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ANALYSIS OF FRAGMENTATION OF SELECTED STEPPE SITES IN THE PANNONIAN REGION OF THE CZECH REPUBLIC

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Abstract

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The aim of this study was to analyze the landscape fragmentation in selected locations of the Pannonian region in three time periods. Landscape fragmentation is a process during which a large habitat is divided into a number of smaller parts. The fragmentation was analysed using the landscape-ecological indices for Patch Analyst extension. Data entering the analysis is in Esri shapefile format and was prepared for 1:10 000 scale size. To calculate the index of overall contrast of edges (borders), we used the FRAGSTATS application. The complete evaluation led us to the conclusion that the landscape fragmentation in the selected area over time rather increased. From the calculation of the overall contrast of edges, it is possible to identify increasing diversity of adjacent patches (small areas) in the landscape mosaic. In addition to the normal work indices, this study also works with Total Edge Contrast Index (TECI) which expresses the percentage difference of neighbouring land use categories depending on the length of edges between these categories. The calculated values of the entire studied area showed that the landscape fragmentation tends to increase over time, which can threaten biodiversity, reduce migration and colonization potential in the landscape, increase the susceptibility of the landscape for invasions of nonnative species and reduce hunting opportunities of local species. The calculation of the TECI proved increasing dissimilarity of neighbouring patches in the landscape mosaic. It can be caused by expansion of built-up area and construction of roads that are the abiotic components which disturb the processes of ecologically important elements of the landscape.

analysis, area development, fragmentation, landscape metrics, GIS

Landscape fragmentation is a process during which a large habitat is divided into a number of smaller parts. Individual fragments then separate less valuable areas that often have the character of a barrier for certain organisms (Alofs and Fowler, 2007). Escalation of the landscape heterogeneity may, therefore, threaten the existence of some species, and result in reduction of migration and colonization potential of the landscape (Otýpková *et al.*, 2011), increased susceptibility of landscape parts to invasions by non-native species, reduction of hunting opportunities for local species and genetic problems of small populations leading to decrease in the population density which may even cause species extinction (Zonneveld, 1995; Ahlqvist, and Shortridge, 2010). Due to the construction of abiotic barriers (highways, railways, fences), the populations are more and more isolated. The problem addressed now by experts is a quantitative expression of landscape fragmentation and diversity (Mimra, 1995). Li and Reynolds (1994) define spatial heterogeneity based on five components: the number of patch types (land use classes), the rate of each type, spatial arrangement, patch shape and the contrast between adjacent patches. In this work, the authors also explain the four selected indicators of spatial heterogeneity that are: i) Fractal dimension – depending on the area and perimeter of individual patches, it determines irregularities in patch shapes in the landscape; ii) Relative contagion index – it indicates the extent to which the patches of the same type are clustered, i.e. their spatial arrangement; it should also react to the number of patch types and their ratios in the landscape; iii) Romme's relative evenness index – it is calculated based on the probability that a randomly selected pixel belongs to the given patch type; therefore, it also depends on the number of patch types and their proportions in the landscape; iv) Romme's relative patchiness index – it measures the contrast between adjacent patches in the landscape mosaic based on the dissimilarity matrix of individual patch types (according to land use). The results of their experiments showed that any definition of spatial heterogeneity is strongly dependent on the basic variables and the methods used, that there are significant interactions between the above-listed components of spatial heterogeneity and that some indices are strongly correlated. All methods of measurement must, therefore, be assessed according to the areas with well-known characteristics of spatial heterogeneity. However, a quantitative understanding of spatial heterogeneity may help determine its role in the landscape functions and processes including the propagation of disturbances. Due to quantification, it is also possible to compare different areas. One of the authors, Habin Li, dealt with this issue already in 1989 in his dissertation called "Spatio-temporal Pattern Analysis of Managed Forest Landscapes: A Simulation Approach". Here, we can find primary information about Romme's relative patchiness index and dissimilarity matrices. To calculate the patchiness, it is possible to use Lloyd's Index of Patchiness which was calculated in the work "Case Study #2: Lloyd's Index of Patchiness" by Xiao, Hao, Subbarao (1997) in the R programme. The relationship between spatial or functional changes in the landscape and partial Romme's relative patchiness index for meadows and pastures was described by Gao and Yang (1997) in their article "A relationship between spatial processes and a partial patchiness index in a grassland landscape". They applied the derived linear relationship on one hectare of observed grazing land in north-eastern China. S. Kumar, Stohlgren, and Chong (2006), in their study "Spatial heterogeneity influences native and non-native plant species richness", determined the landscape heterogeneity of Rocky Mountains National Park in Colorado, USA, by means of landscape metrics using the FRAGSTATS application. They specialize in the diversity of vegetation which also highly influences the occurrence of birds and other animal species. Therefore, they address the role of spatial heterogeneity in the distribution of plant species, and deal with the issue whether the results are different for the original and non-native species of plants and what effect on the results can be attributed to changes in the selected area or changes at another level of ecological hierarchy (in the countryside, in the land use category, in the community).

A landscape structure analysis in time regarding the present territory of the village of Naubinway, Michigan, USA, was carried out by Delcourt (2002). He compared the analyzed area within periods around 1890 (before colonization by Europeans) and 1980. In addition to computing landscape-ecological indices, he also pursued the causes of changes in land use and vegetation types in comparison with the thematic maps of soil types and disturbing impacts (which include, for example, major fires).

Llausŕs and Nogui (2012), in their article "Indicators of landscape fragmentation: The case for combining ecological indices and the perceptive approach", mention three main negative effects of landscape fragmentation. Firstly, the fragmentation process causes changes in abiotic environmental conditions due to the removal of natural habitats of living organisms, modification of their surrounding, increase in noise level and pollution of water and air. The second case of negative environmental effects of fragmentation is represented by linear elements (especially roads and railways) which have a direct impact on the populations due to increased mortality during collisions, expansion of non-native species and changes in their behaviour. The third indicated negative impact of landscape fragmentation is violation of individual habitats of living organisms in consequence of the reduction in stray capacity, the effects on reproduction and natural selection (transfer of genetic information) and recolonisation of formerly abandoned habitats. The result of the landscape fragmentation is a large number of smaller areas (patches), decrease in the mean distance between patches of the same type whereas individual species mingle more widely and the number as well as length of edges linking various habitats with different characteristics increases. Although many people perceive such changes only negatively, it is clear that these changes may also have a positive impact on the landscape in some cases, depending on the specific requirements of individual types of organisms (Llausŕs, Nogui, 2012).

Landscape fragmentation can be quantified by the help of landscape-ecological indices that can be computed using GIS. In addition to the normal work indices, this study also works with Total Edge Contrast Index (TECI) which expresses the percentage difference of neighbouring land use categories depending on the length of edges between these categories. Index values thus range from 0 to 100%. TECI assumes zero values provided that the study area does not contain any edge. On the contrary, the highest value would be achieved if all differences between the categories had the highest possible value, i.e. 1, as will be explained below in the description of dissimilarity matrix.

$$TECI = \frac{\sum_{i=1}^{m}\sum_{j=i+1}^{m}\left(e_{i,j} \times d_{i,j}\right)}{E} \times 100 . \quad (1)$$

In the relation expressed by equation number 1 (McGarigal *et al.*, 2002), the index *m* determines the number of land use categories within the given territory. Unknown e_{ij} expresses the total length of edges between categories *i* and *j*, and d_{ij} is the weight of dissimilarities between categories *i* and *j* specified in the dissimilarity matrix. *E* is the sum of lengths of edges among all categories within the study area. Dissimilarity matrix contains the values of dissimilarity for single land use categories. This dissimilarity is expressed in values ranging from zero to one so that zero means a zero contrast between categories; weight of dissimilarity 0.80 means 80% contrast between two adjacent categories.

MATERIALS AND METHODS

Study area

Inside the territory of the Czech Republic, we selected 68 steppe sites in the Pannonian region. An envelope zone within a distance of 5 km (according to Li and Reynolds, 1994) was created around these points. This method led to a defined area of 1890 km^2.

Data and software tools

Data entering the analysis is in Esri shapefile format (hereinafter referred to only as SHP) and was prepared for 1:10 000 scale size. For each of the three time periods in the given territory, there were two line layers – roads and waterways, and one polygon layer of land use classified into the following eight categories (forest, meadow, pasture, arable land, other land, vineyard, orchard, garden, ornamental garden, park, built-up area and water area).

- 2nd military survey – Data for the period of the 2nd military mapping was obtained by digitizing based on the web mapping services of the INSPIRE National Geoportal. The digitization ran in ArcGIS environment directly in SHP data format.
- Fifties of the 20th century – Input layers for the period of the fifties of 20th century were acquired through digitized black and white aerial photographs from the server http://kontaminace.cenia.cz/ (historical orthophotomap © CENIA 2010; supporting aerial images were provided by VGHMÚř Dobruška, © Ministry of Defence, 2009). These are pictures taken in the period 1950–1953 and are not available as a WMS service; therefore, they were gradually stored as images on harddisk and rectified manually. The rectification was performed according to SHP of the current state.
- The present – Most of the area selected for the analysis of the current status was gained from the archives of the Administration of the White Carpathians Protected Landscape Area. This data was obtained in SHP format. The remaining area was digitized according to aerial photographs of the INSPIRE National Geoportal taken in 2008–2009, supplied by the company Geodis Brno. The layer of water flows was obtained from the Digital base of water-management data (DIBAVOD).

Digitization, editing, and processing of input data was carried out in ArcGIS environment from the company Esri. For subsequent calculations, we used Patch Analyst 4 extension and FRAGSTATS 3.3 application. In each of the used software tools, we calculated the selected indicators of landscape fragmentation. Processing and visualization of the results runs in common applications of the OpenOffice office suite.

Processing

After defining the territory, spatial data was prepared for each time period. Following this preparatory phase, we evaluated the input layers using the Patch Analyst extension and the FRAGSTATS application. These applications calculate the indices of landscape metrics based on the perimeter and the area of single territory fragments as well as their diversity based on land use. Values were calculated for each of the three time periods and subsequently compared with each other. From the Patch Analyst extension, we used the Spatial Statistics instrument that allows calculating the area of patches for each class, number of patches, average patch size, patch size median, patch size variance coefficient, patch size standard deviation, total number of edges, edge density, mean patch edge, average patch shape, patch shape weighted average depending on the area, average perimeter-area ratio, average patch fractal dimension, weighted average of patch fractal dimension depending on the area, Shannon diversity index and Shannon balance index (Rempel *et al.*, 2008).

To calculate the index of the overall edge contrast in the landscape, we used the FRAGSTATS 3.3 application the recent versions of which handle only raster data. The pixel size in the raster grid was fixed at 10 m.

Land use layer for each time period was converted to raster using the Polygon-to-Raster tool in ArcGIS environment where the land use category was chosen as the pixel value. Due to this conversion, however, the edges formed by water streams and roads with zero width in vector format disappeared from the landscape mosaic (Fig. 1). Since these line elements in the landscape structure are a very important fragmentation factor, it was necessary to include them also into the raster format. First of all, envelope zones were created above line layers – within a distance of 0.5 m for water streams (average watercourse was therefore fixed at 1 m) and within a distance of 1 m around the roads. Subsequently, these two layers of envelope zones were connected using the Merge tool and converted to a raster grid with pixel size of 10 m by means of the Polygon-to-raster tool. During this conversion, we chose the Maximum_Area method so that lines were contiguous even in the raster. When retaining the default Cell_Center method, a polygon value is assigned to pixel only if the input polygon lies below the pixel centre which does not occur too frequently in the situation solved. Consequently, it was necessary to add the created raster of line elements into the previously prepared grid of areas of landscape use. This was done using map algebra as follows: based on reclassification, the value of 100, 1 000 and 1 was assigned to watercourses, roads and their surroundings, respectively. The raster of land use areas was then multiplied by the raster prepared in this way. Values of this raster, therefore, increased hundredfold and thousandfold in the places of water courses and roads. The raster was transformed into the resulting form through repeated use of the Reclassify tool. Watercourses were assigned the same value as bodies of water and roads created a special category.

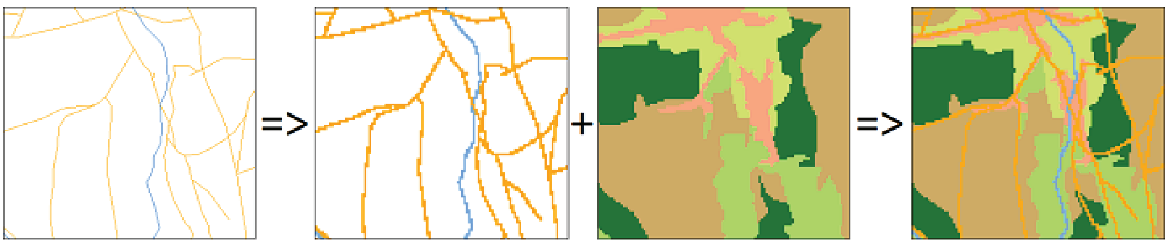
Finally, the resulting raster layer was converted by the Raster-to-ASCII tool to ASCII (American Standard Code for Information Interchange) format which can be well edited and represents a suitable input into the FRAGSTATS application.

Input and output data, pixel size, the number of rows and columns in the raster grid and background pixel values have to be defined. The respective values must be positive so that it is necessary to adjust them in the input layer. The value -999 is automatically assigned by ArcGIS to unknown raster values. However, alteration of this value is very easy in the ASCII file; it can be simply changed to 999 in the text editor using the replacement function. Output data can be obtained at three levels. Statistics can be implemented for each patch, or for each category of land use, or for the whole selected area. A particular index to be calculated must then be selected for each of these levels. It is also suitable to upload the category properties file into the programme. This is a text file with *.fdc extension in which the following is inscribed in the row for each category: raster pixel value, title, and information about whether to enter into the calculations (true / false), and whether it refers to the background value (true / false).

Outputs from the FRAGSTATS application are tables in ASCII format saved with *.patch, *.class, *.land and *.adj extensions. These extensions correspond to the chosen level for which the indices are calculated (patch, land use category, entire territory). The file with *.adj extension contains adjacency matrix which indicates the number of adjacent pixels for every two categories of land use.

To calculate the index of the overall edge contrast in the landscape, it is necessary to determine the values of dissimilarity between the different categories of land use. For the purposes of this study, two matrices were used for the comparison. In one of them, the contrast between categories was set at a constant value of 0.5 and, in the second case, the weight of contrast was calculated based on the ecological significance coefficient (see Tab. I), simply by subtracting the differences between these values (Tab. II, Tab. III).

The value of beech and fir forests was assigned to the forest category according to Klementová (2005), and the ecological significance value of 0.29 was allocated to ornamental gardens and parks. For the period of the fifties of the 20th century and the present, the category of roads was assigned the value of built-up and traffic areas; however, because the



1: *Scheme of converting the vector lines to raster and their addition to the land use raster*

I: *Ecological significance coefficients regarding the land use categories used in this work*

Value in the raster	Land use category	Ecological significance coefficient
1	Built-up area	0.00
2	Forest	0.63
3	Meadow, pasture	0.62
4	Arable land, other land	0.14
5	Orchard, garden	0.43
6	Vineyard	0.29
7	Water surface	0.79
8	Garden, park	0.29
9	Roads – 2nd military mapping / other periods	0.29 / 0.00

II: *Dissimilarity matrix with contrast weights according to ecological significance for the period of the 2nd military mapping*

FTABLE	1	2	3	4	5	6	7	8	9
1	0.00	0.63	0.62	0.14	0.43	0.29	0.79	0.29	0.29
2	0.63	0.00	0.01	0.49	0.20	0.34	0.16	0.34	0.34
3	0.62	0.01	0.00	0.48	0.19	0.33	0.17	0.33	0.33
4	0.14	0.49	0.48	0.00	0.29	0.15	0.65	0.15	0.15
5	0.43	0.20	0.19	0.29	0.00	0.14	0.36	0.14	0.14
6	0.29	0.34	0.33	0.15	0.14	0.00	0.50	0.00	0.00
7	0.79	0.16	0.17	0.65	0.36	0.50	0.00	0.50	0.50
8	0.29	0.34	0.33	0.15	0.14	0.00	0.50	0.00	0.00
9	0.29	0.34	0.33	0.15	0.14	0.00	0.50	0.00	0.00

Dissimilarity matrix (1 – built-up area; 2 – forest; 3 – meadow, pasture; 4 – arable land, other land; 5 – orchard; 6 – vineyard; 7 – water surface; 8 – ornamental garden, park; 9 – roads)

III: *Dissimilarity matrix with contrast weights according to ecological significance for other periods*

FTABLE	1	2	3	4	5	6	7	8	9
1	0.00	0.63	0.62	0.14	0.43	0.29	0.79	0.29	0.00
2	0.63	0.00	0.01	0.49	0.20	0.34	0.16	0.34	0.63
3	0.62	0.01	0.00	0.48	0.19	0.33	0.17	0.33	0.62
4	0.14	0.49	0.48	0.00	0.29	0.15	0.65	0.15	0.14
5	0.43	0.20	0.19	0.29	0.00	0.14	0.36	0.14	0.43
6	0.29	0.34	0.33	0.15	0.14	0.00	0.50	0.00	0.29
7	0.79	0.16	0.17	0.65	0.36	0.50	0.00	0.50	0.79
8	0.29	0.34	0.33	0.15	0.14	0.00	0.50	0.00	0.29
9	0.00	0.63	0.62	0.14	0.43	0.29	0.79	0.29	0.00

Dissimilarity matrix (1 – built-up area; 2 – forest; 3 – meadow, pasture; 4 – arable land, other land; 5 – orchard; 6 – vineyard; 7 – water surface; 8 – ornamental garden, park; 9 – roads)

roads were not yet reinforced with asphalt in the middle of the 19th century when the 2nd military mapping was conducted, they were assigned an ecological significance value of 0.29 for this period. Ecological significance values used to determine the contrast in the dissimilarity matrix for the purposes of this work are listed in Tab. III.

For input into the FRAGSTATS programme, matrices are saved in CSV (Comma Separated Value) format where the first row starts with the FTABLE table identifier, and where the subsequent rows and columns contain comma-separated numbers of land use categories (according to values in the raster) and their mutual contrast. On the diagonal, where the same categories intersect, the dissimilarity remains zero.

RESULTS

Selected indicators of landscape fragmentation were calculated in each of the software tools used. Further, it is therefore possible to find an overview of the indices counted for selected territories in the period of the 2nd military mapping, the fifties of 20th century and the present.

Tab. IV contains the results of calculations for the entire layer of land use, i.e. for all categories together. It is clear that landscape fragmentation increases over time. This is indicated by MSI and MPAR indices that reflect the patch shape (becoming "more complex" as time goes on) as well as MPS and MedPS indices expressing the patch size (decreasing with time).

With regard to the size of individual patches based on the standard deviation (PSSD), the most uneven period is that of the fifties of the 20th century. At this time in the Czech Republic, the acreage of arable land was violently increased which is worth noting when comparing the tables of calculations for each category of land use (Tab. V–VII). Many interaction stabilizing elements, such as game refuges, grassed balks or even the old paths, also disappeared during this period.

The average fractal dimension (MFD) has not changed much over time, and its values occur in the middle of the interval <1, 2> which indicates a moderately complex shape of patches. Slightly lower value appertains to the period of the 2nd military mapping; therefore, the shapes of patches in this period are probably not as complicated as in later periods. Regarding the weighted average (AWMFD), however, this difference disappears.

The values of the mean patch size indices (Tab. IV) show considerably sized patches with arable land and forested patches. Areas of other categories of land use are either small in themselves or are penetrated by a large number of roads or rivers. It

IV: *Selected indices calculated using the Patch Analyst extension for the entire layer*

Period	NP	MPS	MedPS	PSCoV	PSSD	MSI	AWMSI	
2nd military mapping	26 972	7.01	1.42	235.17	16.49	1.93	1.68	
The fifties	21 194	8.92	0.58	446.62	39.82	2.52	1.73	
Today	65 206	2.9	0.11	475.95	13.79	2.88	1.83	
Period	**MPAR**	**MFD**	**AWMFD**	**TE**	**ED**	**MPE**	**SHDI**	**SHEI**
2nd military mapping	9 079.9	1.42	1.29	30 252 433.72	159.97	1 121.62	1.26	0.61
The fifties	25 134.9	1.53	1.27	21 255 602.82	112.5	1 002.91	1.01	0.48
Today	11 3415.5	1.52	1.30	39 108 463.73	206.98	599.77	1.27	0.61

NP (Number of Patches), SHDI (Shannon's Diversity Index) SHEI (Shannon's Evenness Index), MPAR (Mean Perimeter-Area Ratio), MFD (Mean Fractal Dimension), MPS (Mean Patch Size), MedPS (Median Patch Size), PSCoV (Patch Size Coefficient of Variance), PSSD (Patch Size Standard Deviation), TE (Total Edge), ED (Edge Density), MPE (Mean Patch Edge); AW (Area Weighted) abbreviation before MSI and MFD indices means that it is a weighted average where the weight is the patch area.

V: *Results of Patch Analyst for individual categories from the period of the 2nd military mapping*

Category	NP	MPS	MedPS	PSCoV	PSSD	TE	ED	MPE
Forest	3 866	11.409	3.14	207.153	23.635	5 425 595.27	28.69	1 403.413
Meadow, pasture	8 936	4.192	1.08	280.629	11.765	9 502 381.6	50.248	163.382
Ornamental garden, park	45	1.409	0.79	199.422	2.81	26 663.06	0.141	592.512
Arable land, other land	8 687	10.931	3.611	177.508	19.404	11 769 504.78	62.236	1 354.841
Orchard, garden	2 045	1.215	0.619	131.816	1.601	1 035 607.82	5.476	506.41
Vineyard	671	10.361	3.107	150.396	15.583	834 049.57	4.41	242.995
Water surface	233	4.076	0.627	325.211	13.254	286 096.3	1.513	227.881
Built-up area	2 489	0.855	0.465	128.696	1.100	1 372 535.32	7.258	551.44
Category	**MSI**	**AWMSI**	**MPAR**	**MFD**	**AWMFD**	**CA**		
Forest	1.89211	1.56896	9 977.4591	1.37798	1.26911	44108.5688		
Meadow, pasture	2.10574	2.1408	9 943.7894	1.44336	1.33509	37464.0201		
Ornamental garden, park	1.75063	1.76001	1 224.7178	1.434	1.34759	63.4025		
Arable land, other land	1.78848	1.55383	8867.225	1.38246	1.2705	94 960.653		
Orchard, garden	1.6484	1.62719	5 637.7025	1.43502	1.34552	2 484.5506		
Vineyard	2.02272	1.48712	17 550.2988	1.44127	1.26558	6 952.2794		
Water surface	2.95044	2.30398	4 020.994	1.52024	1.3249	949.6194		
Built-up area	1.93323	2.15241	6 486.7554	1.46252	1.41046	2 128.3185		

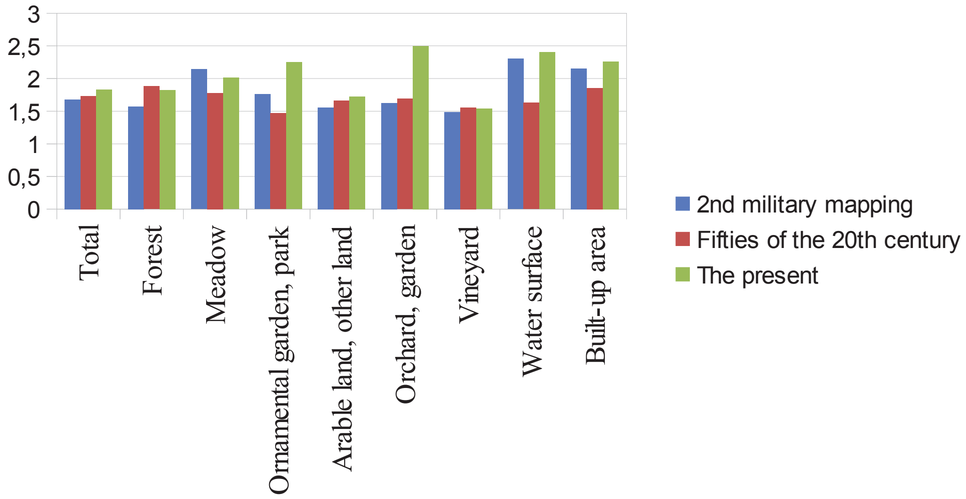
VI: *Results of Patch Analyst for each category from the period of the fifties of the 20th century*

Category	NP	MPS	MedPS	PSCoV	PSSD	TE	ED	MPE
Forest	2 966	14.254	0.526	525.907	74.962	3 502 382.79	18.536	1 180.844
Meadow, pasture	2 851	5.079	0.186	288.523	14.654	2 451 074.48	12.972	859.724
Ornamental garden, park	27	3.086	1.27	135.548	4.183	22 181.93	0.117	821.553
Arable land, other land	8 042	15.272	1.514	286.4	43.739	11 448 198.51	60.59	1 423.551
Orchard, garden	3 665	1.355	0.427	226.238	3.065	1 870 997.31	9.902	510.504
Vineyard	81	4.858	0.266	238.239	11.573	63 254.37	0.335	780.918
Water surface	47	1.641	0.435	227.457	3.733	2 224.97	0.117	468.616
Built-up area	3 515	1.096	0.548	143.391	1.571	1 875 488.47	9.926	533.567
Category	**MSI**	**AWMSI**	**MPAR**	**MFD**	**AWMFD**	**CA**		
Forest	2.5774	1.88375	23 367.3002	1.53838	1.26462	42 277.1022		
Meadow, pasture	2.87296	1.78049	32 668.5858	1.59796	1.29231	14 479.9238		
Ornamental garden, park	2.65135	1.46885	4 264.1963	1.46211	1.29695	83.3232		
Arable land, other land	2.69105	1.66233	30 097.4476	1.51041	1.26239	128 818.2905		
Orchard, garden	2.26736	1.69194	21 125.0515	1.52413	1.33706	4 965.9462		
Vineyard	3.07815	1.55405	63 076.3346	1.57072	1.27775	393.4598		
Water surface	2.19704	1.63044	23 921.3787	1.46658	1.31612	77.1255		
Built-up area	2.01797	1.85563	12 645.2337	1.48933	1.36945	3 851.0533		

VII: *Results of Patch Analyst for individual categories from the present*

Category	NP	MPS	MedPS	PSCoV	PSSD	TE	ED	MPE
Forest	9913	4.76	1.081	228.82	10.892	9622501.29	50.926	970.695
Meadow, pasture	5391	2.627	0.55	349.569	9.183	3696688.82	19.564	685.715
Ornamental garden, park	577	0.48	0.262	156.975	0.754	258695.33	1.369	448.345
Arable land, other land	9203	11.35	0.835	285.232	32.375	11478992.58	60.752	1247.31
Orchard, garden	7477	1.339	0.503	244.357	3.271	5788496.26	30.635	774.174
Vineyard	1556	3.243	0.608	205.098	6.652	1125816.76	5.958	723.533
Water surface	984	0.339	0.082	289.43	0.982	399218.7	2.113	405.71
Built-up area	3.010	0.248	0.018	489.443	1.216	673853.99	35.661	223.818

Category	MSI	AWMSI	MPAR	MFD	AWMFD	CA
Forest	3.77529	1.82581	210315.77	1.4057	1.30666	47186.1282
Meadow, pasture	5.03703	2.01194	371532.5838	1.4052	1.32933	14162.4869
Ornamental garden, park	2.01103	2.24893	4394.0442	1.48852	1.44334	277.228
Arable land, other land	3.64831	1.7238	164873.5604	1.43145	1.27062	104457.2517
Orchard, garden	3.36625	2.49762	132753.5628	1.50142	1.40098	108.9762
Vineyard	2.41968	1.53719	77432.1618	1.40617	1.29325	546.8354
Water surface	2.8785	2.40116	9273.2398	1.63095	1.42101	333.7774
Built-up area	1.88087	2.26135	22106.1094	1.61426	1.40367	7476.6191



2: *Comparison of the weighted average patch shape in three time periods*

is hardly possible to overlook the average size of vineyard patches in the period of the 2nd military mapping which is significantly high compared to subsequent periods.

The values of the edge density in the areas of arable land remains stably high. On the forest areas, the current edge density has increased in comparison with the 2nd military mapping and conversely decreased in the category of meadows and pastures. This decrease may be also influenced by the overall reduction of grassland areas in the last period in view. With regard to the edge density, the orchards, gardens and built-up areas show almost the same trend. But this is not something unexpected since they occur in close proximity and are now "interwoven" with a dense network of roads.

Illustration of the patch shape weighted average in Fig. 2 shows more complicated shapes of polygons of ornamental gardens and parks, orchards and gardens, at the present time. In other categories of land use, the complexity of patch shapes remains relatively stable, ignoring the rivers and built-up areas which are not very suitable for being assessed by these landscape-ecological metrics. That is because the built-up areas are crossed by many roads and many polygons of water bodies are intersected by watercourses that significantly extends their shape.

Values of AWMFD (AWMSI) shows a strong increase in the mean fractal dimension in the present for the categories of ornamental garden and park, orchard and garden, and water surfaces. The weighted mean fractal dimension increases evenly, but relatively modestly, for vineyards. Overall, we can observe a drop of values in the fifties of the 20th century in most cases. This may be also caused by insufficient records on roads in this time period because they were not always clearly identifiable from the black and white aerial photographs during digitization – especially unpaved roads or paths leading under the trees.

However, this tendency is not visible if we calculate MSI as a weighted average where the weight is the patch acreage. In such case, the larger patches (having higher weight in the calculation) do not differ significantly from the circular shape. Strongly increasing value of the average perimeter-area ratio is also noteworthy. Averaged proportions of perimeter and acreage of all patches in grassy areas reveal that the number of patches with large edge length increased in comparison with their acreage. This also explains the increase in MSI. Since the value of MPS index for meadows and pastures is currently the lowest, it can be assumed that many meadows were penetrated by network of roads or divided by fields. This is confirmed by ED index which shows that the edge density within this category increased in the current period compared to the fifties of the 20th century. The highest value of this index was observed for the period of the 2nd military mapping; at that time, however, the number of roads and waterways leading through the meadows was naturally great because the number of meadows was overall much higher.

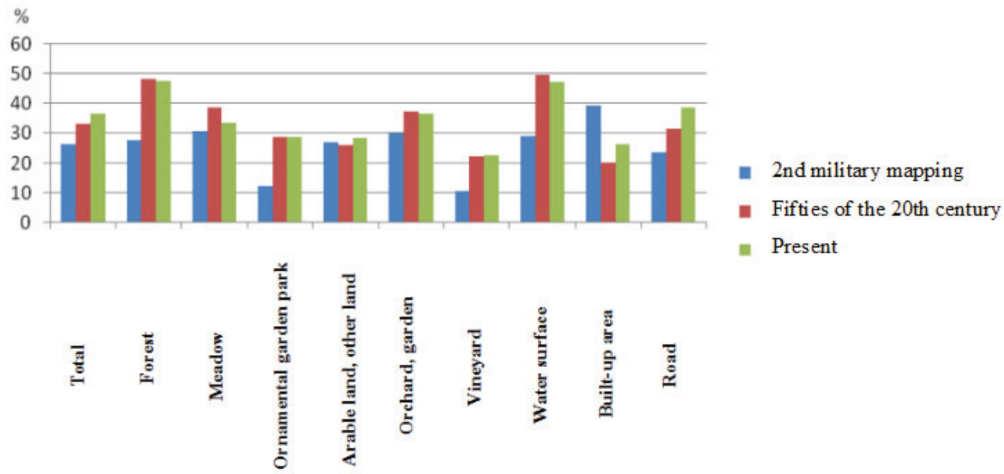
Results from the FRAGSTATS application

Tab. VIII shows the results of calculations of the total edge contrast index (TECI) where A matrix means a calculation using the dissimilarity matrix with a constant difference value of 0.5, and where B matrix means a calculation using contrasts designated according to ecological significance. TECI values in the table are expressed as a percentage. The higher the value, the more edges with higher contrast rate exist.

It is clear that the first case of calculations (A matrix) has almost no informative value. It was rather performed for the purposes of comparison and to demonstrate the importance of individual determination of the contrast between categories. As long as the value of dissimilarity between each pair of land use categories equals to 0.5, the total edge contrast index equals to 50%. Values in Tab. VIII

VIII: *Calculation results regarding the total edge contrast index (TECI)*

Category	2nd military mapping		Fifties of the 20th century		The present	
	matrix A	matrix B	matrix A	matrix B	matrix A	matrix B
Total:	48.2452	26.3684	48.0567	33.2454	48.4079	36.4877
Forest	48.5259	27.6811	48.6818	48.2673	49.1602	47.7238
Meadow, pasture	49.4074	30.9201	49.492	38.619	49.5381	33.5217
Ornamental garden, park	49.7242	12.3034	48.0269	28.7563	49.9873	28.7465
Arable land, other land	48.997	27.1892	48.7627	25.9759	48.7858	28.2386
Orchard, garden	49.7264	30.1767	49.7329	37.2545	49.805	36.7404
Vineyard	48.851	10.4709	48.915	22.1953	49.5917	22.712
Water surface	49.9035	29.2167	49.7091	49.5404	49.6382	47.3175
Built-up area	49.8157	39.3185	49.7874	20.2518	49.798	26.2663
Roads	49.9299	23.4601	49.9266	31.5634	49.8596	38.8701



3: *Comparison of the total edge contrast index according to the coefficients of ecological significance in three time periods* are a little lower because the contrast values of boundary pixels (pixels adjacent to background values) have zero value of dissimilarity.

When looking at the total values of individual periods, we can observe an increase in the index value over time. As time goes on, the differences in ecological significance among neighbouring patches, therefore, increase. This is due to targeted land-use changes (e.g. change of grassland to arable land) or due to expansion of built-up areas. The increase in TECI values is partly also caused by ecological significance of roads which is set at 0.29 for the period of the 2nd military mapping (because of the unpaved field and forest paths existing at that time) and at zero for subsequent periods (mainly asphalt roads already exist). This was reflected in indices for the category of roads the contrast of which thus increased in comparison with ecologically more important areas, as well as, for example, clearly in the forest layer frequently intersected by roads. The category of water bodies is also not lagging behind; an increase in the respective values in the fifties and the present is clearly visible. Since the water surfaces have a high coefficient of ecological significance while the same coefficient for roads is conversely equal to zero in these periods, it probably reflects the places where a road leads along the watercourse. For better imagination, the TECI values calculated from the dissimilarity matrix based on the coefficients of ecological significance are shown in Fig. 3.

DISCUSSION AND CONCLUSION

The aim of this study was to analyse landscape fragmentation in selected locations of the Pannonian region with a total area of 1 890 km^2 in three time periods. The landscape fragmentation was analyzed by calculating the landscape-ecological indices using GIS. From the prepared vector data, we calculated selected landscape-ecological indices using Patch Analyst extension. These indices were used for calculating the indices investigating the density and size of patches, the properties of their shapes and edges, and the indices of diversity. To calculate the total edge contrast index which expresses the percentage difference of neighbouring land use categories depending on the length of edges between these categories, we used the FRAGSTATS application. However, this fails to work with vector data, and input layers had to be therefore transferred to raster.

Landscape fragmentation analysis using the calculations of landscape-ecological indices is strongly dependent on the quality of spatial data, the input values and the calculation methods applied. In the very first stage, in the digitization of land use for each time period, the diversity of sources is obvious. From the period of the mid-19th century, the source materials are represented only by maps from the 2nd military mapping the cartometric accuracy of which is by far not as high as in aerial orthophotos that were used in subsequent periods. These old military maps do not always enable to clearly identify the categories of land use or distinguish watercourses from roads because some map sheets are already somewhat faded. Even in digitizing the land use from aerial photographs, the categories of use might be determined erroneously, particularly for the period of the fifties of the 20th century when only black and white images were available. Furthermore, regarding the current situation, we can certainly take notice of a difference between the data obtained from the archive Protected Landscape Area Administration and digitized data, although an effort was made to adapt the data gained so that the difference was negligible.

Another major step in the organization of input data is the transfer of vector layers into raster format. Here, we chose the pixel size of 10 m which is suited to the digitization scale and adequately preserves the quality of polygonal layers on the one hand, but completely suppresses the expression of roads and waterways on the other. Since these line elements in the landscape mosaic are very important, either as a barrier or rather as an element linking the surrounding landscape components, it was decided to keep them in the raster although they would not correspond to the actual scale.

When calculating the total edge contrast index, it was necessary to choose the values of dissimilarity between different land use categories. As verified by comparing the results after using two different dissimilarity matrices, the determination of contrast values is of unprecedented weight. Therefore, the dissimilarity matrix values were determined according to coefficients of ecological significance.

Considering that the research deals with steppe areas, the category of meadows and pastures was analyzed in more detail when evaluating the results. These areas were heavily disrupted prior to the fifties of the 20th century and their structure has been significantly changed over time. Currently, the grassy areas do not occupy so large an acreage as at the time of the 2nd military mapping, and they are quite well fragmented. Evaluation of the whole suggests that the landscape fragmentation in the selected area rather increases over the years. The calculation of the total edge contrast revealed an increasing diversity of adjacent patches in the landscape mosaic. This is supported by expanding the construction of buildings and roads. Knowledge of the spatio-temporal development of fragmentation serves as important information for landscape planning which points to the locations where, when projecting other activities, it is necessary to take into account the conservation of functional landscape features (Machar and Pechanec, 2011).

SUMMARY

This paper describes landscape fragmentation of the Pannonian steppe sites in the Czech Republic. The total area of the studied landscape is 1 890 square km. Fragmentation was determined by calculation of landscape metrics for selected area in three time periods. Firstly it was period of the Second Military Survey (1836–1852), than fifties of the 20th century and finally the current state.

The preparation of spatial data was made in ArcGIS environment. As the input data, three shapefiles were created for each of the time periods. They consisted of one polygon shapefile, classified into eight categories according to land use, and two line shapefiles – watercourses and communications.

These vector data were used for calculation of the basic landscape metrics by using Patch Analyst Extension for ArcGIS. These extensions are freely available on the Internet. Patch Analyst was used to calculate Patch Density & Shape (Number of Patches, Mean Patch Size, Median Patch Size, Patch Size Coefficient of Variance and Patch Size Standard Deviation), Shape Metrics (Mean Shape Index, Area Weighted Mean Shape Index, Mean Perimeter-Area Ratio, Mean Patch Fractal Dimension and Area Weighted Mean Patch Fractal Dimension), Edge Metrics (Total Edge, Edge Density and Mean Patch Edge) and Diversity Metrics (Shannon's Diversity and Evenness Index). The second of software used for measuring landscape indices in this thesis is FRAGSTATS – Spatial Pattern Analysis Program for Quantifying Landscape Structure. It was used for calculation of the Total Edge Contrast Index (TECI). Unfortunately, FRAGSTATS in version 3.3 cannot work with vector data, so the input shapefiles had to be converted to raster format.

TECI values are expressed as a percentage. The higher the value, the more edges with higher contrast rate exist. It is clear that the first case of calculations (A matrix) has almost no informative value. It was rather performed for the purposes of comparison and to demonstrate the importance of individual determination of the contrast between categories. As long as the value of dissimilarity between each pair of land use categories equals to 0.5, the total edge contrast index equals to 50%. Values in Tab. VIII are a little lower because the contrast values of boundary pixels (pixels adjacent to background values) have zero value of dissimilarity.

The calculated values of the entire studied area showed that the landscape fragmentation tends to increase over time, which can threaten biodiversity, reduce migration and colonization potential in the landscape, increase the susceptibility of the landscape for invasions of nonnative species and reduce hunting opportunities of local species. The calculation of the Total Edge Contrast Index proved increasing dissimilarity of neighbouring patches in the landscape mosaic. It can be caused by expansion of built-up area and construction of roads that are the abiotic components which disturb the processes of ecologically important elements of the landscape.

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