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Analyzing Land Cover Change—The Impact of the Motorway Construction and Their Operation on Landscape Structure

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Abstract

The aim of our study was to assess the influence of motorways on landscape structure changes. The research was situated on segments of the D1 and D3 motorways in the Czech Republic. The method used for determining the impacts of the construction and operation of the motorway on the landscape structure was based on comparing the development of the land cover types in an area where the motorway was present for almost the entire monitored period (D1 motorway segment) with the development of the land cover types in an area where the motorway was constructed towards the end of the monitored period (D3 motorway segment). Monitored period was between years 1949, 1988 (1984 segment of motorway D3) and 2007. Source materials were processed and analyzed in the ArcGIS software environment. Our comparison indicated that the main differences between segments were in the level of development of commercial, industrial and agricultural built-up area in the vicinity of motorways. The existence of the motorway also contributed to the development of residential areas. It should be noted that in both cases there was also an increase in the extension of shrubs and scattered vegetation, and in small quantities also category of forest.

Keywords

Land Use, Landscape Development, Aerial Photos, Commercial Suburbanization, Land Occupation

1. Introduction

Landscape structure has a crucial influence on the functional properties of the landscape, and also is one of the

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most important factors, which affects biodiversity as the fundamental indicator of the ecological value of a landscape [1] [2]. Any changes in land use have a major impact on the landscape characteristics, e.g. landscape structure, ecological stability, landscape character, level of biodiversity, and the course of biotic and abiotic processes. Land-cover change is a main component of global environmental change [3].

Areas not easily accessible to humans are often characterized as stable and natural. Almost immediately after a new transport infrastructure is constructed, these areas begin to change rapidly [1]. They become attractive for commercial development due to strategic localization on the transport network [4]. The gradual urbanization occurs in the vicinity of these areas [4]-[6].

The direct and indirect effects of constructing and operating road structures are studied within scientific discipline known as "Road Ecology" [7] [8]. Researchers typically attribute the dynamics of land use change in the vicinity of motorways to five major forces: political, economic, cultural, technological, and natural/spatial ones [9]-[13].

The issue of environmentally unfavorable aspects of the use and development of the transport infrastructure is increasingly likened in a worldwide context [14]-[16]. In countries with a dense transport network (like Netherlands, Belgium, Germany, etc.), the landscape fragmentation by transport infrastructure has become a major issue in nature conservation [16]. Czech Republic has a density of road transport infrastructure 0.7 kilometres of roads and highways per 1 km^2, significantly outweighing the lower-class roads. Density of motorways in the Czech Republic is still distinctly lower than the EU average [17].

In the Czech Republic, major changes in landscape structure have occurred over the past 40 years [18]. Suburbanization can be seen as one of the main aspects of this trend [4]. The spread of commercial suburbanization throughout the Czech Republic went hand in hand with the development of transport infrastructure [19]. Relative expression of unfragmented areas by traffic in the Czech Republic in 1980 accounted for 83.47% and 64.93% in 2005. Predictions for 2040 amounts to 53.11%, which is significantly decreasing trend [18].

Landscape metrics or indices have been used widely to describe landscape structures, spatial patterns and landscape change [6] [20]-[23]. However, the significance of landscape metrics for practical applications remains questionable [5] [24] [25] and their dependence on data quality is important in particular in highly dynamic landscapes, such as suburban ones [15] [26]-[28]. The use of time series of historical maps and aerial photographs is a common practice in historical geography and has proven to be very useful for landscape metrics analysis [27] [29]-[32].

Land cover changes can be used to identify the direct and indirect processes of land degradation. Human/ natural modifications on land cover have resulted in degradation, deforestation, biodiversity loss, global warming, and increase in natural disasters. Growing population, urban expansion, cropland loss, and so on create a pressure on land cover. This pressure results in unplanned and uncontrolled changes in land cover. Land cover changes leading to severe environmental problems are generally caused by mismanagement of agriculture, urbanism, and forestlands [6] [8] [33]. Localities in the vicinity of motorways are often without any management. Therefore the aim of our study was to evaluate real effects on the landscape structure due to the construction and operation of the motorways and the associated secondary development. We expected significant changes especially in land occupation and loss of agricultural land. By our study we would like to find out regularities in the development of natural areas in the vicinity of motorways and also we would like to find out how extensions are natural areas transform on manmade localities.

2. Study Area

The place of interests comprises from D1 motorway segment between Prague and Hvězdonice (in the Prague-West district, ca 13 km from Prague), and the segment of the D3 motorway between Moraveč and Měšice (Tábor District, approximately 75 km away from Prague, **Figure 1**).

The D1 motorway is the Czech Republic's main motorway (the research section is in operation from 1977). The traffic load in this section is 73,397 automobiles per 24 hours (in year 2010). By contrast, the D3 motorway is relatively new and only parts of it are already completed. In the monitored segment of the D3, which is already operational from year 2007, and the traffic load is 10,275 automobiles per 24 hours (in year 2010).

3. Methodology

Aerial photographs from three time period were used in analysis 1949, 1988 (1984 in the segment of D3 motor-

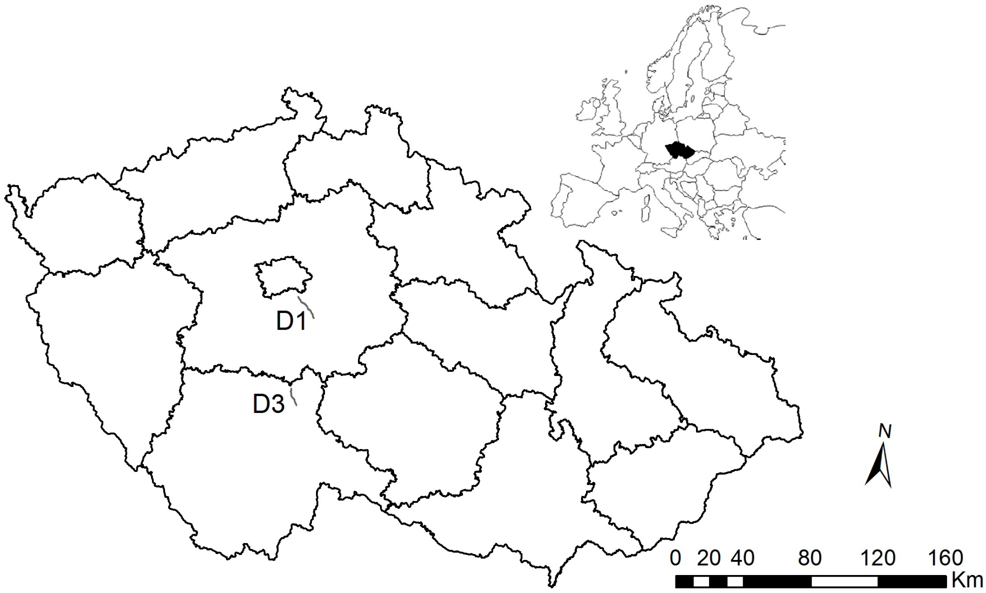

Figure 1. Areas of interest.

way) and 2007 (**Figure 2**; **Figure 3**). Photographs from 1949 and 1988 (1984) were black and white. The last sets of aerial photographs from year 2007 were colors. These time points represent crucial milestones in the development of the Czech landscape. In the first period, up until 1949, the countryside comprised a mosaic of small fields divided by narrow strips of permanent grassland and scattered vegetations. This is also the period when construction of the D1 motorway segment began. The second time period (up to 1988) was selected especially with respect to the political and social changes after year 1968. The third period is the present (up to 2007). The source documents and materials were processed, and individual analyses were prepared in the ArcGIS 9.3 software environment. Processing was carried out in three basic steps: georeference, vectorization and interpretation.

Aerial photos were first positioned in the area established using a coordinate system. An orthophoto map from the CENIA geoportal (cenia_b_ortorgb05m_sde) was used as the map underlay. It is drawn in the S-JTSK Krovak EastNorth coordinate system. After rasters had been placed on the area and manual vectorization was performed. The line layer of motorways was provided by the Road and Motorway Directorate of the Czech Republic [34].

Changes in the landscape matrix are most significant at the distance of the "road affected zone", which is 20 - 300 m from the road [35]. The width of the disturbed zone can also be estimated according to the empirical relationship defined by [36]:

$$D = (\log I - 2) * w,$$

where D = width [m] of the disturbed zone on each side from the edge of the road; I = traffic intensity (number of vehicles per 24 h); w = width [m] of the road to the edge of the cutting or embankment.

A distance of 200 m on either side of the motorway axis was defined as potentially the most affected area from the perspective of landscape structure changes. The area affected by a motorway can have various dimensions, from tens of meters to thousands of meters [8] [37]-[39]. Inside this road-effect zone, manual vectorization was performed and followed by identification of polygons and its classification into individual land cover categories. The type of land cover was recorded in the attribute table for each polygon layer. The area (m^2) and perimeter (m) of each patch was calculated, and subsequently analyzed. The following use categories were employed:

Communication-unpaved; Communication-paved; Forest land; Commercial, industrial and agricultural built-up area; Residential built-up area; Arable land; Future development areas; Roads under construction; Shrubs and scattered vegetation; Orchards and gardens; Permanent grassland; Water areas; Railway; Others.

The type of land cover categories were defined after partial reconnaissance of all aerial photos from all three

Figure 2. D3 Motorway segment.

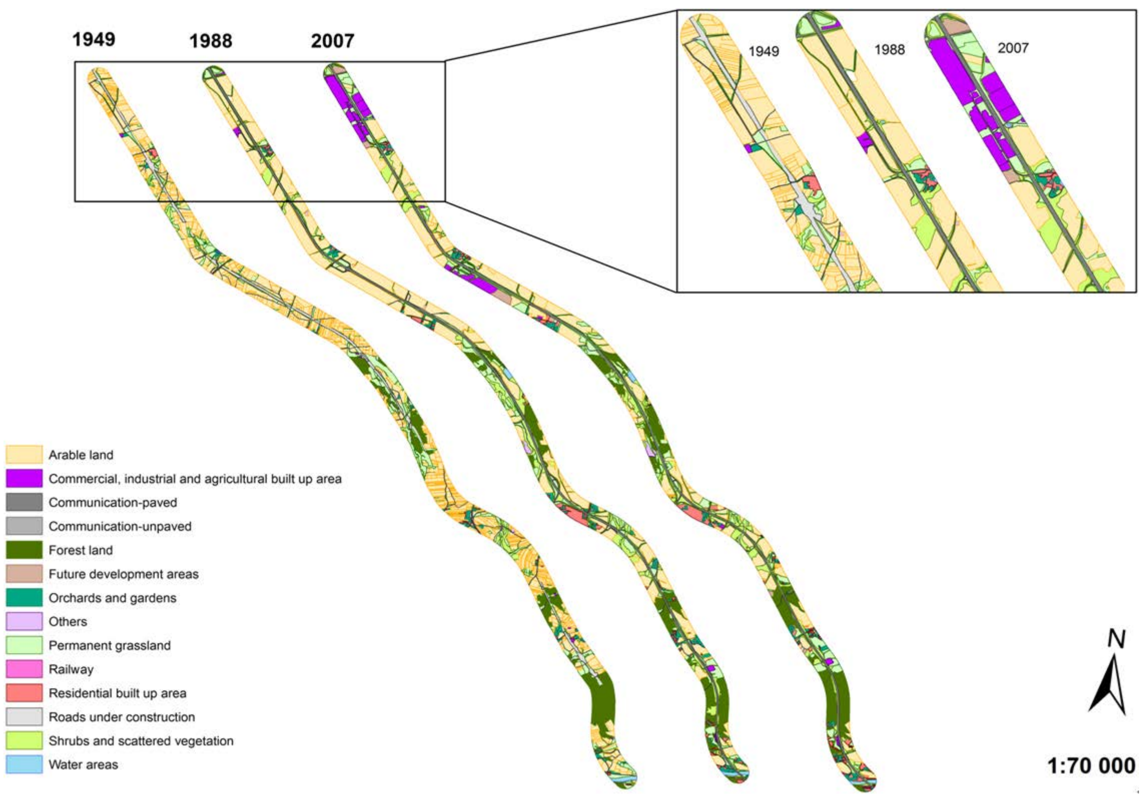

Figure 3. D1 motorway segment.

time. The landscape macrostructure was characterized by composition and the coefficient of ecological stability (CES). To calculate CES, we selected the Agroprojekt method, which is that most suitable for comparing changes in ecological stability over time [40].

$$\text{CES} = \frac{1.5\text{A} + \text{B} + 0.5\text{C}}{0.2\text{D} + 0.8\text{E}},$$

where: A = percentage of area with quality level 5 (the best); B = percentage of area with quality level 4; C = percentage of area with quality level 3; D = percentage of area with quality level 2; E = percentage of area with quality level 1 (the poorest).

The evaluation output is as follows [41]:

CES ≤ 0.1, devastated landscape

0.1 < CES < 1.0, disturbed landscape capable of autoregulation

CES = 1.0, balanced landscape

1.0 < CES < 10.0, landscape with dominating natural component

CES ≥ 10.0, natural landscape, or nearly natural landscape

We also used Shannon's diversity index (SDI), which is a comprehensive indicator of the relative level of diversity of patches and land cover classes. The index records higher values with increasing numbers of patches and landscape cover classes, and also with growth in the proportional representation of patches [19]. We also used Simpson's evenness index (SEI), which expresses a measure of the placement and quantity of patches (the more diverse the placement, the closer the value of the index to zero; the more regular the placement, the closer the value of the index to one [42].

Landscape microstructure was characterized on the basis of the properties of the patches of each land cover category. The V-LATE tool (Vector-based Landscape Analysis Tools Extension) was used in calculating selected statistical indices and characteristics of patches. Following indexes were examined: the total number of patches (NumP), mean patch size (MPS), index of the mean perimeter of the edges for the individual land cover categories (MPE), mean shape index (MSI)—complexity of the shape, which is based on the ratio between the total perimeter and the area of the individual patches for the individual categories. The index (MSI) provides low values if the shapes of the patch edges are compact and simple, and high values if the shapes are complicated and elongated [42]. The mean perimeter-area ratio (MPAR) reflects small patches in the landscape, and also provides information on the shape complexity of the patches. The mean patch fractal dimension (MFRACT), a measure of the complexity of shape, is a characteristic that allows us to describe the average complexity of the patch shapes. The value for the index approaches one if the patch shape is simple and if its perimeter is similar in shape to that of a circle or a square. When the shapes of the boundaries are more complex (e.g. elongated), the value approaches two [42].

4. Results

In both motorways segments, the dominant type of surrounding countryside is arable land. Along the segment of D1 motorway, a decreasing trend in the amount of arable land was observed due to construction of the motorway (until 1988), and also due to the increasing amount of scattered vegetation, permanent grassland, as well as commercial and residential built-up area. Along the D3 motorway segment, the amount of arable land followed a growing trend until 1988 (**Table 1**). Thereafter it began to decline, and the ratio has been decreasing due to motorway construction and an increase in areas of scattered vegetation and permanent grassland. Regarding permanent grassland, a similar development trend can be observed at both segments: the relative amount decreased in favor of arable land until 1988, after which it increased. In both areas, the influence of completion of the construction of the highway on an increase in the area of certain land cover categories can be observed, and in particular an increase in paved roads, residential and commercial construction, and scattered vegetation. Residential construction showed a slightly increasing development trend over the entire monitored period, but it increased markedly only in the period after the motorway was completed (*i.e.*, along the D1 motorway up to 1988, and along the D3 up to 2007). The amount of orchards and gardens followed the increasing trend of residential construction only until 1988, after which it began to decrease due to the increasing density of the conurbations. Commercial, industrial and agricultural construction, along with areas for future development, only started to develop in both segments during the recent period (up to 2007). This was probably due to the construction of the motorway. A comparison of the development of the amount of land in each of the two segments is presented in **Table 1**.

According to the CES calculation, both areas of interest can be characterized in the pre-1949 period as landscapes with a dominating natural component (1.0 < CES < 10.0). In the subsequent period, the CES of the two monitored segments decreased rapidly due to disturbance of the landscape. In the final monitored period, there is an apparent improvement over the pre-1988 state in both segments, though the landscape has not sufficiently recovered from the interventions in the landscape that occurred during the previous period. It therefore remains in the disturbed landscape category (**Table 2**). Meanwhile, in the case of the D1 motorway, the Shannon's diversity index and the Simpson's evenness index rose continuously all through the monitored years. Along the D3 motorway, these indices initially decreased slightly (between 1949-1988) and then recorded a more marked increase up to 2007 (**Table 2**).

The statistical indices show that the number of patches of arable land has diminished enormously. As of 2007, a 10-fold decrease had occurred in both monitored segments in comparison to the state in 1949. In the cases of unpaved roads and permanent grassland there was a 50% decrease. The numbers of paved communication

Table 1. Developments in relative amounts by land cover type.

Land use category	Motorway D1			Motorway D3		
	1949	1988	2007	1949	1984	2007
Communication-unpaved	1.1	0.5	0.4	0.9	0.6	0.6
Communication-paved	0.9	9.6	10.0	0.8	0.9	9.2
Forest land	12.1	11.4	14.4	5.4	5.8	6.7
Commercial, industrial and agricultural built-up area	0.2	0.5	6.0	0.1	0.3	1.4
Residential built-up area	0.7	3.1	4.0	0.1	0.2	0.3
Arable land	56.7	45.0	31.2	66.8	76.2	59.0
Others	0.1	0.4	0.5	0.0	0.0	0.3
Future development areas	0.0	0.1	1.6	0.0	0.0	0.2
Roads under construction	6.7	0.0	0.0	0.0	0.0	1.3
Shrubs and scattered vegetation	3.0	13.4	14.0	1.5	1.8	3.5
Orchards and gardens	2.1	3.6	2.8	0.2	0.9	0.8
Permanent grassland	15.8	11.6	14.4	23.4	11.6	15.0
Water areas	0.5	0.7	0.6	0.7	1.6	1.6
Railway	0.1	0.1	0.1	0.1	0.1	0.1

Table 2. SDI, SEI and CES indices through the monitored periods.

	Years	SDI	SEI	CES
Motorway D1	1949	1.42	0.55	1.198
	1988	1.70	0.66	0.373
	2007	1.98	0.77	0.476
Motorway D3	1949	0.98	0.41	1.244
	1984	0.92	0.38	0.127
	2007	1.42	0.54	0.165

SDI: Shannon's diversity index; SEI: Simpson's evenness index; CES: coefficient of ecological stability.

patches tripled, and the number of patches under residential construction and scattered vegetation doubled. All these changes were markedly apparent for the period between 1949 and 1988, and they have remained steady up to the present time. As of 2007, only the number of permanent grass stand patches had balanced out at a level almost the same as that in 1949 within the D3 segment. The average area of patches of certain categories also changed markedly over the years. In arable land, the average area was substantially greater in 1988 than in 1949—8 times greater in the D1 segment and 12 times greater in the D3 segment. As of 2007 the average area had fallen, but even now it remains 6 times bigger than the 1949 value along the D1 and 10 times bigger in the D3 segment. Commercial, agricultural and industrial buildings have increased 6-fold in average area over the last 60 years, paved roads have tripled in area, and residential area has doubled. The MPE index tracks the development of average patch areas. The MSE indices have high values if their categories are represented evenly across the landscape. In both study areas, this was observed, for example, in the case of unpaved roads, which formed a dense network through the landscape until 1949. Thereafter, their numbers have decreased, and a marked decrease in the index can be observed in the subsequent periods. For paved communications, the index decreased due to construction of the motorway. In the D1 segment, this decrease can already be seen in the pre-1988 period, while in the D3 segment the decrease is only visible in the period leading up to 2007. The MPAR and MFRACT index values show values approaching 2 among patches with substantially complex perimeters (*i.e.*, paved and unpaved roads, and railroads). By contrast, the categories of forests and arable land, as well as commercial, agricultural and industrial built-up areas have low values, as their shapes resemble squares or circles. There are marked differences between the values from 1949 and 1988, during which period the shapes of the patches mostly became simpler. The results for all characteristics are stated in **Table 3**.

5. Discussion

5.1. Road Affected Area

The width of the area affected by a motorway varies considerably, and always depends on the type of influence that is being monitored, traffic intensity, and the state of the natural and other conditions [43]. According to certain approaches, the selected width of the direct impact zone (200 m on either side from the axis of the motorway) is wider than the actual direct impact area. In some cases, however, it can also be insufficiently wide, always depending on the attributes of a specific stand.

The actual width of the "road affected zone" in relation to its influence on the landscape matrix can range from less than 5 m to 100 m, or even 1000 m, depending on landscape type, season, traffic density, compass directions of the orientation of the road, etc. [35] [44] [45]. Forman, Deblingeer [46] estimated the average width of the "road affected zone" in Massachusetts in the context of its influence on landscape structure to be 600 m.

A study from Great Britain reports that, due to the divergent distribution of nitrogen caused by road traffic, changes in species on the herbal level can be observed at distances of 100 - 200 m [47].

Defining the "road-affected zone" in the context of the influences of road traffic on the landscape is a very difficult and time-consuming process. Liu [48] attempted to prove for the period 1980 to 2000 whether more important changes in landscape occurred in the immediate vicinity of a road (at distances ≤ 500 m) than at greater distances (500 - 1000 m). The values for all monitored indices (Shannon's diversity index, Simpson's evenness index, number and density of patches, and an index of anthropogenic disturbance) were observed to diminish with increasing distance from the road. A study [49] monitored changes in landscape structure in the periods between 1974, 1988 and 2007 in two different segments of the Czech Republic's D1 motorway at a distance of 200 m from the edge of the roadway. In both of the segments, agricultural areas were markedly reduced while areas of forests and early successional communities increased slightly.

5.2. Trends in Macrostructure Development

The development trends are similar in both segments. From the perspective of the coefficient of ecological stability, both areas were rather balanced landscapes in 1949, with relatively good autoregulatory capacities. The landscape was capable of functioning without large inputs of energy or materials. The 1988 CES indicates that the landscape was still capable of autoregulation, but relatively high inputs of additional energy were required for its operation. Weakening of the autoregulatory abilities in the agricultural systems led to considerable instability in them [40]. In the most recent monitored period, CES was again rising in both monitored segments. This

Table 3. Overview of statistical indices.

Land use category	Motorways segment	Year	NP	MSI	MPAR	MFRACT	MPE (m)	MPS (m^2)
Communication-unpaved	D1	1949	50	6.96	0.80	1.93	1002.7	1380.5
		1988	28	4.94	0.64	1.85	608.3	1053.0
		2007	38	4.56	0.71	1.88	447.5	714.1
	D3	1949	35	6.53	0.77	1.92	841.1	1131.2
		1984	14	6.06	0.57	1.83	1035.6	1955.7
		2007	18	4.53	0.49	1.79	623.3	1410.1
Communication-paved	D1	1949	20	5.84	0.43	1.77	1177.8	3011.9
		1988	59	4.86	0.46	1.76	1386.8	10630.8
		2007	66	4.50	0.41	1.74	1188.8	10068.8
	D3	1949	9	5.73	0.36	1.74	1241.4	3896.5
		1984	8	5.04	0.34	1.72	1283.6	4751.4
		2007	42	3.59	0.32	1.67	1093.4	9544.1
Forest land	D1	1949	23	1.67	0.09	1.40	876.7	34531.4
		1988	20	1.77	0.05	1.36	1186.6	37051.2
		2007	36	1.86	0.10	1.43	888.5	26429.4
	D3	1949	9	1.57	0.10	1.41	656.6	26408.6
		1984	8	1.64	0.09	1.40	825.6	31745.8
		2007	17	1.56	0.09	1.39	570.9	17379.7
Commercial, industrial and agricultural built-up area	D1	1949	16	1.40	0.24	1.51	158.0	1296.2
		1988	6	2.05	0.14	1.47	439.5	5389.6
		2007	28	1.39	0.10	1.38	484.5	14256.6
	D3	1949	4	1.17	0.13	1.41	141.1	1225.8
		1984	2	1.22	0.09	1.37	346.7	9166.1
		2007	7	1.37	0.09	1.39	377.6	8194.0
Residential built-up area	D1	1949	48	1.30	0.23	1.50	128.3	973.3
		1988	86	1.40	0.18	1.47	200.6	2348.5
		2007	100	1.42	0.18	1.47	226.5	2664.6
	D3	1949	6	1.24	0.24	1.50	84.7	402.1
		1984	12	1.17	0.21	1.47	96.6	601.3
		2007	15	1.39	0.22	1.50	146.2	998.9
Arable land	D1	1949	876	1.49	0.11	1.42	309.5	4285.0
		1988	86	1.44	0.05	1.34	848.9	35090.1
		2007	85	1.47	0.06	1.36	709.4	24278.9
	D3	1949	638	1.67	0.13	1.44	364.9	4591.1
		1984	51	1.38	0.05	1.32	1023.6	65468.7
		2007	49	1.41	0.04	1.31	1058.7	52753.0
Others	D1	1949	3	1.12	0.09	1.36	185.0	2360.5
		1988	5	1.24	0.08	1.36	307.5	5752.9
		2007	4	1.55	0.15	1.45	416.9	8029.8
	D3	1949	0	0.00	0.00	0.00	0.00	0.00
		1984	0	0.00	0.00	0.00	0.00	0.00
		2007	2	2.11	1.47	1.47	603.3	6931.5

Continued

Future development areas	D1	1949	0	0.00	0.00	0.00	0.00	0.00
		1989	1	1.31	0.06	1.35	370.9	6429.9
		2007	7	1.26	0.05	1.33	482.6	14702.2
	D3	1949	0	0.00	0.00	0.00	0.00	0.00
		1989	0	0.00	0.00	0.00	0.00	0.00
		2007	1	1.12	0.04	1.30	405.7	10431.0
Roads under construction	D1	1949	34	1.95	0.08	1.42	788.2	12893.5
		1989	0	0.00	0.00	0.00	0.00	0.00
		2007	0	0.00	0.00	0.00	0.00	0.00
	D3	1949	0	0.00	0.00	0.00	0.00	0.00
		1989	0	0.00	0.00	0.00	0.00	0.00
		2007	11	2.09	0.13	1.48	485.2	5135.2
Shrubs and scattered vegetation	D1	1949	90	2.25	0.28	1.60	318.7	2152.3
		1989	160	2.69	0.23	1.57	626.0	5477.2
		2007	83	2.36	0.22	1.55	530.7	5049.6
	D3	1949	21	1.72	0.18	1.49	283.0	3084.6
		1989	24	1.51	0.15	1.45	249.4	3256.6
		2007	55	2.24	0.21	1.55	406.7	2777.4
Orchards and gardens	D1	1949	50	1.60	0.15	1.46	237.8	2703.2
		1989	60	1.72	0.14	1.46	355.5	3892.6
		2007	68	1.57	0.14	1.46	273.7	2721.8
	D3	1949	4	1.72	0.15	1.49	291.8	2537.9
		1989	8	1.63	0.10	1.43	386.3	4726.3
		2007	15	1.68	0.19	1.51	266.2	2284.2
Permanent grassland	D1	1949	309	2.14	0.25	1.55	349.8	3356.7
		1989	154	2.35	0.23	1.55	486.3	4917.8
		2007	165	2.12	0.18	1.51	495.8	5769.4
	D3	1949	121	2.63	0.34	1.60	524.7	8447.4
		1989	80	3.09	0.31	1.63	595.3	6360.6
		2007	125	2.74	0.22	1.57	650.4	5265.5
Water areas	D1	1949	1	1.68	0.03	1.35	1031.5	29948.8
		1989	5	1.30	0.08	1.37	394.9	8639.7
		2007	6	1.29	0.10	1.39	337.5	7072.7
	D3	1949	2	1.37	0.21	1.47	481.4	15417.9
		1989	3	1.92	0.06	1.39	909.5	23308.2
		2007	9	1.37	0.18	1.46	327.0	7619.1
Railway	D1	1949	3	0.48	0.48	1.80	919.5	2322.8
		1989	6	0.34	0.34	1.68	416.7	1492.7
		2007	6	0.45	0.45	1.75	495.0	1282.2
	D3	1949	3	0.42	0.42	1.77	847.3	2136.2
		1989	3	0.49	0.49	1.81	843.5	1751.9
		2007	6	0.47	0.47	1.78	427.4	923.6

NP: number of patches; MPE: mean perimeter of the edges; MSI: mean shape index; MPS: mean patch size; MPAR: mean perimeter area ratio; MFRACT: mean patch fractal dimension.

may indicate increasing ecological stability, especially due to growing amounts of permanent grass stands and forest soil.

The motorway itself does not have a very strong negative influence on landscape stability, as is indicated by the calculated CES values for the D3 motorway segment in 1988 and 2007. However, it does have a strong influence on landscape fragmentation [17] [50], which is apparent, in the D3 motorway segment, from the increasing total number of patches. In the D1 motorway segment, after the construction of the motorway had been completed (before 1988), the number of patches decreased drastically. The landscape development context indicates that the cause for this was not motorway construction, but rather the changes in the situation in the agricultural sector.

A number of scientific studies [38] [46] [50] [51] have shown that the impact of the transport infrastructure, especially on ecosystems, the hydrological situation and population in the vicinity, also should not be ignored. The landscape structure markedly affects the extent of the negative impacts of a motorway. An example is seen in the scattered vegetation within the immediate vicinity of a busy road, which helps to mitigate negative impacts of the motorway, e.g. noise and exhaust emissions [52] [53]. Vegetation in the vicinity of roads frequently provides a refuge, living space or migration corridors for a whole array of animal species [52] [54], and in certain species it can even be a priority biotope. Landscape structure provides a basis for defining an area that can be potentially sensitive and influential for animals.

5.3. Trends in Microstructure Development

The existence of roads leads to increased numbers and increased density of patches and decreased average and maximum size of patches in their vicinity [35]. This statement is fully supported by the results of our study. The number of patches defines the possibility for organisms living on a given type of patch to move within the landscape [19] [42]. Of course, a motorway is an impermeable barrier, but, at the same time, it leads to greater variability in natural land cover categories along both sides of the road. This change in the natural environment can affect the original populations, thereby providing a space for invasive species [38] [55] [56]. Mean patch size partially expresses the intensity of use for arable land, and in natural stands it partially expresses the level of fragmentation [19]. The most visible impact on landscape structure was the occurrence of large fields of arable land, due to land consolidation, followed by the ploughing up of field boundary areas, groves and field roads that had provided very valuable ecosystems both for animals inhabiting the landscape and for the stability of the landscape. These areas had provided permeability for the landscape, had contributed to water retention, and had served to prevent erosion [2] [40].

The arable land category differs significantly from the others. In both areas of interest, arable land retreated in the face of the motorway construction and commercial and residential building, which took place at different times in the two locations studied here [34]. In the D1 motorway segment, agricultural collectivization caused the area of arable land to increase up until 1988. The effect was different for the D3 segment, where motorway construction did not begin until after 1988.

In both segments, commercial and industrial construction started to expand only after 1989, the main causes probably being the construction of the motorway and the opportunity for foreign investors to enter the Czech market, which had not existed before 1989 [57] [58]. The presence of a motorway in the vicinity of a large city leads to the development of residential and commercial construction, which in turn leads to irreversible changes in the landscape structure and in land use [40] [58].

6. Conclusions

A comparison of the development of selected landscape characteristics in the motorway D1 segment, and motorway D3 segment, has shown that the main mechanism shaping the landscape in both segments was not the motorway but rather the political and economic changes. Construction of the motorway led to conspicuous occupation of biotopes, but the ensuing secondary land occupation for commercial and residential purpose has been much greater. Historical land-use studies clearly confirm that the recent state of land use is also the result of long-term nature-society relations. It is fortuitous that historical land-use data from Czechia are available from the years that represent important milestones of modern Czech history [59].

- Landscape structure has an important role in the context of extent of the negative influence of a motorway on fauna and flora. The landscape can either mitigate the negative impacts of the motorway on the human health

and nature ecosystems, or it can help to spread them. Therefore the right management of surroundings ecosystem and knowledge about its development are really essential.
- There was a decreasing trend in the amount of arable land, due to occupation for construction of the motorway. The edges affected by construction were probably left mostly fallow, and they began to grow over spontaneously with self-seeded trees. As a result of succession, areas of scattered vegetation expanded. Lack of specific management of these plots can be problematic.
- Due to property rights (e.g. in relation to restitution), areas with difficult access and parts of agricultural patches gradually began to grow over. Meanwhile, arable land also decreased due to immense construction of commercial and industrial areas. These areas are usually situated in the vicinity of highway exits, and, in the absence of preventive planning, they increase the barrier effect.
- Construction of the motorway led to additional occupation of biotopes, which was not necessary for motorway body, but for secondary development of commercial and residential character.
- The share of residential areas also increases, since the motorway makes these sites readily accessible and more attractive, especially for city-dwellers who long live in the countryside while needing to commute regularly to the city for work.

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References

[1] Lipský, Z. (2001) Vývoj české kulturní krajiny. Česká zemědělská univerzita v Praze, Kostelec nad Černými Lesy.

[2] Sklenička, P. (2003) Základy krajinného plánování. Praha, Nakladatelství Naděžda Skleničková.

[3] Munteanu, C., Kuemmerle, T., Boltižiar, M., Butsic, V., Gimmi, U., Halada, Ľ., Kaim, D., Király, G., Konkoly-Gyuró, E., Kozak, J., Lieskovský, J., Mojses, M., Müller, D., Ostafin, K., Ostapowicz, K., Shandra, O., Štych, P., Walker, S. and Radeloff, V.C. (2014) Forest and Agricultural Land Change in the Carpathian Region—A Meta-Analysis of Long-Term Patterns and Drivers of Change. *Land Use Policy*, **39**, 685-697. http://dx.doi.org/10.1016/j.landusepol.2014.01.012

[4] Romportl, D. and Chuman, T. (2010) Změny struktury krajiny vlivem rezidenční a komerční suburbanizace v České republice. Suburbanizace.cz.

[5] Antrop, M. (2005) Why Landscapes of the Past Are Important for the Future. *Landscape and Urban Planning*, **70**, 21-34. http://dx.doi.org/10.1016/j.landurbplan.2003.10.002

[6] Ikiel, C., Dutucu, A.A., Ustaoglu, B. and Kilic, D.E. (2013) Land Use and Land Cover (LULC) Classification Using Spot-5 Image in the Adapazari Plain and Its Surroundings, Turkey. *The Online Journal of Science and Technology*, **2**, 37-42.

[7] Keken, Z., Kušta, T. and Ježek, M. (2001) The Effect of Roads and Road Transport on the Environment and Defining of Road Affected Zone. *Acta Pruhoniciana*, **99**, 183-188.

[8] van der Ree, R., Jaeger, J.A.G., van der Grift, E.A. and Clevenger, A.P. (2011) Effects of Roads and Traffic on Wildlife Populations and Landscape Function: Road Ecology Is Moving towards Larger Scales. *Ecology and Society*, **16**, 48.

[9] Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.B., Angelsen, A., Bruce, J.W., Coomes, O.T., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., Skanes, H., Steffen, W., Stone, G.D., Svedin, U., Veldkamp, T.A., Vogel, C. and Xu, J. (2001) The Causes of Land-Use and Land-Cover Change: Moving beyond Themyths. *Global Environmental Change*, **11**, 261-269. http://dx.doi.org/10.1016/S0959-3780(01)00007-3

[10] Bürgi, M., and Turner, M.G. (2002) Factors and Processes Shaping Land Cover and Land Cover Changes along the Wisconsin River. *Ecosystems*, **5**, 184-201. http://dx.doi.org/10.1007/s10021-001-0064-6

[11] Lambin, E.F., Geist, H.J. and Lepers, E. (2003) Dynamics of Land-Use and Land-Cover Change in Tropical Regions. *Annual Review of Environment and Resources*, **28**, 205-241. http://dx.doi.org/10.1146/annurev.energy.28.050302.105459

[12] Bürgi, M., Hersperger, A.M. and Schneeberger, N. (2004) Driving Forces of Landscape Change—Current and New Directions. *Landscape Ecology*, **19**, 857-868. http://dx.doi.org/10.1007/s10980-004-0245-8

[13] Hersperger, A. and Bürgi, M. (2009) Going beyond Landscape Change Description: Quantifying the Importance of Driving Forces of Landscape Change in a Central Europe Case Study. *Land Use Policy*, **26**, 640-648. http://dx.doi.org/10.1016/j.landusepol.2008.08.015

[14] Forman, R.T.T. (2002) Foreword. In: Gutzwiller, K.J., Ed., *Applying Landscape Ecology in Biological Conservation*, Springer, New York, 7-10.

[15] Van Etvelde, V. and Antrop, M. (2004) Analyzing Structural and Functional Changes of Traditional Landscapes—Two Examples from Southern France. *Landscape and Urban Planning*, **67**, 79-95. http://dx.doi.org/10.1016/S0169-2046(03)00030-6

[16] Anděl, P., Gorčicová, I. and Petržílka, L. (2008) Atlas vlivu silniční dopravy na biodiverzitu. Evernia, Liberec.

[17] Anděl, P., Gorčicová, I., Hlaváč, V., Miko, L. and Andělová, H. (2005) Hodnocení fragmentace krajiny dopravou—Metodická příručka. Agentura ochrany přírody a krajiny ČR, Praha.

[18] Anděl, P., Gorčicová, I., Hlaváč, V., Romportl, D. and Strnad, M. (2009) Koncepce ochrany migračních koridorů velkých savců a územní systém ekologické stability. ÚSES-zelená páteř krajiny, Kostelec nad Černými lesy, Příspěvek ve sborníku.

[19] Romportl, D. and Chuman, T. (2009) Změny struktury krajiny v České republice po roce 1990. http://www.cenelc.cz/

[20] Jansen, L.J.M., Carrai, G., Morandini, L., Cerutti, P.O. and Spisni, A. (2006) Analysis of the Spatio-Temporal and Semantic Aspects of Land-Cover/Use Change Dynamics 1991-2001 in Albania at National and District Levels. *Environmental Monitoring and Assessment*, **119**, 107-136. http://dx.doi.org/10.1007/s10661-005-9013-8

[21] Fan, F., Weng, Q. and Wang, Y. (2007) Land Use and Land Cover Change in Guangzhou, China, from 1998 to 2003, Based on Landsat TM/ETM + Imagery. *Sensors*, **7**, 1323-1342. http://dx.doi.org/10.3390/s7071323

[22] Akbulak, C. (2010) Land Use Suitability Analysis of the Upper Basin of the Kara Menderes River Using Analytical Hierarchy Process and Geographical Information Systems. *International Journal of Human Science*, **7**, 557-576.

[23] Sleeter, B.M., Wilson, T.S., Soulard, C.E. and Liu, J.X. (2011) Estimation of Late Twentieth Century Land-Cover Change in California. *Environmental Monitoring and Assessment*, **173**, 251-266. http://dx.doi.org/10.1007/s10661-010-1385-8

[24] Dramstad, W.E., Fjellstad, W.J. and Fry, G.L.A. (1998) Landscape Indices—Useful Tools or Misleading Numbers? In: Dover, J.W. and Bunce, R.G.H., Eds., *Proceedings of the* 1998 *European Congress of IALE*, *Key Concepts in Landscape Ecology*, IALE, 3 September 1998, 63-68.

[25] Hietel, E., Waldhardt, R. and Otte, A. (2004) Analysing Land-Cover Changes in Relation to Environmental Variables in Hesse, Germany. *Landscape Ecology*, **19**, 473-489. http://dx.doi.org/10.1023/B:LAND.0000036138.82213.80

[26] Turner, M.G., Gardner, R.H. and O'Neill, R.V. (2001) Landscape Ecology in Theory and Practice: Pattern and Process. Springer, New York.

[27] Kara, F. (2010) Determination of Land Use/Land Cover Change and Urban Growth by Using Remote Sensing: A Case Study of Duzce Province in Turkey. *Fresenius Environmental Bulletin*, **19**, 1312-1319.

[28] Yin, J., Yin, Z., Zhong, H.D., Xu, S.Y., Hu, X.M., Wang, J. and Wu, J.P. (2011) Monitoring Urban Expansion and Land Use/Land Cover Changes of Shanghai Metropolitan Area during the Transitional Economy (1979-2009) in China. *Environmental Monitoring and Assessment*, **177**, 609-621. http://dx.doi.org/10.1007/s10661-010-1660-8

[29] Vuorela, N. (2000) Can Data Combination Help to Explain the Existence of Diverse Landscapes? *Fennia*, **178**, 55-80.

[30] Guler, M., Yomralioglu, T. and Reis, S. (2007) Using Landsat Data to Determine Land Use/Land Cover Changes in Samsun, Turkey. *Environmental Monitoring and Assessment*, **127**, 155-167. http://dx.doi.org/10.1007/s10661-006-9270-1

[31] Olah, B. and Boltižiar, M. (2009) Land Use Changes within the Slovak Biosphere Reserves Zones. *Ecology* (*Bratislava*), **28**, 127-142. http://dx.doi.org/10.4149/ekol_2009_02_127

[32] Gerard, F., Bugár, G., Gregor, M., Halada, Ľ., Hazeu, G., Huitu, H., Köhler, R., Kolar, J., Luque, S., Mücher, C.A., Olschofsky, K., Petit, S., Pino, J., Smith, G., Thomson, A., Wachowicz, M., Bezák, P., Brown, N., Boltižiar, M., De Badts, E., Feranec, J., Halabuk, A., Manchester, S., Mojses, M., Petrovič, F., Pons, X., Roda, F., Roscher, M., Sustera, J., Tuominen, S., Wadsworth, R. and Ziese, H. (2010) Land Cover Change in Europe between 1950 and 2000 Determined Employing Aerial Photography. *Progress in Physical Geography*, **34**, 183-205. http://dx.doi.org/10.1177/0309133309360141

[33] Olah, B., Boltižiar, M. and Gallay, I. (2009) Transformation of the Slovak Cultural Landscape Since the 18th Cent. and Its Recent Trends. *Journal of Landscape Ecology*, **2**, 41-55. http://dx.doi.org/10.2478/v10285-012-0018-z

[34] ŘSD (2009) Silnice a dálnice v České republice 2009. Ředitelství silnic a dálnic ČR, Praha.

[35] Saunders, S.C., Mislivets, M.R., Chen, J. and Cleland, D.T. (2002) Effects of Roads on Landscape Structure within

Nested Ecological Units of the Northern Great Lakes Region, USA. *Biological Conservation*, **103**, 209-225. http://dx.doi.org/10.1016/S0006-3207(01)00130-6

[36] Müller, S. and Berthould, G. (1997) Fauna/Traffic Safety. Manual for Civil Engineers, LAVOC—EPFL, Lausanne.

[37] Forman, R.T.T., Friedman, D.S., Fitzhenry, D., Martin, J.D., Chen, A.S. and Alexander, L.E. (1997) Ecological Effects of Roads: Toward Three Summary Indices and an Overview for North America. In: Canters, K., Ed., *Habitat Fragmentation and Infrastructure*, Ministry of Transport, Public Works and Water Management, Delft, 40-54.

[38] Forman, R.T.T. and Alexander, L.E. (1998) Roads and Their Major Ecological Effects. *Annual Review of Ecology and Systematics*, **29**, 207-231. http://dx.doi.org/10.1146/annurev.ecolsys.29.1.207

[39] Forman, R.T.T. (1999) Horizontal Processes, Roads, Suburbs, Societal Objectives, and Landscape Ecology. In: Klopatek, J.M. and Gardner, R.H., Eds., *Landscape Ecological Analysis*: *Issues and Applications*, Springer-Verlag, New York, 35-53. http://dx.doi.org/10.1007/978-1-4612-0529-6_4

[40] Lipský, Z. (1999) Sledování změn v kulturní krajině. Česká zemědělská univerzita v Praze, Praha.

[41] Nováková, J., Skaloš, J. and Kašparová, I. (2006) Krajinná ekologie. Skripta ke cvičení. Česká zemědělská univerzita v Praze.

[42] Balej, M. (2006) Krajinné metriky jako indikátory udržitelné krajiny. České Budějovice, Česká geografická společnost.

[43] Carr, L.W. and Fahring, L. (2001) Effect of Road Traffic on Two Amphibian Species of Differing Vagility. *Conservation Biology*, **15**, 1071-1078. http://dx.doi.org/10.1046/j.1523-1739.2001.0150041071.x

[44] Reed, R.A., Johnson-Barnard, J. and Baker, W.L. (1996) Contribution of Roads to Forest Fragmentation in the Rocky Mountains. *Conservation Biology*, **10**, 1098-1106. http://dx.doi.org/10.1046/j.1523-1739.1996.10041098.x

[45] Fu, W., Liu, S.L. and Dong, S.K. (2010) Landscape Pattern Changes under the Disturbance of Road Networks. *Procedia Environmental Sciences*, **2**, 859-867. http://dx.doi.org/10.1016/j.proenv.2010.10.097

[46] Forman, R.T.T. and Deblinger, R.D. (2000) The Ecological Road-Effect Zone of a Massachusetts (U.S.A.) Suburban Highway. *Conservation Biology*, **14**, 36-46. http://dx.doi.org/10.1046/j.1523-1739.2000.99088.x

[47] Angnold, P.G. (1997) The Impact of Road upon Adjacent Heathland Vegetation: Effects on Plant Species Composition. *Journal of Applied Ecology*, **34**, 409-417. http://dx.doi.org/10.2307/2404886

[48] Liu, S.L., Cui, B.S., Dong, S.K., Yang, Z.F., Yang, M. and Holt, K. (2008) Evaluating the Influence of Road Networks on Landscape and Regional Ecological Risk: A Case Study in Lancang River Valley of Southwest China. *Ecological Engineering*, **34**, 91-99. http://dx.doi.org/10.1016/j.ecoleng.2008.07.006

[49] Keken, Z., Kušta, T., Ježek, M. and Martiš, M. (2011) A Comparison of Changes in Landscape Structures in Model Sections of the D1 Motorway. *Journal of Landscape Studies*, **4**, 25-34.

[50] Rico, A., Kindlmann, P. and Sedláček, F. (2007) Barrier Effects of Roads on Movements of Small Mammals. *Folia Zoologica*, **56**, 1-12.

[51] Forman, R.T.T. (1998) Road Ecology: A Solution for the Giant Embracing US. *Landscape Ecology*, **13**, 3-5. http://dx.doi.org/10.1023/A:1008036602639

[52] Neubergová, K. and Smejkalová, I. (2008) Funkce zeleně podél dopravních cest. *The Conference on the III*. *Česko slovenská konference Doprava*, zdraví a životní prostředí, Litomyšl.

[53] Hagler, G.S.W., Tang, W., Freeman, M.J., Heist, D.K., Perry, S.G. and Vette, A.F. (2011) Model Evaluation of Roadside Barrier Impact on Near-Road Air Pollution. *Atmospheric Environment*, **45**, 2522-2530. http://dx.doi.org/10.1016/j.atmosenv.2011.02.030

[54] Bissonette, J.A. and Rosa, S.A. (2009) Road Zone Effects in Small-Mammal Communities. *Ecology and Society*, **14**, 27.

[55] Bennett, A.F. (1991) Roads, Roadsides and Wildlife Conservation: A Review. In: Saunders, D.A. and Hobbs, R.J., Eds., *Nature Conservation* 2: *The Role of Corridors*, Surrey Beatty & Sons, New South Wales, 99-117.

[56] Gelbard, J.L. and Belnap, J. (2003) Roads as Conduits for Exotic Plant Invasions in a Semiarid Landscape. *Conservation Biology*, **17**, 420-432. http://dx.doi.org/10.1046/j.1523-1739.2003.01408.x

[57] Gregorcik, J. (1997) Máme se obávat suburbanizace našich velkých měst? *Územní plánování a urbanismus*, **24**, 39.

[58] Miko, L. and Hošek, M. (2009) Příroda a krajina České republiky: Zpráva o stavu 2009. Agentura ochrany přírody a krajiny ČR, Praha.

[59] Bičík, I., Jeleček, L. and Štěpánek, V. (2000) Land-Use Changes and Their Social Driving Forces in Czechia in the 19th and 20th Centuries. *Land Use Policy*, **18**, 65-73. http://dx.doi.org/10.1016/S0264-8377(00)00047-8