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The effects of landscape structure and road topography on mortality of mammals: A case study of two different road types in Central Slovakia

Vplyv štruktúry krajiny a topografie cesty na mortalitu cicavcov: prípadová štúdia z dvoch typov ciest na strednom Slovensku

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Abstract. The magnitude, composition, temporal and spatial patterns of mammal road mortality were assessed along some sections of two different road types (I/51 and R1) connecting the towns of Banská Bystrica, Zvolen and Banská Štiavnica (Central Slovakia). Road kills were surveyed using a car, three or four times per week from March 2008 to December 2012. We conducted 440 surveys, traveling a total of 39,700 km, and recorded 5,416 road mortality events (120 kills per km on average). Mammals were represented by 693 individuals (12.8% of the total number of carcasses) identified into 20 species and categories, respectively. The most frequently identified species were fox, hedgehog and domestic cat, a substantial part fell into the category of small mammals, as they could not be mostly identified to a genus. We found significant temporal and spatial differences in the magnitude of road-kills and identified several road segments as mortality hotspots both for all observations and for each season. Using logistic models we found significant relationships between the number and composition of the mammal casualties and higher proportion of arable land, built-up areas and roads in the landscape bordering the roads. Road topography was found to be among the important variables in explaining road-kills as carnivores were most susceptible to be killed on the raised segments and insectivores and herbivore mammals on the raised or buried segments of the roads. Construction of the fence along the R1 expressway in 2010 was related to significant decrease in road-kills, however, significantly higher mortality level was recorded at the segments with the underpass where streams with line riparian vegetation are crossed by the road. This effect was not identified at segments with expressway feeders. This finding suggests that the line vegetation continues to serve as migration corridor and leads animals to the R1 road where they find defects in fencing and try to cross through them and enter the road.

Key words. Traffic, wildlife-vehicle collisions, road characteristics, mortality hotspots.

INTRODUCTION

In the connection with increasing demands for a passenger and material transportation in the last decades, roads and road networks expanded substantially across Europe. Roads in many countries now constitute the most important barriers to the movement of wildlife. Therefore, the conflicts between transportation and wildlife are continuously growing. Wildlife-related accidents are the most visible effect of collisions between motorised vehicles and wild animals resulting often in human injury, economic losses, and in high rates of mortality for many animal species. Data related to the numbers of animal casualties on the European and North American roads are alarming (e.g. Bisonette 2002, Seiler et al. 2004, Glista et al. 2008, Cserkész et al. 2013).

Mortality of individuals caused by collisions with vehicles is one of the most obvious impact of roads, often directly affecting population characteristics, i.e. abundance, sex structure (e.g. Huijser & Bergers 2000, Gibbs & Steen 2005), and species composition and community diversity (Forman et al. 2003). However, ecological effects of roads are much more diverse ranging from habitat loss, altering their structure and loss of habitat connectivity, the formation of barriers to animal dispersal and gene flow, to introducing pollutants, and increasing susceptibility to alien species invasion (Forman & Alexander 1998, Trombulak & Frissell 2000, Ament et al. 2014).

The studies of road fatalities have remained an important basis for determination of the location of road kill aggregations and identification of natural corridors functioning as traditional migration routes. Consequently, the results may help to reduce collision rates and road impact upon wildlife (e.g. Saeki & Macdonald 2004, Seiler 2005, Conard & Gipson 2006). Local evaluations of road-kills may be important before adoption of general recommendations for mitigative structures to increase permeability of roads (Coelho et al. 2008).

Compared to the West-European countries where passenger transportation, number of vehicles and length of the road network have grown substantially since 1970 (Banister et al. 2000), in Slovakia the traffic and vehicle speeds have increased and infrastructure networks expanded since the beginning of the 1990s. The process has accelerated after the accession to the European Union whereby new roads and motorways have been built or reconstructed. As a result, the traffic flow on the Slovak roads, especially on highways and expressways, has increased with about 123% while their length has increased by 1.5–9 times, respectively since 2000 to 2012 (Masárová & Šedivá 2013).

Investigations of traffic accidents related to wild animals have a relatively long tradition when the first data were collected already at the end of the 19th century (see e.g. Gryz & Krauze 2008 for review). In Slovakia, relatively small number of studies has been published on the topic (as reviewed by Hell et al. 2004). The ongoing surveys are focusing on the identification of migration corridors for large carnivores and ungulates as they are sensitive to habitat fragmentation and destruction in connection with rapid development of main roads (Finďo et al. 2007). However, little is known about the impacts of the lower category roads running across mountainous areas.

In the light of this, the main goals of our study were to assess the magnitude, composition and spatial patterns of mammal road mortality along the sections of two different road types in the southern part of Central Slovakia. Although interconnected, the roads differ in traffic volume and structure of the surrounding landscapes. Our study aimed at the identification of the role of habitat structure along the road in the distribution of the fatality hotspots as a basis for further investigations and mitigation planning. Because the fencing of one of the roads was finished during the survey, we also assessed the fence impact on the road kill patterns.

MATERIAL AND METHODS

Study area

The study area comprises the parts of three districts (Banská Bystrica, Zvolen and Banská Štiavnica) that are located in the southwest part of the Banská Bystrica Province in Central Slovakia.

The surveyed road sections were as follows (Fig. 1):

(1) The R1 road, 26 km long section. The road is an expressway with two lanes in each direction separated by a median. The section starts in a south part of Banská Bystrica town (48° 44’ 24” N, 19° 08’ 07” E) and ends at the turn to Hronská Dúbrava village (48° 33’ 50” N, 19° 00’ 43” E). The posted speed limit is 130 km/h and is restricted to 100 or 110 km/h in certain sections. The average traffic volume at this section was 20.582 (from 11.781 to 28.366) vehicles per day. The fencing over the whole surveyed road section was finished at the end of 2010 with a 180 cm high wire mesh (15×15 cm). Located in a broad valley at altitude from ca. 370 to 270 m a. s. l., the road crosses smooth and moderately undulating landscape, respectively. The immediate road vicinity is composed of a mosaic of cultivated land used mostly for agriculture, grasslands and built-up areas. In southern part only, the road section (about 3 km) runs around hills with deciduous forests.

(2) The national I/51 road, 19 km long section. It starts near the turn of the R1 road in the Hron river valley (48° 33’ 45” N, 19° 00’ 33” E) and ends in Banská Štiavnica town (48° 27’ 32” N, 18° 53’ 59” E). Winding (sinuous) section runs through the narrow valley at altitude from ca. 270 to 600 m a. s. l. The immediate road vicinity is composed mostly of deciduous forests, riparian vegetation and meadows. Due to the relatively low human population density the built-up and agriculture areas create the smaller proportion of the landscape mosaic. This section of the road has a moderate traffic intensity 3.080 (from 2.512 to 3.802) vehicles per day.

The data about level of traffic volume were obtained from the Slovak Road Administration which collected them within the international program “Combined census of motor traffic and inventory of standards and parameters on main international traffic arteries in Europe in 2010”.

Data collection

Mammal road kills were surveyed by car, travelling at an average speed of 50–80 km/h (at I/51) and 90–110 km/h (at R1) three to four times per week from 1 March 2008 to 28 December 2012. The counts were made twice per day: between 6:00 and 7:00 A.M. (the direction from Banská Štiavnica to Banská Bystrica) and between 17.00 and 18.00 P.M. (the direction from Banská Bystrica to Banská Štiavnica).

All carcasses found between the outer shoulders of the roads were recorded. Whenever possible, the road traffic victims were identified to species level. If the corpse disintegration made species identification impossible, or the observer could not reduce a speed, even stop (especially on the R1 road), they were pooled into higher taxa or a group, e.g. small mammals.

Data analysis

For analytical purposes and to avoid a large number of zeros and to eliminate the infrequent occurrence data in the final matrix, road casualties were aggregated into four groups: small carnivores (mustellids and fox), hedgehog, small mammals (rodents and insectivores), and domestic mammals (cats and dogs). Squirrel, hare and ungulates were excluded from statistics due to low number of carcasses recorded (25, 16 and 20 specimens, respectively). Data collected in the winter months (December to February) were excluded from further comparative analyses because of decreased detection possibilities under bad light conditions and snow removal from roads.

We used the orthophoto maps from www.maps.google.com.and the GIS program ArcGis 10.1 to obtain the spatial extent and location of a landscape patches.

For an analysis, the studied roads were divided into 45 segments, each 1000 m long. A buffer 500 m wide was created on both sides of each segment, and we obtained a total of 45 rectangular polygons (≈100 ha). For the reasons to choose 500 m buffers see Carvalho & Mira (2009).

To describe site-specific attributes of each polygon we chose two groups of explanatory variables for describing each road-kill segment: landscape-level variables and road-related variables (see Table 1 for more details).

The contingency tables and chi-square tests were used to test the differences in magnitude and composition of the road-kills between the I/51 and R1 roads. The same tests were also used for evaluation of fencing impact, presence of line vegetation crossed by R1, presence of expressway feeders and roadside topography. The landscape-level variables were evaluated with the cumulative logistic probability plot and ROC curves. All analyses were carried out with PASW Statistics 18 software (SPSS 2009).

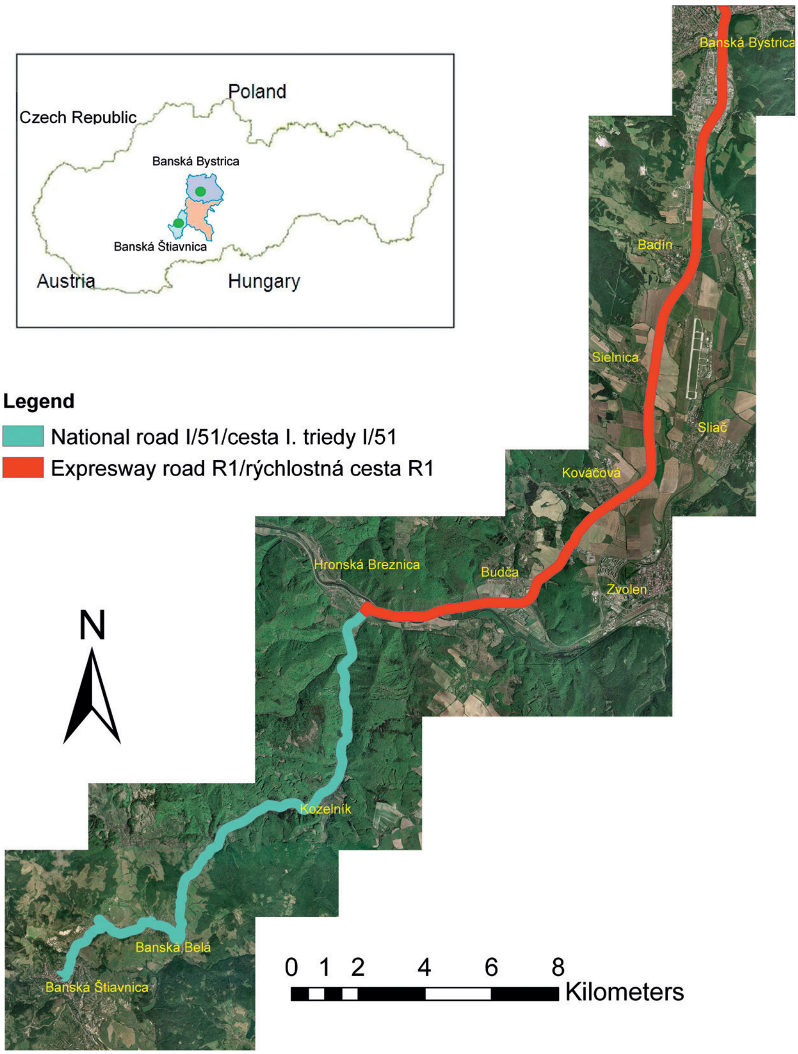

Fig. 1. Location of the studied area in Central Slovakia and segments of the R1 and I/51 roads investigated for road-kills of mammals in 2008–2012.
Obr. 1. Poloha skúmanej oblasti v rámci stredného Slovenska a úseky ciest R1 a I/51, na ktorých bola sledovaná mortalita cicavcov v rokoch 2008–2012.

Table 1. Description of variables used in the analysis of factors explaining road-kill occurrence of mammals (for details on roadside topography see Clevenger et al. 2003)
Tab. 1. Opis premenných použitých pre analýzu faktorov vysvetľujúcich mortalitu stavovcov na sledovaných cestách (viac detailov k jednotlivým kategóriam topografie cesty uvádzajů Clevenger et al. 2003)

variable name premenná	definition definícia	source of data zdroj údajov
landscape-level variables	the variable area (in m^2) on each road segment: (1) forests, (2) discontinuous tree and shrub vegetation, (3) agricultural arable land, (4) grasslands, (5) built-up areas, (6) waters, (7) roads	orthophoto maps, GIS
premenné súvisiace s krajinou	plocha (m^2) premennej v jednotlivých cestných segmentoch: (1) les, (2) rozptýlená zeleň, (3) poľnohospodárska pôda, (4) pasienky a lúky, (5) zastavaná plocha, (6) vodné plochy, (7) cesty	ortofoto mapy, GIS
road-related variables premenné súvisiace s cestou	roadside topography / topografia cesty: buried (A) / zaklesnutá raised (B) / vyvýšená buried-long raised (C1) / zaklesnutá-vyvýšená buried-raised (C2) / zaklesnutá-vyvýšená partly raised (D)/ čiastočne vyvýšená	field observation terénne pozorovania
	presence/ absence of tree and shrub line vegetation crossed by R1 road prítomnosť / neprítomnosť líniovej vegetácie prerušenej cestou R1	map mapa
	presence / absence of access roads prítomnosť/ neprítomnosť prístupových ciest	map mapa
	absence / presence of fencing along R1 road prítomnosť / neprítomnosť oplotenia na R1	field observation terénne pozorovania

RESULTS

Taxonomic composition and spatial distribution

We conducted 440 surveys, traveling a total of 39,700 km, and recorded 5,417 vertebrate road mortality events; 686 carcasses of them were registered on the R1 road and 4,731 ones on the I/51 road, for an average of 120 kills per km surveyed across both surveyed routes per whole surveyed period.

Of the total number of carcasses, 693 (12.8%) were mammals belonging to 20 taxa (Table 2). The most frequently identified species were *Felis catus* (n=124), *Vulpes vulpes* (n=107) and *Erinaceus roumanicus* (n=105). A substantial part of the mammals fell into the category of small mammals, i.e. shrews and rodents (n=194) as they could not be mostly identified to genus.

Road-kills of mammals among the studied roads were significantly different ($p<0.01$), being higher for the R1 road (394 individuals, 62.3%) than for the I/51 road (238 specimens, 37.7%), while the mean numbers of victims per kilometer were 15 and 12, respectively. The mean value of road-kill index for both roads and the whole surveyed period was 15.4 victims per kilometer.

Small carnivores accounted for about 37% of the total number of road-kills on the R1 road followed by domestic mammals (27%), small mammals (18%) and hedgehog (17%). Among the victims observed on the I/51 road small mammals represented nearly 52% of the total road mortality, followed by carnivores, hedgehog and domestic mammals that accounted for 17%, 16% and 15%, respectively.

Road-kill events showed visible non-random spatial distribution on both roads and we identified several segments as mortality hotspots. Regarding the I/51 road, the highest mean annual mortality was recorded at the segment I/51-G, and the segments I/51-B, I/51-L, and I/51-Q were different by higher mortality from the others (Fig. 2). Concerning the R1 road, the highest number of casualties was recorded at the segment R1-I. The segments R1-M, R1-E and R1-S can be considered as other mortality hotspots along the road (Fig. 3).

Factors affecting road mortality

Logistic regression was used for evaluation of the landscape-level variables. All seven logistic models were statistically significant ($p<0.0001$) (Table 3).

Forest areas correlated significantly positively with road-kills of small mammals that were considerably more likely to be killed with the increase of forested areas. The mortality of domestic mammals was decreasing, small carnivores and hedgehog were not significantly affected by the area of forests. Domestic mammals were more likely to be killed with the increase of discontinuous tree and shrub vegetation while probability of mortality in small carnivores and small mammals declined with it. Hedgehog was not significantly affected by the area of discontinuous tree and shrub vegetation. The increase of the share of built-up areas was significantly positively correlated with road-kills probability of domestic mammals. Conversely, the probability of mortality of small mammals declined. Small carnivores and hedgehog were not significantly affected by built-up areas. While probability of small mammal killings declined

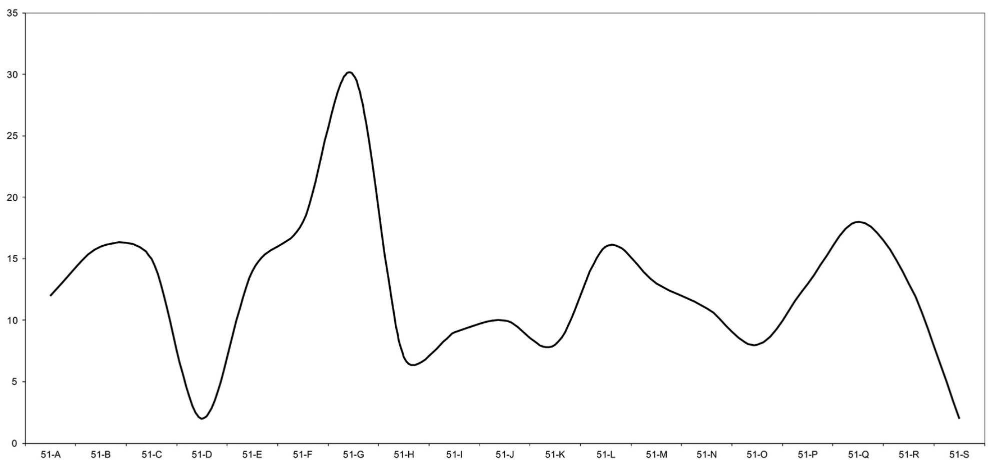

Fig. 2. Numbers of mammal road-kills in segments of the I/51 road in 2008–2012.
Obr. 2. Počty zaznamenaných úhynov cicavcov na jednotlivých úsekoch cesty I/51 v rokoch 2008–2012.

Table 2. Abundance of mammals killed on roads R1 and I/51 in 2008–2012
Tab. 2. Počty zaznamenaných mŕtvych cicavcov na cestách R1 a I/51 v rokoch 2008–2012

years / roky species, groups / druhy, skupiny	2008	2009	2010	2011	2012	2008	2009	2010	2011	2012	total spolu
hedgehog / jež											105
Erinaceus roumanicus Barrett-Hamilton, 1900	21	18	18	5	5	6	6	7	10	9	105
carnivores / šelmotvaré											187
Vulpes vulpes (Linnaeus, 1758)	20	17	12	15	18	5	7	4	2	7	107
Martes foina (Erxleben, 1777)	15	9	9	10	12	1	3	5	3	1	68
Mustela nivalis / M. erminea Linnaeus, 1758	0	0	1	0	1	0	0	0	0	1	3
Mustela putorius (Linnaeus, 1758)	0	0	1	0	1	0	0	0	0	0	2
Meles meles (Linnaeus, 1758)	0	0	3	2	0	0	0	0	0	0	5
Lutra lutra (Linnaeus, 1758)	0	0	0	0	1	0	1	0	0	0	2
Felis silvestris (Schreber, 1777)	0	0	0	0	0	0	0	0	1	0	1
domestic animals / domáce zvieratá											146
Felis catus Linnaeus, 1758	10	14	16	31	19	6	6	5	10	6	124
Canis familiaris Linnaeus, 1758	7	8	2	1	2	0	0	0	1	1	22
ungulates / kopytníky											20
Sus scrofa Linnaeus, 1758	1	0	0	0	1	0	0	0	0	0	2
Cervus elaphus Linnaeus, 1758	1	0	0	0	0	0	0	0	0	0	1
Capreolus capreolus (Linnaeus, 1758)	3	2	2	1	2	0	1	1	3	2	17
small mammals / malé cicavce											235
unidentified rodents & insectivores / neurčené	18	11	8	13	8	9	12	21	50	26	176
Cricetus cricetus (Linnaeus, 1758)	0	0	1	1	1	0	0	0	0	0	3
Rattus norvegicus (Berkenhout, 1769)	0	4	3	3	0	0	1	4	0	0	15
Sciurus vulgaris Linnaeus, 1758	1	1	0	1	0	3	7	1	5	6	25
Lepus europaeus Pallas, 1778	4	3	3	4	2	0	0	0	0	0	16
total / spolu	101	87	79	87	73	30	44	48	85	59	693

Table 3. Effect of landscape structure in the surveyed road vicinity on mammal mortality. With increasing of the area of landscape variable a probability of mortality: ↑ = increases, ↓ = declines, ↔ without effect
Tab. 3. Vplyv štruktúry krajiny v okolí sledovaných ciest na mortalitu cicavcov. S narastajúcou rozlohou krajinnej premennej sa pravdepodobnosť mortality: ↑ = zvyšuje, ↓ = znižuje; ↔ bez vplyvu

krajinná premenná / landscape variable	forest les	scattered vegetation rozptýlená zeleň	built-up area zastavaná plocha	water bodies vodné plochy	grassland pasienky a lúky	agricultural arable land poľnohospodárska pôda	roads cesty
small carnivores malé mäsožravce	↔	↓	↔	↑	↔	↑	↑
hedgehog jež	↔	↔	↔	↔	↔	↔	↑
small mammals drobné cicavce	↑	↓	↓	↓	↔	↓	↓
domestic mammals domáce cicavce	↓	↑	↑	↔	↔	↔	↑

with the increase of agricultural land and water areas, it rose for carnivores. Domestic mammals and hedgehog were not significantly affected by the area of both landscape structure predictors. The share of roads affected mortality in all mammal groups. Kill probability of small carnivores, domestic mammals and hedgehog increased and the mortality of small mammals decreased

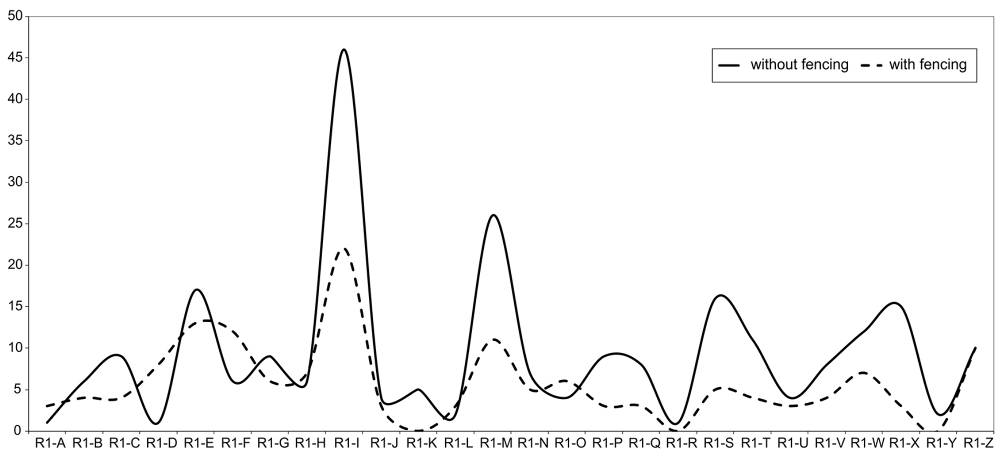

Fig. 3. Numbers of mammal road-kills on segments of the R1 road in 2008–2010 and after fence construction in 2010–2012 (dashed line).
Obr. 3. Počty zaznamenaných úhynov cicavcov na jednotlivých úsekoch cesty R1 v rokoch 2008–2010 a po dokončení oplotenia v rokoch 2010–2012 (prerušovaná čiara).

with the increase of the area with roads. The proportion of grasslands was not correlated with probability of road mortality in all groups.

Significant differences were found to be among the road topography categories (p=0.003). The road kills of mammals had a tendency to be mostly found on raised (B) segments (56.9%) while least significant effect on mortality was found on the buried-long raised (C-1) segments (5.1%). The presence of fencing has a significant effect (p<0.01) on the number of mammal-vehicle collisions. The total number of killed mammals was significantly higher in the period before the fence construction (62.2%) compared to the period after completion of the fencing (37.8%) with the most significant effect in hedgehogs (85.1% casualties were recorded in the period before fencing and 14.9% in the presence of the fence). The same mortality hotspots are visible after completion of the fencing but the number of casualties is significantly lower (Fig. 3).

After the completion of the fence we found significantly higher mortality (p=0.01) at the segments bisecting the line vegetation (69.8%) compared with the segments without contacts with line vegetation (30.2%) while there were no significant differences (p=0.20) in mortality in the period before the fence construction. The fencing had no significant effect on mortality at segments with expressway feeders (p=0.88).

DISCUSSION

Taxonomic composition and spatial distribution

In Slovakia, a relatively small number of studies related to negative impact of roads on wild animals have been done so far. They are associated mainly with the mortality caused by vehicle traffic, and very often have been concerned with a single group of mammals, especially with a game (see Hell et al. 2002 for a review). Moreover, they have been carried out with different methods, and covered different types of roads, or short road stretches with identical traffic volume, and especially some of them were done several decades ago when the traffic intensity was incomparably lower. Consequently, their results, very often confined to the list of killed species and numbers are hardly comparable.

The obtained results regarding taxonomic composition of mammal victims, despite the difficulties with the determination in some cases, are to a large degree the reflection of their habitat preferences. It is obvious in the high proportion of species typical for central European modified landscape (Heroldová et al. 2007, Krištofík & Danko 2012).

Our data on the number of casualties per kilometre of road are consistent with the roadkill indices for small and medium-size mammals from farmland areas in Germany and Poland (see Orlowski & Nowak 2006 and citations therein). In spite of it, we aware that road mortality magnitude is doubtless underestimated. In fact, results of all studies may be affected by some possible biases in sampling detection probability and removal rates (e.g. Teixeira et al. 2013). Our surveys were performed by observers in a car travelling at relatively high speed, especially on the R1 road, in addition, without stopping at carcasses. Consequently, small victims may not have been recorded and identified. Slater (2002) estimated that actual mortality rates can be 12–16 times higher that recorded from a moving vehicle. We compare our method with a survey using a bike on the I/51 road. Seven surveys performed by bike discovered 209 vertebrate road-kills while only 26 carcasses were detected from a car at the same time. Detection failure is higher for small animals (namely for rodents and insectivores) than for the large-bodied ones. However, there are exceptions: the ungulate carcasses were removed sooner by huntsmen than it was possible to record them. On the other hand, the advantage of our method is the high frequency of the surveys, i.e. three to four times per every week throughout the year. Moreover, the observations were made by the same persons, so the results of all the surveys are comparable.

Factors affecting road mortality

The present study shows differences in the quantitative and qualitative structure of road-kills both between the surveyed roads and among the segments of the same road. Landscape structure, road topography and fencing largely affected these differences. On the I/51 road with a prevalence of forested areas and presence of riparian vegetation, grasslands and water habitats higher number of small mammal road-kills occurred, whereas on the R1 road was dominated by small carnivores. The used method did not allow to determine specimens included in the group of small mammals in detail, however small rodents, especially *Apodemus* predominated. Many studies demonstrated that forest rodents cross narrow roads more often than wide ones (see Rico et al. 2007 and literature therein). Higher mortality of small mammals on the I/51 road, despite of lower traffic intensity, can be explained by the smaller width in combination with close canopy above many segments of the road that encourage movements of small rodents.

We found that higher proportion of arable land, roads and water bodies increase the number of road kills of small carnivores that were the most frequent victims on the R1 road. The red fox (*Vulpes vulpes*) was the wild carnivore with the highest number of casualties. It is not surprising because red fox may be one of the most adaptable carnivores inhabiting a variety of biotopes, feeding on a broad range of food types and can be particularly common in open landscape with high anthropogenic activity (Bateman & Fleming 2012). The stone marten (*Martes foina*) highly prevailed among mustellid victims on the R1 road. The stone marten is a habitat generalist with synanthropic behaviour using human structures in villages and towns at least in Central Europe (e.g. Herr 2008, Santos & Santos-Reis 2010). Two hedgehog species are considered one of the mammals most affected by the road traffic in Europe (Orlowski & Nowak 2004). In this study, the eastern hedgehog (*Erinaceus roumanicus*) mortality was relatively low on both roads, and the area of roads in the vicinity was only landscape variable with positive association with road kills. This suggests that the modified landscape adjoins both roads supports higher densities of hedgehog populations in accordance with the requirements of the species (Krištofík & Danko 2012).

As expected, road-kills of domestic mammals were significantly positively correlated with the variables associated with cultural landscape. Domestic cats highly prevailed over dogs as the dogs are kept in houses, while the cats roam free in the countryside.

As mentioned above, our ungulate mortality data have not been included in the statistics due to low number of the road-kills recorded. Local hunting organizations have provided higher numbers from the hunting districts relevant to the study area. Unfortunately these data could not be used in our study due to missing unambiguous localization of the vehicle collisions. Nevertheless our ungulate data show the same associations with landscape structure as small carnivore ones. The roe deer (*Capreolus capreolus*) comprised 85% of all detected carcasses. Road-killed ungulates were recorded twice as often on the R1 road. Since the beginning of the 20th century this species has colonised a wide range of habitats and can now be found in almost all European landscapes (Linnell et al. 1998). In Slovakia it prefers broadleaved forests but very high population density it reaches in agricultural landscape with scattered groups of shrubs and trees (Krištofík & Danko 2012). The surrounding areas along the R1 road are attractive feeding sites where roe deer can be seen during all seasons. Results of spatial behaviour of red deer confirmed the horizontal dispersal movements between the mountain ranges therefore red deer have a tendency to cross the R1 road (Kropil et al. 2015).

Road topography has been found to be among important variables in explaining road-kills (e.g. Clevenger et al. 2003). In this study, however, the explanatory power of topography is reduced due to low variability of topographic characteristics; moreover it is overlaid by the importance of landscape characteristics. For example, only two modifications of buried-raised road segments occur on the I/51 road, consequently it was impossible to compare the effects of various topographic types on a number of collisions. The same is true for the R1 road, where the segments raised above ground level highly predominated. It might be interesting that hedgehog had a tendency to be killed on the partly raised segments with easier access to the road and the higher incidence of domestic mammal road-kills at buried segments, while Borkovcová et al. (2012) stated that roads below ground level seem to be safest for all categories of animals.

Identification of mammal road-kills aggregation could be an important background for mitigation measures to minimize collisions. In our study, the reasons for higher mortality at some road segments are unclear. Interestingly, most of the identified mammal mortality hotspot is common to other vertebrate groups (unpublished data). Perhaps the close vicinity of built-up areas along these segments together with the higher elevation could be important. Further study on this issue is needed.

Fences along roads are controversial mitigation solution. Using of fencing can result in the drop of road-kills, on the other hand fences may separate a population into smaller subpopulations with a higher risk of extinction and without the possibility of recolonization of local extinctions (Jaeger & Fahrig 2004, Klar et al. 2006).

Construction of the fence along the R1 expressway has been related to significant decrease in road-kills. Fence construction is very expensive, so fencing is often used without association with costly wildlife crossing structures as is the case of the R1 road. Czerkesz et al. (2013) underlined the importance of interchanges and passages where the continuity of the fence is interrupted. Our results show that the road segments with the underpass where the streams with line riparian vegetation are crossed by the R1 road have become places with significantly higher vertebrate mortality after the fencing construction. This finding suggests that the line vegetation continue to serve as migration corridor and guides animals to the road where they find defects in fencing and to try cross through them and enter the road.

We expected that there will be an obvious effect of access roads, where the fence is interrupted, to the number of road-kills. However, the number of victims recorded at these sections was not significantly higher relative to the fenced sections.

SÚHRN

V rokoch 2008–2012 bol hodnotený rozsah, taxonomické zloženie a priestorová štruktúra mortality cicavcov na úsekoch dvoch ciest, ktoré spájajú mestá Banská Bystrica a Banská Štiavnica (Stredné Slovensko). Pozorovania boli vykonávané z auta 2× denne, 3–4× týždenne. Celkovo bolo vykonaných 440 pozorovaní a najazdených 39.700 km, pričom bolo zaznamenaných 5.416 úhynov stavovcov (v priemere 120 úhynov na 1 km), z toho 693 cicavcov (12,8 %) identifikovaných do 20 druhov, resp. skupín. Najčastejšími obeťami stretov s automobilmi boli *Felis catus*, *Vulpes vulpes*, *Erinaceus roumanicus* a drobné cicavce (hlodavce a hmyzožravce). Oba sledované úseky ciest sa signifikantne líšili nielen počtom úhynov, ale aj taxonomickou štruktúrou. Na rýchlostnej ceste R1 bolo zistená signifikatne vyššia mortalita s prevahou

malých mäsožravcov (lasicovité a líška), na ceste 1. triedy I/51 prevládali medzi úhynmi drobné cicavce. Rozmiestnenie úhynov vykazovalo agregovanú štruktúru, a tak bolo možné na oboch cestách identifikovať úseky s najvyššou mortalitou. Zistilo sa, že mortalitu cicavcov signifikantne ovplyvňuje štruktúra krajiny v okolí cesty, ako aj topografia cesty. S výnimkou drobných cicavcov bola mortalita všetkých ostatných skupín pozitívne ovplyvňovaná vyšším podielom antropicky pozmenených krajinných štruktúr. Vybudovaním oplotenia okolo rýchlostnej cesty R1 sa mortalita preukazne znížila s najsilnejším efektom na mortalitu *Erinaceus roumanicus*. V porovnaní so stavom pred výstavbou oplotenia bol však zaznamenaný vyšší počet obetí na miestach, kde cesta križuje líniovú, zvyčajne brehovú vegetáciu, čo naznačuje nedostatky v oplotení, ktorými zvieratá prenikajú na cestu. Prekvapujúco nebol tento efekt preukazný v miestach pripájania príjazdových ciest.

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