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GIS ANALYSIS OF ECOTONE VARIABILITY

ANALIZA GIS ZMIENNOŚCI EKOTONU

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Introduction

There have been intensive changes in the landscape over the last 250 years. The landscape has changed continuously from a natural landscape, determined only by the physical-geographical conditions of the area, to an agricultural landscape. This process took place across almost the entire area of the Czech Republic, with the exception of elevated locations and those areas where climate, terrain and soil conditions did not allow greater expansion of agricultural production. Nowadays, the authentic structure of the landscape is evident only in these areas of less favorable physical-geographical conditions.

The transformation of the landscape structure proceeded continuously during the past centuries. However, faster and more significant landscape changes happened in the 20th century. These changes have led to a remarkable simplification of the landscape structure as a result of compounding and re-allotment of land, destruction of balks, field paths and land cover. During the 1950's, blocks of arable land were established whose sizes increased several times during the further development of socialist agriculture. This continued with the increasing concentration on large-scale agricultural production in 1970s. The formation of larger blocks of arable land totally destroyed the native landscape structure as the land was fanatically adapted for only one purpose – large-scale agricultural production supported by heavy mechanization.

The increase of the size of the individual landscape components resulted in a decrement of the mosaics of the landscape and its generic diversity. This has also affected the ecotones and transition zones between the different ecosystems which have decreased together with the simplification of the landscape structure.

The landscape structure, its components and developments, can be monitored from several, mutually complementary, aspects: the arrangement of gradients (abiotic and biotic) across the area without significant and sharp boundaries; the arrangement of areas in the mosaic of the landscape; the network of areas and corridors; and the system of boundaries and rims in the landscape mosaic (Forman and Gordon, 1993).

The aim of this paper is the analysis of the spatial dependences of ecotones. The study was carried out using maps with a scale of 1:25 000 for the Trkmanka River basin. The study is a part of the project of GA ČR 205/07/0821 “Analysis and modeling of spatial relationship dynamics of ecotones in GIS”.

Ecotones

The boundaries between natural landscape components most frequently exhibit the character of transition zones. They are very rarely sharp or clearly defined. Sharp lines can be found at terrain edges, beside rivers and reservoirs or at anthropogenic boundaries; they are formed as a result of differential effective usage of the landscape. An ecotone is generally defined as a boundary or transition zone, or edge community between two or more ecosystems. As a consequence of a crossover, the ecotone often has higher biodiversity and more favorable conditions for organisms than the boundary biocoenosis, thus exhibiting the presence of a greater variety of plant and animal species (Hansen, 1988; Jeník, 1995). In other words, the ecotone is an element of the spatial structure of the landscape component (i.e. ecosystem), which represents a wide transition zone or line of interface between neighboring landscape components (i.e. ecosystems). It is characterized by a higher diversity of organisms and density of population in comparison with those in both neighboring biocoenosis (the so-called edge-effect) (Odum, 1971; Luczaj, 1994). In the ecotone, one can thus find both species from the neighboring biocoenesis and species specific to this transition zone. However, Hansen and Di Castri (1992) also consider sharp boundaries (i.e. narrow transition zones) to be a ecotone. In today’s cultural landscape, the ecotones are the places of contact between a natural area and an area influenced or controlled by humans (i.e. agroecosystems).

From the spatial perspective, the ecotones are characterized by a space and time which reflect the forces of interactions among boundary units (i.e. ecosystems). Hansen and Di Castri (1992) have reported that changes of the space-time structure, or functions taking place in the ecotone, are faster than changes in the landscape as a whole. The ecotones, as a spatial unit, have a different internal structure and construction, spatial attributes and other properties that are conditioned abiotically and biotically (i.e. contrast, internal product differentiation, width, shape). Simultaneously, they also exhibit properties determined by time, development and function – transmittance, stability and elasticity. Spacially, they can be characterized by following typical properties (Hansen and Di Castri, 1992; Kovář, 1994; Míchal, 1994; Sklenička, 2003):

- **Plasticity of transition.** The transition zone can have a different appearance, from gradual to sharp and discontinuous gradients. Sometimes, the ecotones can display the appearance of wedged ledges or tongues, protruding from neighboring systems.
- **Time stability.** Their existence and/or persistence are determined by the mechanism or factor of their formation. It is affected by a varying degree of dependence on external or internal natural processes and their manifestations. Human activities can also have an influence (planted hedgerows compared with a non-grubbing forest belt).
- **Ledges from landscape structure.** They occur in different degrees of contrast with each other and neighboring surface objects (in geology, geomorphology – rock and terrain shifts, in succession age of neighboring vegetation, in salinity in aquatic environments – for example at a river estuary).

- **Biological and spatial stability.** The stabilization functions in the landscape result from their graded ability to react to a disturbance in terms of both the resistance and/or resilience of the system and in dependence on a degree or intensity of the action of the respective factor.
- **Source, support (standby) function.** The ecotones influence neighboring and especially adjoining ecosystems. They act as a source of germs or nutrients, they pollute or entrap (dust, pollen, seed, etc.) or "eject" predators or pests into the surrounding areas.
- **Increased density of biomass.** The edge-effect represents a tendency of comunities for densification and diversification of the biota in the transition zone. There exist either species from both neighboring formations or specific species, absent in neighboring territories.

In the landscape, the ecotones thus create a network which presents a stabilization and source element of the landscape and landscape components. The properties of the ecotones are influenced by the physical-geographical and socioeconomic conditions of the area.

Area of interest

The area of the Trkmanka River basin, restricted by the boundary of the drainage basin, is situated in Southern Moravia, east of Brno. The Trkmanka River rises in the Ždánický les Mts., and is located northwest of the town of Ždanice, at an altitude of 300 m above sea level. The river then flows in a southerly direction and after 42.5 km it joins the Dyje River, just northeast of the town of Lednice, at an altitude of 158 m. The area of interest has an elongated shape. In the north, the area is comprised of a system of Ždanické vrchy hills with the highest point called U Slepice (437 m above sea level). In the south, the area reaches to the floodplain of the Dyje River. The northern part of the area is forested, the middle part of the interested area represents a typical agricultural landscape with a small portion of woods and the southern part of the area is intensively farmed.

The Trkmanka River basin is part of a region with a long history of settlement and a landscape highly influenced by humans. Suitable conditions of this landscape favor highly developed agricultural production that is concentrated mainly on the growing of grapes, which is a long-time tradition in this area.

Methods and procedure of solution

The ecotones have a spatial pattern that appears to be suitable for research into their use with geoinformation technologies. In a GIS environment, the individual components of the real world, which are thematically divided, can be saved in separate digital spatial layers. These layers can be arbitrarily piled up and from them, one can derive new information. In addition, these layers and their combinations can be subjected to spatial analyses that provide further valuable spatial information which is not obtainable with other methods.

The research data of the ecotone properties of the basin of the Trkmanka River originated from a transfer of the spatial phenomena of the real landscape to the digital vector thematic layers. We have analyzed the digital layers of landscape use of the study area from the years 1764, 1836, 1877 and 2007, at a map scale of 1:25 000.

The 1st Military Survey maps from 1764-1768 were not made on the basis of astronomical-geodetic measurements. The absence of a mathematical basis results in a very low map accuracy (Boguszak and Císař 1961). The 2nd Military Survey from 1836–1840 required the preparation of a coherent astronomical-geodetic network. The 3rd Military Survey from 1876–1878 was carried out mainly because of improvements in measurement precision. The present land use/land cover (LU/LC) was created from a coloured ortho-photomap, derived from aerial photography from 2004–2006.

The layers of the land use were modified with respect to the aim and purpose of the study. Therefore, in constructing a model corresponding to the real landscape as much as possible, certain administrative and ownership features within one facet have been omitted. Vector layers of the land use have been created as a competent theme, whose categories have been treated as landscape components. Every facet (i.e. polygon) represents a space of the landscape component.

Results

Edges or lines between each facet are considered as ecotones. The net of polygons could be termed the net of ecotones in the real landscape. The development of the identified landscape elements in the studied time horizons is shown by means of NP (number of patches) and MPS (mean patch size) indexes in Table 1.

Table 1 clearly shows the trend in the change of element numbers during the years 1764 –2007. Two increases are visible, namely during the 2nd Military Survey (1836) and at the present time (2007).

Table 1. NP a MPS indexes development from 1764 to 2007 in the Trkmanka River basin

	NP (number of patches)				MPS (mean patch size) (ha)			
	1764	1836	1876	2007	1764	1836	1876	2007
Built-up areas	197	245	234	302	5,09	3,77	3,8	7,89
Unmetalled road	13	50	134	317	35,81	14,9	3,83	2,1
Metalled road	1	9	11	24	10,88	4,35	10,05	10,23
Railway	0	1	1	2	0	7,11	7,15	36,99
Arable land	730	1055	828	1043	30,34	15,78	27,73	20,92
Permanent grassland	323	825	499	528	25,22	8,51	9,2	2,53
Orchards and gardens	0	11	2	343	0	2,15	3,05	3,52
Vineyards	127	412	225	601	27,34	11,72	11,4	5,17
Wood	198	477	205	1207	46,08	15,01	29,97	5,74
Water areas	56	17	39	67	19,3	29,36	2,88	1,89
Total	1645	3102	2178	4434				

This trend can be identified in all categories, with the exception of the built-up area, orchards and gardens, where the number of patches constantly grew. In the water areas category, where the situation is opposite to most of the LU/LC categories, there was an exception to the trend, because there was a visible decrease in the number of patches during the 2nd Military Survey followed by moderate growth.

It is impossible to find a uniform trend for most categories within the index of mean patch size. MPS of arable land and woods during the 2nd Military Survey (1836) and at the present time (2007) is decreasing, meaning that the sizes of individual elements decreased. In contrast, the mean patch size of water areas increased between 1764 and 1836, then in 1876 rapidly decreased and finally between 1876 and 2007 only a slight MPS decline is noticed. The development of mean element sizes of permanent grassland and vineyards is almost identical. In particular, between 1764 and 1836 an MPS decrease is noticed, then stagnation and between 1876 and by 2007 the mean patch size was again lower. The built-up area, orchards and gardens, was distinguished by moderate MPS growth.

Each ecotone is the element of the net, whose qualitative and quantitative properties are influenced by the type of landscape. The spatial character of the ecotones could be considered as the quantitative indicator. This work is based on the study of these indicators.

The length of the ecotone an attribute which is composed of two different characteristics. The first one is the absolute length of the ecotone – the length of the centre line in the landscape segment. The analysis of these characteristics in three different time horizons is shown in the Table 2. The second one is the relative length of the ecotone. It shows the length of the active border of the ecotone. The proportion of these characteristics influences the area of the ecotone. In table 2, TE index is given in absolute (km) and in relative (%) values.

Table 2. TE index during 1764– 2007 in the Trkmanka River basin

	TE (total edge)						
	1764	1836		1876		2007	
	%	km	%	km	%	km	%
Built-up areas	3,25	236,62	2,95	224,2	3,41	448,41	5,23
Unmetalled road	30,3	2968,72	37,04	2050,02	31,19	2649,48	30,89
Metalled road	0,36	78,5	0,98	221,35	3,37	440,76	5,14
Railway	0	9,52	0,12	9,56	0,15	98,6	1,15
Arable land	32,74	1879,16	23,45	2385,69	36,3	2093,02	24,4
Permanent grassland	16,88	1356,69	16,93	799,79	12,17	469,65	5,48
Orchards and gardens	0	8,09	0,1	1,5	0,02	294,08	3,43
Vineyards	4,77	608,59	7,59	326,43	4,97	608,03	7,09
Wood	9,58	821,79	10,25	522,28	7,95	1431,97	16,69
Water areas	2,12	46,55	0,58	33,93	0,52	43,64	0,51
Total	100	8014,23	100	6572,53	100	8577,68	100

The edges length index of individual LU/LC categories is the calculation of patch circumferences (total edge – TE) and edge lengths between two given categories (e.g. wood – arable land, permanent grassland – water areas, etc.). A patch edge can be considered as the boundary between two patches of different types.

From the percentage substitution of the individual categories edge lengths, it is easy to determine the development of the TE index that has a different course for each LU/LC category. The most substituted (about 30%) are the categories of arable land and unmetalled roads that include woodland and field roads. The TE value of unmetalled roads increased in the 2nd Military Survey (1836) from 30% to 37%, and then decreased again to the original value by 2007. The category of arable land had a very dynamically changing value of the TE index, with a decline during the 2nd Military Survey and at the present time to about 24%, contrasting with high values during the 1st and 3rd Military Survey (1764–1876), when the TE value fluctuated over 30%. A very rapid decrease was noticed for the LU/LC class of permanent grassland: between the 1st and 3rd Military Survey the value stagnates, then rapidly decreases from 17% to today's value of 5,5%. For the grassland category the TE index increased from 10% (1764) to almost 17% at the present time. No distinct changes were noticed for other categories, with the exception of metalled roads (today's highways and motorways) where the number grew, as would be expected.

Table 3 shows the boundary lengths between chosen LU/LC categories in all the monitored time horizons. The values are given as absolute and relative for the comparison with the 1st Military Survey.

It is obvious that the longest boundaries are created by unmetalled roads, i.e. field and woodland roads and the most area substituted categories. In the past, the dominant type of boundary was the arable land – unmetalled road. At the present time the most common boundary is the boundary between the woods – unmetalled road. This is due to the large number of woodland roads in the present LU/LC. Also a huge decrease in boundary length between arable land and permanent grassland was recorded. That varied between 10 and 15% in the past, but according to the present LU/LC, it captures only about 4%. This sharp decline is explained by the drastic reduction of the permanent grassland areas. Such categories of boundaries like between arable land and woods or arable land and vineyards have the social character of development. The progress of both of them imitates the arable land development in the monitored time periods. Their area decreased during the 2nd Military Survey (1836), then it increased in 1876, and finally a moderate decrease of the areas was observed in the present LU/LC.

Table 3 shows also percentile insignificant boundary lengths between chosen categories. There is a noticeable change in the boundary length between water areas and permanent grasslands, which between 1764 and 1836 decreased by about 3/4; this decrease is continuing, but not so sharply. In the monitored time periods, the percent of substitution of the length between water areas and arable land increases. There is also a very big decrease in the boundary length between woods and permanent grassland, which dropped by about 2/5 between 1764 and 1836. It then stagnated and recently decreased by about 2/5 when compared to 1876. A great change also appears between built-up areas and arable land, where the decrease of area is evident between 1764 and 1830. The reason for this situation lies in the increase of vineyard areas that often occurred close to farms and permanent grassland at that time. Between 1836 and 2007 the boundary length of arable land – built-up areas increased due to the decrease of permanent grassland areas and also due to the increase of built-up areas. A very similar course of development occurred in boundaries like vineyard – woods

Table 3. The boundary lengths between chosen LU/LC categories during 1764–2007

	TE (total edge)						
	1764	1836		1876		2007	
	%	km	%	km	%	km	%
Wood – Unmetalled road	9,81	608,3	15,44	267,61	8,31	1076,6	25,5
Arable land – Unmetalled road	37	1131,35	28,71	1337,77	41,54	921,32	21,82
Vineyards – Unmetalled road	2,35	406,66	10,32	111,51	3,46	313,95	7,44
Arable land – Metalled road	0,47	44,74	1,14	174,39	5,42	237,52	5,63
Arable land – Woods	3,91	53,31	1,35	129,35	4,02	198,99	4,71
Arable land – Permanent grassland	14,71	445,83	11,31	413,76	12,85	178,32	4,22
Arable land – Vineyards	5,51	78,5	1,99	159,64	4,96	145,18	3,44
Arable land – Built-up areas	3,47	45,22	1,15	76,97	2,39	139,89	3,31
Permanent grassland – Woods	3,43	75,98	1,93	62,61	1,94	47,22	1,12
Permanent grassland – Vineyards	0,64	57,88	1,47	28,43	0,88	39,65	0,94
Wood – Vineyards	0,81	40,9	1,04	13,08	0,41	26,02	0,62
Water areas – Arable land	0,13	8,95	0,23	11,36	0,35	21,67	0,51
Permanent grassland – Built-up areas	0,48	28,44	0,72	19,27	0,6	16,87	0,4
Water areas – Permanent grassland	3,92	31,78	0,81	17,02	0,53	12,58	0,3
Total	100	4969,6	100	4777,81	100	5382,78	100

and vineyard – permanent grassland. In both cases the data expressed as a change of the vineyard area, which according to the 2nd Military Survey was increasing. This meant that the boundaries woods – vineyard and permanent grassland – vineyard also increased. After this time, a decrease in the vineyard area followed (1876), along with a decrease of boundary with woods and permanent grassland. Today, according to the present LC/LU, a moderate increase in vineyard area and its boundary length with woods and permanent grassland has been observed again. The boundary length between permanent grassland and built-up area imitates the changes of permanent grassland in the monitored time horizons with the maximum length in 1836 and the minimum length at the present time.

The last parameters to be monitored were the landscape diversity indexes. From these indexes it is possible to measure spatial landscape patterns. The Shannon diversity index (SDI), Shannon equilibrium index (SEI), and Domination index (D) were calculated for the whole area, not for individual LU/LC categories, with following results:

- The Shannon diversity index (SDI) quantifies landscape diversity based on two elements: the number of different area types (richness) and their evenness. SDI is increases when the number of different areas is increasing, or when the evenness for the individual types of area is uniform. The maximum value is reached when the maximum number of area classes is substituted with landscape equally (Balej, 2006).
- The Shannon equilibrium index (SEI) is based on the distribution and substitution of the individual types of area. It originates from the Shannon diversity index, which is then calculated for the maximum SDI for the monitored area types (Balej, 2006).

Table 4. The SDI, SEI and D indexes development during 1764–2007 in the Trkmanka River basin

	1st Military Survey	2nd Military Survey	3rd Military Survey	2007
SDI (Shannon Diversity Index)	1,4	1,49	1,22	1,37
SEI (Shannon Equilibrium Index)	0,67	0,65	0,53	0,6
D (Domination index)	0,68	0,81	1,08	0,93

- The Domination index (D) is a supplement of SEI. The higher the value, the lower landscape diversity and only one type of area dominates.
  Calculated values for SDI, SEI and D indexes are shown in the Table 4.

Table 4 demonstrates that the highest landscape diversity was in the time of the 1st Military Survey (1764). Even though the SDI calculated for 1836 was higher than for 1764, there was a lower number of categories presented in the Military Survey. The smallest diversity is noted during the 3rd Military Survey (1876).

Conclusion

The main trends in the development of land use/land cover of the Trkmanka catchment area show a significant decline in permanent grassland from almost 20% of the entire river basin to today's less than 4%; a decrease in the area of water (2.4%) and the size of their patches (200 hectares in the 2nd Millitary Survey) to today's area of 0.2%, with a maximum unit of 15 hectares; and the huge changes in the distribution of vineyards from the original disseminated vineyards located throughout the area to today's strong wine region in the southern part of the Trkmanka catchment.

The ecological stability in the period between the 1st and 2nd Military Survey was almost unchanged. A transformation is reported in the 3rd Military Survey and especially in the current data where the landscape with the prevailing natural component becomes difficult to identify due to distortion of the lanscape caused by the current mechanization and chemicalisation of the land. According to the calculated indices of landscape metrics, the current landscape of the Trkmanka catchment compared to the historical period is characterized by a larger number of patches and thus of smaller size and greater length edge. On the contrary, in terms of spatial arrangement there is less diversity of landscape.

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Abstract

The term ecotone has larger sense: it comprises the transitional zone between two biomes (taiga – tundra), meadow-forest border and differentiation of forest edge (Falińska, 1996), but ecotones are also generally border zones between adjoining diverse societies. From a spatial perspective, an ecotone is characterized by space and time, which reflects the powers of interaction between boundary elements (ecosystems). Ecotones, like spatial elements, have a diverse inner structure and construction, spatial attributes and other properties conditioned abiotically and biotically (contrast, inner differentiation, width, and shape). Simultaneously, they have properties conditioned by time, development and function: permeability, stability and elasticity (Hansen et al., 1988). To analyze the spatial relation of landscape parts means to identify its components and also systems and the relationships between these parts. In order to understand the landscape and landscape parts, ecotones will be analyzed and typologically distinguished using the concepts of spatial bonds, heterogeneity, elasticity (influence), physical-geographic conditions and spatio-temporal stability.

Streszczenie

Termin ekoton posiada szerokie znacznie: jest równocześnie strefą przejściową pomiędzy dwoma biomami (tajga – tundra), granicą pomiędzy lasem a łąką i rozróżnieniem krawędzi lasu (Falińska, 1996), jednakże ekotony są również ogólnie strefami granicznymi pomiędzy rozmaitymi sąsiadującymi społeczeństwami. Z perspektywy przestrzennej, ekoton opisany jest przez przestrzeń i czas, co odzwierciedla siły oddziaływania pomiędzy elementami granicznymi (ekosystemami). Ekotony, jako że są elementami przestrzennymi, mają zróżnicowaną strukturę wewnętrzną oraz budowę, atrybuty i inne właściwości uwarunkowane abiotycznie i biotycznie (kontrast, rozróżnienie wewnętrzne, szerokość i kształt). Jednocześnie posiadają właściwości uwarunkowane przez czas, rozwój oraz funkcję: przepuszczalność, trwałość i elastyczność (Hansen i in., 1988). Analizowanie relacji przestrzennej części krajobrazu jest identyfikowaniem jego składników oraz systemów i związków pomiędzy tymi częściami. Ażeby zrozumieć krajobraz i jego części, ekotony będą analizowane i rozróżniane topologicznie za pomocą pojęć granic przestrzennych, różnorodności, elastyczności (oddziaływania), warunków fizyczno-geograficznych oraz trwałości czaso-przestrzennej.

ANALÝZA PROMĚNLIVOSTI EKOTONŮ V PROSTŘEDÍ GIS

Klíčova slova: ekoton, prostorové analýzy, změny využití země

Shrnuti

Termín ekoton je pojímán velmi široce. Zahrnuje přechodné pásmo mezi dvěma biomy (tajga – tundra), hranici les – louka i diferenciaci lemu lesa (např. Falińska, 1996 aj.). Z prostorového hlediska je ekoton charakterizován prostorem a časem, které odráží síly interakcí mezi hraničními jednotkami (ekosystémy). Ekotony, jako prostorové jednotky, mají různou vnitřní strukturou a stavbou, prostorovými atributy a jiné vlastnosti, podmíněné abioticky a bioticky (kontrast, vnitřní diferenciaci, šířku, tvar). Současně mají vlastnosti podmíněné časem, vývojem a funkcí – propustnost, stabilitu, elasticitu (Hansen et al., 1988). Analyzovat prostorové vazby krajinných složek znamená identifikovat její stavební složky a také systém a kvalitu vztahů mezi těmito složkami. V souladu s chápáním krajiny a krajinných složek a současným stavem řešení dané problematiky budou ekotony analyzovány a typologicky rozlišeny z hlediska prostorových vazeb, heterogenity, elasticity (ovlivnění), fyzickogeografických podmínek, časoprostorové stability apod.

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