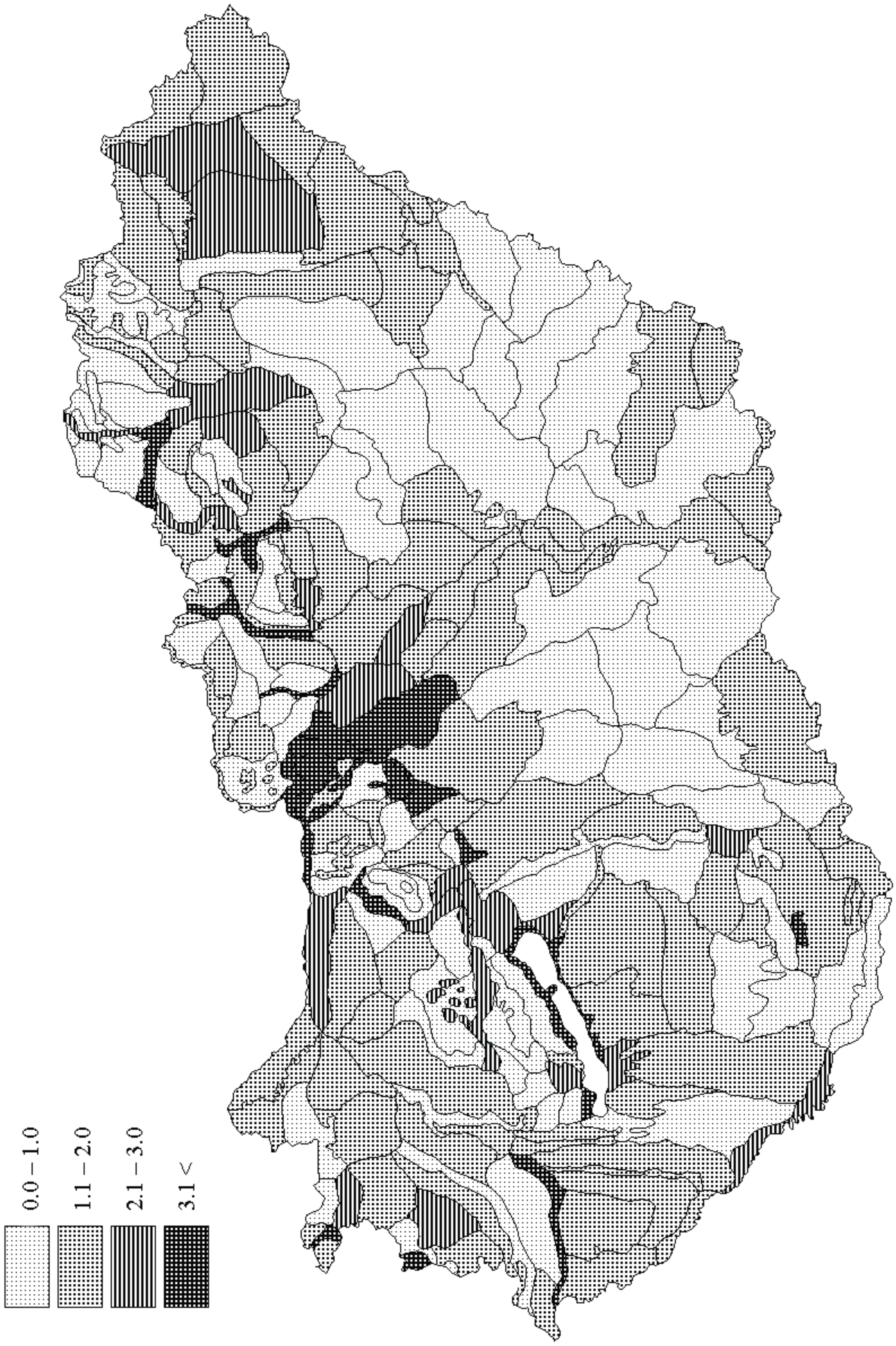
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