Evaluation of changes in the landscape management and its influence on animal migration in the vicinity of the D1 motorway in Central Bohemia

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ABSTRACT: The article summarizes changes detected in landscape structures and interrelated changes in landscape management surrounding a model section of the D1 motorway (11^{th}–29^{th} km). Biotopes' gradual development was determined based on historical aerial photographs from 1949, 1974, 1988 and 2007. Issues evaluated include especially direct occupation of biotopes and agricultural lands due to constructing industrial areas in the motorway's vicinity, changes in area dimensions of agricultural and forest land, construction of residential complexes and complementary infrastructure. Also investigated was how these transformations and other negative factors of the linear construction, particularly barriers along the motorway and traffic intensity, influence migration of large ungulates. The aerial photographs show significant decrease in polygons in the Crop fields category between 1949 and 2007. While in 1988 the area of Commercial zones in this territory was only 0.16%, in 2007 these already constituted 8.53% of the entire territory. Forested area increased slightly. Traffic intensity and barriers along the motorway were found to create sections through which large mammals have great difficulty passing.

Keywords*:* landscape; migration; wildlife; motorway

A basic feature of every landscape is its spatial heterogeneity expressed by the landscape structure. Landscape structure has a crucial influence on the functional properties of a landscape. Any changes in the landscape structure (in space and time) change the course of energy-material flows in the landscape, affect the permeability and habitability of the landscape, change its ecological stability as well as its other properties and characteristics (Lipský 2000).

Landscape fragmentation is a process by which, owing to the construction of roads and other infrastructure, the landscape is divided into smaller and smaller areas. These gradually lose their ability to perform their natural function as spaces for the existence of viable populations of animals and places where these populations are able to reproduce repeatedly. The phenomenon known as population fragmentation is thus becoming a serious and very complicated issue of environmental protection, and, in future, it can have catastrophic consequences for the structure of biocoenoses, biotopes and consequently entire ecosystems. Therefore, there is an effort to protect the integrity of valuable areas by means of various legislative instruments, not only at the national but currently at the European level (Hlaváč, Anděl 2001; Luell et al. 2003).

Fragmentation of natural wildlife habitats and of natural localities of ecosystems into ever smaller and isolated places is one of the greatest word threats to the environment as well as to biological diversity protection (Broker, Vastenhout 1995). This threat has been the main reason for initiating activity concerning this issue. A report known as COST 341 was established that presents informa-

Supported by the Grant Agency of the Czech University of Life Sciences Prague No. 43150/1313/3104.

tion about this activity and summarizes European reviews and recommendations. At an international level, the process of preventing landscape fragmentation is coordinated by the organization IENE (Infra Eco Network Europe).

Loss of biotopes due to construction of transport infrastructure is considered a major problem, especially at a local level. At regional and national levels, greater importance is attributed to other types of land use (particularly residential construction). Even in states with very dense transport networks (the Netherlands, Belgium and Germany) the total area occupied by infrastructure is estimated to be less than 5–7% (Trocme 2003). Impacts of fragmenting habitats and populations are most intensively manifested particularly in developed countries with high population density, dense transport infrastructure, and highly intensive agriculture. An increasingly important issue regarding environment protection is the growth in urbanization and infrastructure (Eetvelde, Antrop 2004). These forms of land use further fragment agriculture and forest land and increase its separation effect.

Lipský (2000) stated that overall changes in the landscape, and especially in the manner of land use, are most preferably monitored using a time series of aerial or satellite images. These can best show any disturbance of the landscape, devastation of specific areas, changes in the landscape structure, grain size, mosaic structure, changes in the landscape matrix, dynamics in the development of enclaves and other parameters of the landscape structure development. Methods of remote sensing (RS), however, can be applied also to monitor changes in individual components of the environment. Overall, it can be said that a landscape transformed by humans is considered to be less diverse and less coherent than the original landscape (Klijn, Vos 2000). Antrop (2000), Ihse (1996) and Wrbka (1998) monitored whether structural changes between an original and new landscape are recognizable and whether they are significant. It is unlikely that in future the diversity of landscape will increase (Meeus 1993). When looking at the accelerating biological and cultural degradation of landscapes, there is a need for better understanding of the mutual interaction between the landscape and the urbanization that transforms the landscape and is the basis for its sustainable management (Naveh 1993). Holistic dimension of the landscape, as well as landscape dynamics, can be easily studied using time series of aerial photographs, which provide more reliable results than do counting statistics (Ihse 1995; Lipský 1995; Dramstad et al. 1998). Using time series of historical maps and aerial photographs is common practice in historical geography, and here, they have proven to be very useful (Ihse 1996; Skånes, Bunce 1997; Vuorela 2000).

Stanfield et al. (2002) tested the spatial relationships between forest vegetation affected by water communities in the USA using a geographic information system (GIS) and regression analysis. Mutual influence between the environment and the spatial arrangement was also studied in a forested landscape in northern Wisconsin, USA (Crow et al. 1999). Alig et al. (2005) reported that the fragmentation of extensive forest vegetation in the USA is indicated to be the primary threat to biological diversity. A GIS analysis from a segmented wooded environment in the USA signals that this separation is a very negative process in the landscape, and especially in countries with high proportions of forest vegetation in their landscapes (Ritters et al. 2002). With more than 150 million acres of forest land in the USA, change in use is planned in the next 50 years due to infrastructure and urbanization (Alig, Plantinga 2004). Also wetlands and natural areas are likely to be transformed into agricultural land, especially in densely populated areas (Eetvelde, Antrop 2004). Sanchez et al. (2009) monitored the loss of space for wildlife and disturbance of localities near 13 large US cities. He used analyses from more than 13 billion square feet in the peripheral areas of cities, where new office space was established. Thus, he monitored the expansion of large cities in the USA.

Swenson et al. (2000), for example, dealt with the influence of roads on mortality of individual wildlife species. Furthermore, the impact of road construction on specific wildlife species was monitored in 2001 by Konôpka and Hell (2001) and Huber and Kusak (2006). Keller (2003) stated that transport primarily reduces natural environment that serves as a link between the localities on both sides of the road infrastructure and a great number of animals is killed in collisions with vehicles.

Publications of Clevenger and Waltho (2005), Rico et al. (2007), Saeki and Macdonald (2004), among others, monitor roads' impacts on wild mammals. The influence of specific roads, notably busy motorways and freeways, are addressed by Alexander and Wateers (2000), Mata et al. (2007); among others. Hell et al. (2005) found that most collision occurs on the roads in the Slovak part of Danube basin is general with deer (*Capreolus capreolus*), and more frequently in summer period than in winter. Biotope relationships and demands on the environmental character in migration of selected wildlife species with greater territorial claims have been described abroad (e.g. Swenson, Angestam 1993; Miquet 1994; Aberg et al. 2000), as well as in particular localities of the Czech Republic (e.g. Cerveny et al. 2007; Šustr, Jirsa 2007).

Methodology

Using GPS and a GIS application, the project involves mapping both the landscape permeability regarding migration and landscape structure changes in an area influenced by a linear construction in the form of a motorway. Remote sensing was used in selected surveyed areas to monitor quantification of the landscape macrostructure's evolution as affected by the construction and subsequent operation of the linear structure in the form of a motorway and by associated linear and polygon constructions. Aerial photographs were used to monitor changes in the landscape structures and various approaches to their management in the vicinity of the motorway. These images were compiled into a time series depicting development of the landscape's character, and then the impacts of these changes on migration and mortality of selected species of large mammals was evaluated. A section (11th–29th km) of the D1 motorway was monitored. The time series was compiled taking images from the years 1949, 1974, 1988 and 2007 and comparing them with one another. This section was chosen primarily because of its proximity to Prague and its associated strong anthropogenic pressure influencing the landscape structures in the vicinity of the linear construction in the form of a motorway, and especially due to the accompanying structures of linear or polygon character and having service functions.

The individual images were fixed into a system of coordinates. A line set on the layer modified in this manner designates the centre of the motorway within the investigated section. A buffer zone was created that takes in 200 m on each side from the centre of the motorway and which stipulates the extent of the polygon in the area of interest. In the polygon thus marked out, the individual biotopes were vectored (Fig. 4). Finally, their changes over time were compared. These changes were determined by cluster analysis (Fig. 2) and by measuring the variability of area changes (Fig. 3). All data were tested for normality, and, inasmuch as they did not fall into a normal distribution, nonparametric tests were used. To determine the dependence of traffic intensity on animal mortality, Kruskal-Wallis ANOVA was used.

Traffic intensity was divided into the following categories (for data processing nonparametric tests):

(A) 0–1,000 (vehicles/0.5 h),

(B) 1,001–2,000 (vehicles/0.5 h),

(C) ≥ 2,001 (vehicles/0.5 h).

The traffic intensity was set according to a manual approved by the Ministry of Transport – Determination of traffic volume roads in 2008. This methodology is not modified to monitor the traffic volume at night, therefore, measurements were made by direct counting of vehicles during 24 h (Figs. 5 and 6). The traffic intensity measuring was took place at 12 km of motorway D1 in date of 17th March, 14th April and 19th May during all day (24 h). Grand total of traffic intensity per day was counting like average amount from these three days and was 79,000 vehicles a day. All motor vehicles are included in one category.

The direct effect of traffic on wildlife migration (Fig. 5) was evaluated from the time gaps between the passing vehicles. The time gaps between vehicles were counted in these intervals (using coeffi-

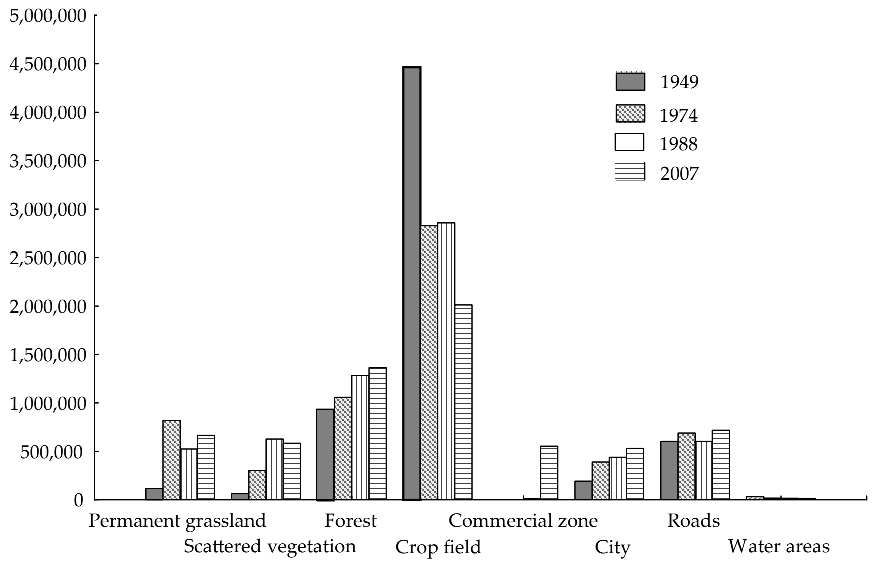

Fig. 1. Size of polygon areas (m^2) in monitored years 11–29 km section

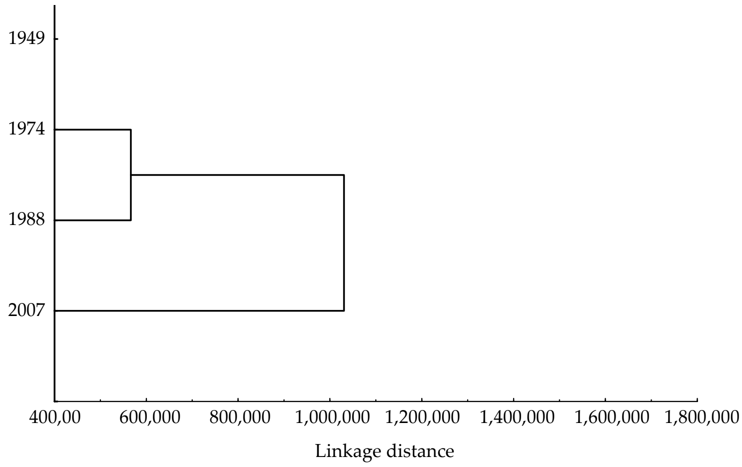

Fig. 2. Cluster analysis showing changes of polygons in the monitored years in a test section in 11th–29th km section

cients to evaluate the impact of traffic intensity on migration and mortality of animals):
(a) gaps of more than 10 s (coefficient 1);
(b) gaps of more than 15 s (coefficient 1.5);
(c) gaps of more than 20 s (coefficient 2);
(d) gaps of more than 25 s (coefficient 2.5).

The numbers of gaps in individual hours were counted – based upon the intervals – and each type (a, b, c, and d) was multiplied by the relevant coefficient. According to this sum, the overall possibility for animals to get across the road was evaluated. The interval was 0–1 where 0 is 0% and 1 is 100% possibility of crossing the motorway. These parameters were evaluated in accordance with Table 1.

Table 1. Probability of animals getting across the motorway, as influenced by traffic intensity

Interval	Resulting number of gaps	Permeability (%)
0.0	0–5	**> 5**
0.1	5–10	**> 10**
0.2	10–20	**> 20**
0.3	20–30	**> 30**
0.4	30–40	**> 40**
0.5	40–50	**> 50**
0.6	50–60	**> 60**
0.7	60–70	**> 70**
0.8	70–80	**> 80**
0.9	80–90	**> 90**
1.0	90–100	**> 100**

The resulting value of gaps is the sum of types a, b, c, and d and adjusted using individual coefficients.

Using GPS, barriers were located that effectively bar animals from crossing the road. This data was transferred using the GIS application into the current digital orthophotomap. For individual barriers, a value was established corresponding to the separation effect that each individual type has in the landscape. A detailed description of all individual anthropogenic barriers in the model sections was made, and these were classified according to type and were parameterized based on their spatial and technical characteristics. The aim was to obtain information on the migration of wildlife in relation to change in the landscape structure and to evaluate the influence of limiting barriers on the migration of large mammals.

Wildlife mortality was evaluated using the statistical chi-square test. Mortality of the animals was examined by combining several methods. Due to cooperation with the Directorate of Roads and Highways were data taken from their records, furthermore, carcasses of animals were recorded during walking in the area of interest and also were used data from the Police CR (Fig. 6). When the accidents is recorded by the Police listed the date, exact time, visibility and reasons of accidents. From these data (visibility and time) were set up graph (Fig. 7). These statistics do not distinguish different types of game, therefore deaths of different kinds of animals have been summarized into one category (mortality of animals on motorway D1).

Due to the fact that it is very difficult to obtain precise information on the number of animals living along this motorway, work deals only with the quantification of mortality and not its effect on population density and spatial dispersion of the game.

RESULTS

The time series show that in each year of the monitoring, polygons of the category crop fields were always largest in the area of interest (200 meters

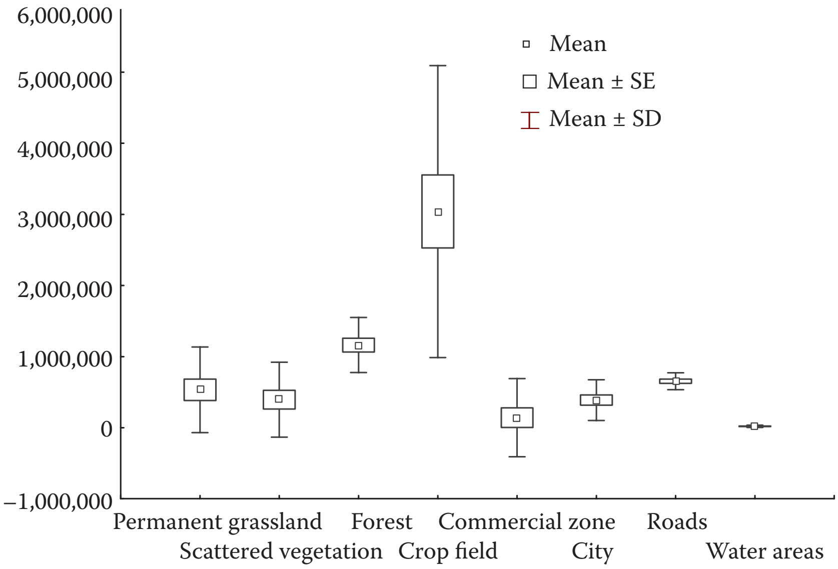

Fig. 3. Variability of changes in size of individual categories in model section of the D1

on both sides of the motorway's axis). In 1949, crop fields occupied 69.43%, and in 1974 it was 44.24% of the size of the area of interest. Commercial zone had only begun to appear there in 1988, when they accounted for 0.16% of the area. At the same time, the area of forest vegetation gradually grew. In 1949, forest comprised 14.72%, in 1974 it was already 16.53%, and in 1988 it was more than 20%. In 2007, crop fields polygons occupied only 31% of the area of interest. These still remained, however, the largest in size. The area of polygons for commercial zone, which already accounted for 8.53% of the area, increased. The area of forest complex increased to 21% in that year.

The bar chart describes the dynamics for the development of individual polygons in the monitored area. It evidences a gradual decrease in the size of crop fields and simultaneous increase in forest polygons and commercial zone.

The figure above shows that the greatest differences between individual polygons are between the

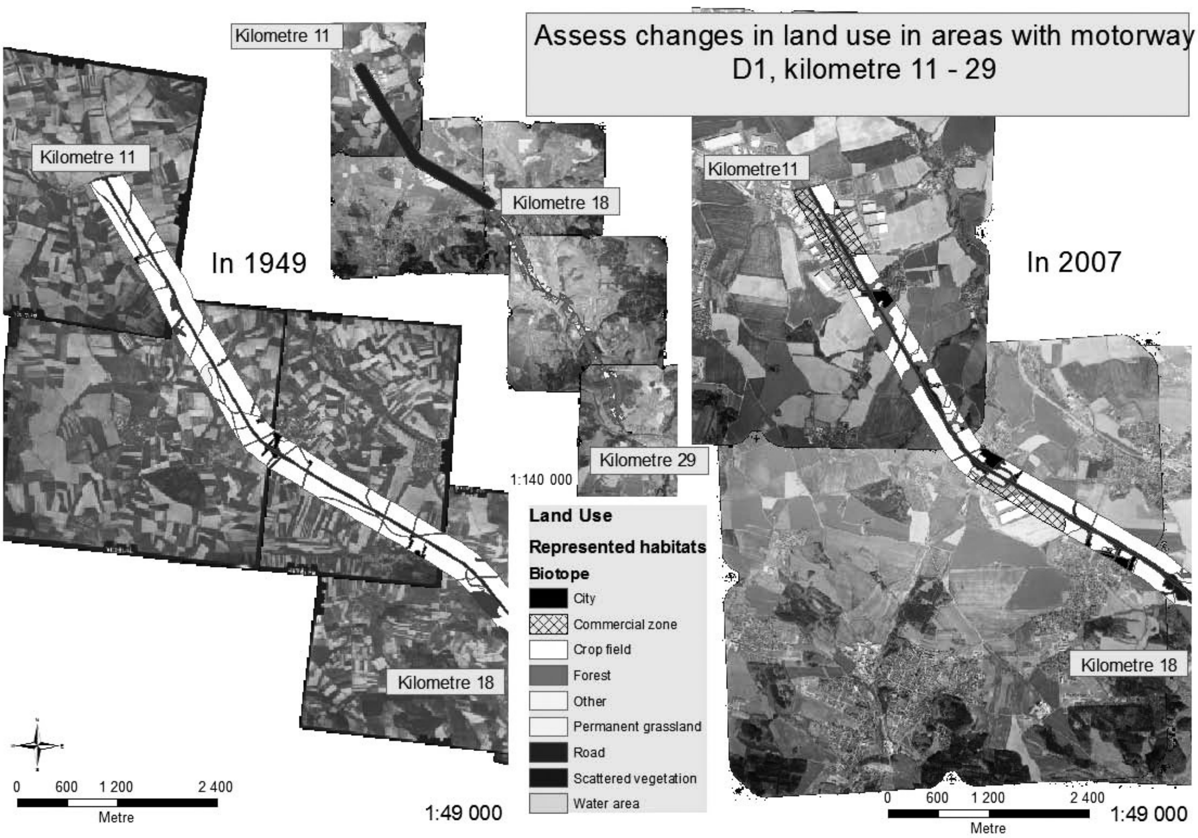

Fig. 4. Graphic output from the GIS application – comparison of the 11th–18th km of D1 (1949 and 2007)

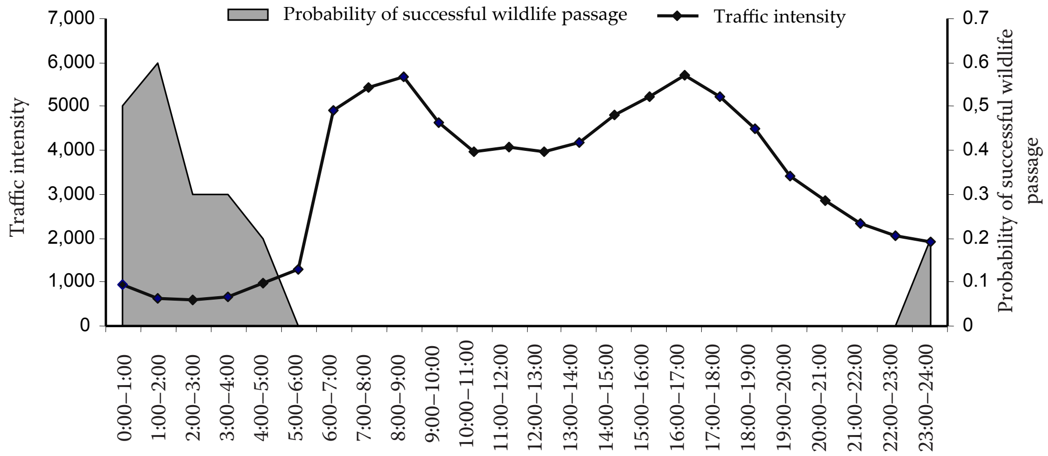

Fig. 5. Probability of successful wildlife passage and traffic intensity in a model area on D1 motorway

years 1943 and 2007. At the same time, it shows that in 1974 and 1988, the areas of individual polygons did not change much.

Fig. 3 shows the degree of variability of changes in the size of individual categories. The biggest change in size was observed for crop fields. Other types of polygons appear relatively stable.

Multivariate regression did not demonstrate that reducing the impact of crop field size has a significant influence on the change in any other type of polygon.

When the probability is greatest for wildlife to successfully cross the motorway was determined using time gaps existing between passing vehicles. Frequent long intervals between vehicles were recorded only at night. In accordance with these time gaps, it has been calculated that animals are most likely to cross the motorway successfully between 0:00 and 4:00 a.m.

Fig. 6 compares traffic intensity and wildlife mortality on the D1 motorway. It shows that collisions between vehicles and wildlife occur mainly at night, although the probability of its successful crossing is highest during these hours. Collisions recorded during the day occurred mostly in winter, when the daylight hours are substantially shorter.

The nonparametric chi-square test (comparison of observed vs. expected frequency of monitoring) with the result of $X^2 = 100.4627$ (df = 3, $P = 0.00000$) shows that animal-vehicle collisions on the D1 motorway did not occur during the day with the same regularity. The vast majority of animal-vehicle collisions happened at night, or in poor visibility at dawn or sunset. Only 13% of traffic accidents occurred in daylight.

According to the Kruskal-Wallis ANOVA – H [(2, N = 48) = 8.0606 $P = 0.0178$], there was a statistically significant finding that in the individual traffic intensities (A) 0–1,000 (vehicles/0.5 h), (B) 1,001–2,000 (v/0.5 h), (C) ≥ 2,001 (v/0.5 h) collisions with wildlife also are not regular. The same conclusion was

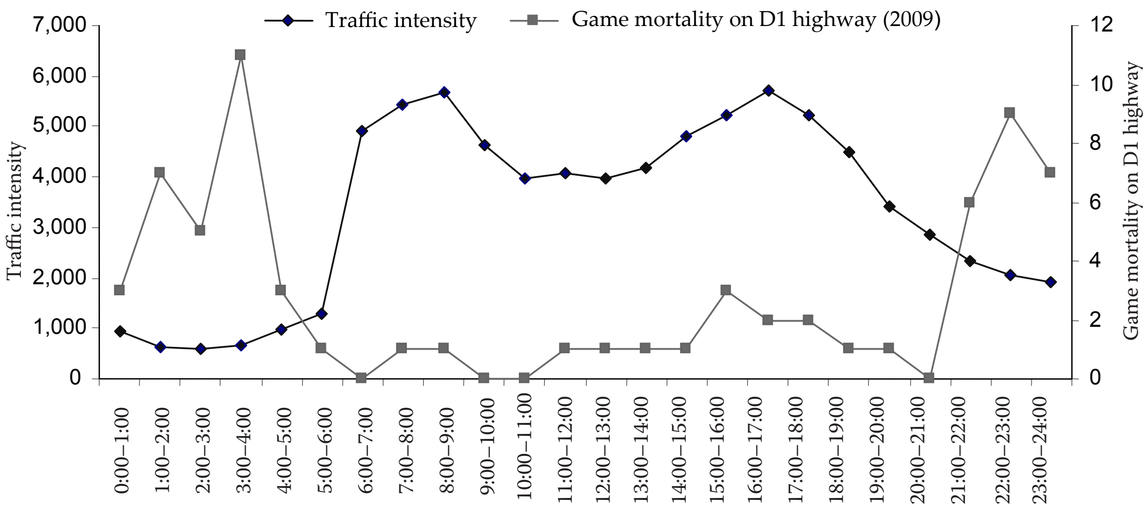

Fig. 6. Wildlife mortality and traffic intensity in a model area on D1

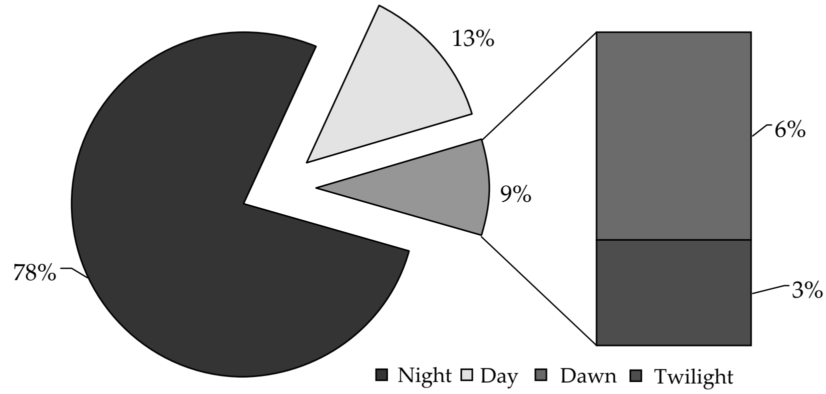

Fig. 7. Game mortality on the D1 motorway

reached even using the nonparametric chi-square test (X^2 = 12.16403, df = 2, P = 0.0023). According to the Kruskal-Wallis test, a statistically significant difference was demonstrated between intensity types A and C (P = 0.0207).

The survey found that the most common barrier along the motorway is a concrete panel (31% barrier effect), which is a significant barrier to animal migration. Freely accessible sections have such barriers on 27% of their length, but often only on one side. This is more dangerous from the perspective of animal migration than a fully fenced motorway. Animals may enter a motorway that cannot be crossed. These situations often end with the death of an animal inasmuch as it begins to behave erratically and is unable to return to safety at the edge of the motorway. The monitored section of motorway is less than 1% fenced and less than 5% enclosed by noise barrier walls.

CONCLUSION AND DISCUSSION

Negative effects of linear constructions include direct occupation of biotopes, recolonization of the landscape in the construction of roads, environmental contamination, and widely various types of interference (noise, etc.). Therefore, the indirect effects of motorway construction, such as increasing civilization pressure and complementary construction along the roads of linear or polygon character is also important.

The research clearly shows that the landscape along the D1 motorway has changed dynamically. Polygons in the crop fields category have decreased significantly (field comprised 69.43% in 1949 and in 2007 it was only 31% of the size of the area of interest). The area covered by commercial zone increased notably after 1989. Their construction markedly affects wildlife populations, primarily through direct occupation of biotopes. Gradual increase in acreage of forest vegetation in the surroundings of the D1 motorway was found. Forests accounted for 14.72% of the area of interest in 1949, and in 2007 that was already 21%. The biggest change of variability in the size of category land use for the individual time period were found in the category of land use "field", however, multivariate regression demonstrated that a reduction in the size of category "field" has not a significant effect at change in other categories of land use. The traffic intensity and barriers along the motorway create sections that are very difficult for large mammals to cross. The most common barrier along the D1 motorway in the area of interest is comprised of concrete panels. Simple crash barriers (13% of barriers) do not themselves constitute a major barrier for animals, but, in combination with noise and lighting effects, they may discourage wildlife migration, especially if those barriers are doubled and hedged. Barriers that absolutely prevent wildlife migration enclose 6% (fences and noise barrier walls).

Kruskal-Wallis ANOVA showed a statistically significant difference in the number of accidents with game in the different level of intensity of traffic. The greatest traffic intensity was recorded in the monitored section of the D1 motorway between 4:00 and 5:00 p.m. (5,728 vehicles). A similar value (5,669 vehicles) was measured in the same section between 8:00 and 9:00 a.m. The greatest likelihood for successful crossing of the motorway, which was determined by time gaps between passing vehicles, was between 1:00 and 2:00 a.m. (0.6). In daylight hours, because of high traffic volumes, there is virtually zero chance for an animal to cross the motorway successfully. Overall, it had been assumed that the highest probability for the animals to cross the motorway successfully is at night. The research shows, however, that the highest number of animal-vehicle collisions occurs during these hours. At high traffic intensities during the day, the wildlife do not dare to cross the motorway. They attempt to do so only in their night migrations, at which time collisions often occur even though the traffic intensity is considerably lower. During daylight hours the game tries to overcome the motorway only exceptionally, for example in case when is escaping from danger. The overall probability of successful overcome of motorway by wildlife depends on several factors, primarily on traffic intensity and kinds of barriers along the motorway. The nonparametric chi-square test shows, that accidents with game do not happen periodically during the day.

An important question is what proportion of the population is actually affected by road mortality. The published data vary considerably by individual research site. For instance, Luell et al. (2003) and Trocme (2003) state that traffic kills about 5% of the population of common species (red fox, roe deer and wild boar). Swiss research (Righetti et al. 2003) focused on the death of roe deer and red deer (data from 1999) describes traffic mortality as clearly the most common cause of death in both species (roe deer 49.3% and red deer 33.2%). It is probably always necessary to consider the specific situation in a given territory. Müller and Berthould (1997) state that both deer and wild boar greatly dislike crossing over the central crash barrier. Roe deer, wild boar and European deer clearly preferred two-lane sections for crossing the road. The statistical data processing method using general linear models, however, did not conclusively prove an influence of road width on the number of road crossings.

Lipský (2000) stated that a basic feature of every landscape is its spatial heterogeneity expressed by the landscape structure. The landscape structure has a crucial influence on its functional properties. Any changes in a landscape structure (in space and time) change the course energy-material flows in the landscape, affect the permeability and habitability of the landscape, change its ecological stability as well as its other properties and characteristics.

References

Aberg J., Swenson J.E., Andren H. (2000): The dynamics of hazel grouse (*Bonasa bonasia*) occurrence in habitat fragments. Canadian Journal of Zoology, ***78***: 352–358.

Alexander S.M., Waters N.M. (2000): The effects of highway transportation corridors on wildlife: a case study of Banff National Park. Transportation Research Part C: Emerging Technologies, ***8***: 307–320.

Alig R.J., Plantinga A. (2004): Future forest land area: impacts from population growth and other factors that affect land values. Journal of Forestry, ***102***: 19–24.

Alig R.J., Lewis D. J., Swenson J. J. (2005): Is forest fragmentation driven by the spatial configuration of land quality? Forest Ecology and Management, ***9381***: 1–9.

Antrop M. (2000): Changing patterns in the urbanized countryside of Western Europe. Landscape Ecology, ***15***: 257–270.

Broker H., Vastenhout M. (1995): Nature across motorways. Ministry of Transport, Delft, Public Works and Water Management: 103.

Clevenger A.P., Waltho N. (2005): Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. Biological Conservation, ***121***: 453–464.

Crow T.R., Host G.H., Mladenoff D.J. (1999): Ownership and ecosystem as sources of spatial heterogeneity in a forested landscape, Wisconsin, USA. Landscape Ecology, ***14***: 449–463.

Cerveny J., Bufka L., Suk M., Sustr P., Belková M. (2007): Spatial activity of the roe deer (*Capreolus capreolus*) in the Bohemian Forest. Zoologické dny Brno 2007. In: Bryja J., Zukal J. (eds): Sborník abstraktů z konference: 161. (in Czech)

Dramstad W.E., Fjellstad W.J., Fry G.L.A. (1998): Landscape indices – useful tools or misleading numbers? In: Dover J.W., Bunce R.G.H. (eds): Key Concepts in Landscape Ecology, Proceedings of the 1998 European Congress of IALE, 3rd–5th September 1998, Myerscough College, UK: 63–68.

Eetvelde V.V., Antrop M. (2004): Analyzing structural and functional changes of traditional landscapes – two examples from Southern France. Landscape and Urban Planning, ***67***: 79–95.

Hell P., Plavý R., Slamečka J., Gašparík J. (2005): Losses of mammals (*Mammalia*) and birds (*Aves*) on roads in the Slovak part of the Danube Basin. European Journal of Wildlife Research, ***51***: 35–40.

Hlaváč V., Anděl P. (2001): Methodological manual to providing continuity trespassing of motorways for wildlife. Praha, AOPK ČR: 51. (in Czech)

Huber D., Kusak J. (2006): Green bridges and other mitigation structures on highways in Croatia for large carnivores. In: 1st European Conference in Conservation Biology, 22–26 August 2006 Eger, Hungary. Book of Abstracts: 37.

Ihse M. (1995): Swedish agricultural landscapes – patterns and changes during the last 50 years, studied by aerial photos. Landscape Urban Planning, ***31***: 21–37.

Ihse M. (1996): Monitoring cultural landscapes in Sweden – methods and data of landscape change. In: Jongman R.H.G. (ed.): Proceedings of the First ECNC Seminar on Land Use Change and its Ecological Consequences, Ecological and Landscape Consequences of Land Use Change in Europe, Vol. 2, 16–18 February 1995. ECNC Publication Series on Man and Nature, Tilburg: 103–129.

Keller V. (2003): Fauna passages and other things: an overview of measures to mitigate habitat fragmentation by transport infrastructure. Habitat fragmentation due to transportation Infrastructure – IENE: 53–54.

Klijn J., Vos W. (2000): From Landscape Ecology to Landscape Science. Wageningen, Kluwer Academic Publishers: 162.

Konôpka J., Hell P. (2001): Impact monitoring of highways construction on wildlife. Folia Venatoria, ***30–31***: 159–171. (in Czech)

Lipský Z. (1995): The changing face of the Czech rural landscape. Landscape Urban Planning, ***31***: 39–45.

Lipský Z. (2000): Monitoring changes in the cultural landscape. Praha, ČZU Praha: 71. (in Czech)

Luell B., Bekker G.J., Cuperus R., Dufek J., Fry G., Hicks C., Hlavac V., Keller V., Rosell C., Sangwine L., Torslov N., Wandall B. (2003): Wildlife and Traffic: A European Handbook for ldentifying Conflicts and Designing Solutions. Brusel, KNNV Publisher: 172.

Mata C., Hervas I., Herranz J., Suarez F., Malo J.E. (2007): Are highway wildlife passages worth building? Vertebrate use of road-crossing structures on a Spanish highway. Journal of Environmental Management, ***88***: 407–415.

Meeus J.H.A. (1993): The transformation of agricultural landscapes in Western Europe. The Science of the Total Environment, ***129***: 171–190.

Miquet A. (1994): Effects of summer human disturbance on carrying capacity for Black Grouse in an alpine touristic area. Atti del 6° Convegno Italiáni di Ornitologia. Museo Regionale di Scienze Naturali, Torino, 315–324.

Müller S., Berthould G. (1997): Fauna/Traffic safety. Manual for Civil Engineers, Lausanne, LAVOC – EPFL: 119.

Naveh Z. (1993): Interactions of landscapes and cultures. Landscape and Urban Planning, ***32***: 43–54.

Rico A., Kindlmann P., Sedlacek F. (2007): Barrier effects of roads on movements of small mammals. Folia Zoologica, ***56***: 1–12.

Rigehetti A., Malli H., Berthold G., Georgii B., Leuzinger E., Schlup B. (2003): Effect of unfenced (high-speed)-railway lines on wildlife. IENE: 23–24.

Ritters K.H., Wickham J.D., O'Neill R.V., Jones K.B., Smith E.R., Coulston J.W., Wade T.G., Smith J.H. (2002): Fragmentation of continental United States forests. Ecosystems, ***5***: 815– 822.

SaekiM., Macdonald D.W. (2004): The effects of traffic on the raccoon dog (*Nyctereutes procyonoides viverrinus*) and other mammals in Japan. Biological Conservation, ***118***: 559–571.

Sanchez T.W., Oner A.C., Lang R.E. (2009): Betone edge city: office geography in the new metropolis. Urban Geography, ***30***: 726–755.

Skånes H.M., Bunce R.G.H. (1997): Directions of landscape change (1741–1993) in Virestad, Sweden – characterised by multivariate analyses. Landscape Urban Planning, ***38***: 61–75.

Stanfield J.B, Bliis J.C., Spies T.A. (2002): Land ownership and landscape structure: a spatial analysis of sixty-six Oregon (USA) Coast Range watersheds. Landscape Ecology, ***17***: 685–697.

Swenson J.E., Angelstam P. (1993): Habitat separation by sympatric forest grouse in Fennoscandia in relation to boreal forest succession. Canadian Journal of Zoology, ***71***: 1303–1310.

Swenson J.E., Gerstl N., Dahle B., Zedrosser A. (2000): Action plan for the conservation of the brown bear in Europe (*Ursus arctos*). Nature and Environment, No. 114. Strassbourg, Council of Europe Publishing: 69.

Šustr P., Jirsa A. (2007): Spatial activity and use of the environment by red deer (*Cervus elaphus*) in the Bohemian Forest. In: Bryja J., Zukal J. (eds): Zoologické dny Brno, Sborník abstraktů z konference: 201–202. (in Czech)

Trocme M. (2003): Habitat Fragmentation due to Transportation lnfrastructure — The European Review. European Commission, Directorate – General for Research, Luxembourg: 8–9.

Vuorela N. (2000): Can data combination help to explain the existence of diverse landscapes? Fenina, ***178***: 55–80.

Wrbka T. (1998): Landscape structure as indicators for sustainable land use? A case study in alpine and lowland landscapes of Austria. In: Dover J.W., Bunce R.G.H. (eds): Key Concepts in Landscape Ecology, Proceedings of the 1998 European Congress of IALE, 3rd–5th September 1998, Myerscough College, UK: 177–180.

Received for publication September 23, 2010
Accepted after corrections March 30, 2011

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