SZENT ISTVÁN UNIVERSITY

FACULTY OF AGRICULTURAL AND ENVIRONMENTAL SCIENCES

STUDY ON THE CONFLICT BETWEEN HUNGARIAN HIGHWAYS AND WILDLIFE SPECIES MEANING POTENTIAL RISK FOR TRAFFIC SAFETY

Theses of Ph.D. dissertation

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1. BACKGROUND, AND OBJECTIVES OF THE STUDY

„The Lord God took the man and put him in the Garden of Eden to work it and take care of it." (Genesis 2:15)

In the past centuries man changes the environment to such an extent that makes adaptation to these changes more and more difficult for nature. It leads to biodiversity losses, which inspired the „Rio Convention on Biodiversity" in 1992, and it drove UN to name year 2010 the International Year of Biodiversity, and our current decade by 2011 as Decade of Biodiversity. It is not too much to state that maintaining biodiversity is one of the conditions of man's survival on our planet (HALES et al. 2014).

Among factors threatening biodiversity, habitat fragmentation, caused mostly by linear infrastructures, is one of with the biggest impact. The lesser this infrastructure's permeability to local populations the more it can be considered as barrier, and the stronger its habitats and populations fragmenting effect (SPELLERBERG 1998). Reducing their sizes, isolated populations are more and more prone to consequences of random events: stochastic events start dominating. Genetic, (e.g. genetic drift, inbreeding), demographic, and ecological stochasticity are all pushing local populations towards extinction (HITCHINGS és BEEBEE 1998, MCCARTHY 1996, SAWCHIK et al. 2002). Ever-reducing sizes of habitats due to fragmentation may also lead to problems when it can no longer provide sufficient amount and quality of resources. This especially applies to species migrating long-distances (SPELLERBERG 1998, WIEGAND et al. 2005).

Highways, as linear infrastructures have further negative effects on environment. The area covered by the road surface is net habitat loss, and habitats close to reads get degraded. Traffic makes it worse with its physical, chemical pollution and disturbances. It raises road's barrier effect, and, due to roadkills it implements a new mortality factor. Generalist, invasive species spread among roadside verges, which expansion is often driven by the traffic itself (IUELL et al. 2003). New transportation infrastructure eases access to areas less assessable before, which raises human pressure and its further consequences (IUELL et al. 2003, NÉMETH 2005).

Highway network means danger not only for nature. Collision with a species a size of a fox, badger, or even bigger means remarkable risks for traffic safety. The higher the vehicles' value, and vehicles' speed, the bigger is the damage in property in case of such accidents, not even mentioning injuries or deaths.

According to FORMAN et al. (2003), exclusion (protective fencing) is the most effective method to maintain traffic safety. However, protective fencing, as singe method, serves only traffic safety, and turns road into an almost impermeable habitat barrier. This conflict can only entirely be solved by treating its both sides at once (MARKOLT et al. 2009a): traffic safety must be maximized (by excluding nature from the road using protective fencing, and by getting out all individuals from the protected side), reducing negative impact of road infrastructure on nature (by supporting its permeability to local populations).

There was more than 1300 km highway built in Hungary until 2013. The speed of this construction is five times bigger since 2001 than it was before. Still, this 1300 km is not even the half of the overall length of 2800 km in long-term plans. According to current standards, these highways are to be surrounded by protective fencing on their entire path (MAGYAR.ÚTÜGYI.TÁRSASÁG 2007). Thus, Hungarian highways can be considered as generally impermeable for most of the species (FORMAN et al. 2003, IUELL et al. 2003), and therefore as one of the biggest threats to Hungarian habitat continuity.

The earliest sections (first 150 km of M1, first 100 km of M7, and first 80 km of M3) were built without wildlife passages; therefore only wildlife exclusion was applied. The Act about nature protection (Act LIII. in 1996) requires consideration of nature's and wildlife's needs during designing transportation infrastructure, but its exact way is not defined. A big part of M7 highway was developed among these circumstances, when several wildlife passages were built, but not according to a clear guidance, but according to occasional expert studies. Not only law was late in reaction, but national scientific studies were missing, as well. However impact assessments, and separate studies must have been prepared (HELTAI és SZEMETHY 2009, MARKOLT et al. 2009b), the first summarizing study came in 2010 (MARKOLT et al. 2010b), where I approach the effect of Hungarian highways on nature through roadkills.

I have defined the conflict between Hungarian middle/big sized terrestrial wildlife species and transportation infrastructure as target of my study. I spent special attention on species that potentially mean traffic safety.

I also aimed to develop recommendations for relieving this conflict. I have built my dissertation on five central hypotheses:

1. Hungarian middle/big sized terrestrial fauna is generally involved into the conflict with transportation (road) infrastructure that carries remarkable risks to traffic safety in case of bigger species. This also means, that this conflict has no winners, but both sides necessarily loose on the current situation.
2. The overall number of wildlife roadkills on Hungarian highways is continuously growing
3. Temporal distribution (yearly, seasonal, weekly, daily) of wildlife roadkills on Hungarian highways are unequal.
4. Spatial distribution (along network) of wildlife roadkills on Hungarian highways are unequal, and therefore
5. factors, which are influencing spatial distributions of wildlife roadkills on Hungarian highways, may be identified.

In order to be able to decide about keeping or refusing these hypotheses I drew up the following detailed study questions:

a. Which wildlife species, and to what extent are involved into this conflict?
b. Which species are the main risks for traffic safety on the study area?
c. Does frequency of wildlife roadkills change in time?
d. Does the frequency of wildlife roadkills change in space (along network)?
e. Is there any relation between wildlife roadkill frequency and estimated density of surrounding species?
f. Are there any relations between wildlife roadkill frequency and characteristics of surrounding area (distance to forested areas, rate of natural vegetation, and distance to settlements)?
g. Are there any relations between wildlife roadkill frequency and presence/absence, and characteristics of wildlife mitigation measures (discontinuities on protective fencing, distance to exit roads, wildlife passages)?

I aimed to draw up the current situation typical for Hungarian highways with its ruling factors, and tendencies. Moreover, evaluating the answers given to my study questions, I aimed to develop recommendations for relieving the conflict discussed in this dissertation.

2. MATERIALS AND METHODS

The study area was Hungarian highways managed by State Motorway Management Ltd. (SMM) between 2000 and 2011 for picturing the general view. Further, more detailed analyses were carried out accordingly to the respective methodology, typically on M1, M3, and M7 highways, as oldest and longest segments.

Hungarian **roadkill database** of SMM was one of my main dataset to base on. It includes main parameters, location, and time of roadkills found since year 2000. The database contains roadkill data of exit roads, too. Carcasses found on the territory of highways (and within its fencing) were considered to be roadkills. Road managers, due to practical reasons, don't collect data of roadkilled fauna under certain size (so we don't expect invertebrates, amphibians, reptiles, small mammals among these records).

Database of wildlife-vehicle collisions (WVC) was provided by SMM as well. This is a list of VWC, where policeman was present. This obviously includes lesser data, than roadkill database, but one of its positives is that the time of event is very precisely given.

National Road Databank (NRD) of Hungarian Transport Administration (HTA) provided me with **geospatial, time-depending maps of Hungarian highways** (which was not completely ready database yet), but the gaps were covered by help of data received from Magyar Közút Zrt. **Attributive data of Hungarian highways** were accessed from NRD as well, which had to first be combined (spatially joined) to geospatial highway maps.

Density estimations of relevant wildlife species were gained from the National Game Management Database (NGMD) from the Institute for Wildlife Conservation of Szent István University.

Furthermore, Corinne Land Cover (CLC) 2000 and 2006 coverages, and available coverages of the Országos Térinformatikai Alapadatbázis were used, too.

According to my general aim, I was interested in the entire list of species of the animal roadkill database (which includes domestic and wildlife species, too), and incorporates categories such as „unidentifiable", and „others". To make it suitable for further use, I have strictly filtered and re-structured the data.

Birds and bats were excluded due to their flying ability (because mechanisms behind spatial roadkill patterns are totally different than in case of mammals). Domestic and small sized mammals were not considered for further calculations, either. Keeping in mind the possible taxonomical unprecisenesses of roadkill database, and excluding methodological bias deriving from this fact, I have only kept records, where identification of roadkilled individual was considered to be sure. Otherwise I excluded („wild cat”), or grouped respective records to higher taxonomic categories (e.g. „polecat”). Incomplete records and those were error was suspected were deleted. As a result of data preparations nine classes were created. These nine classes of records are the basis for further „wildlife roadkill” analyses.

1. Eurasian badger (Meles meles),
2. „polecat” (that could be Mustela putorius or eventually Mustela eversmanni, too),
3. stone marten (Martes foina),
4. „hare” that is, with minimal chance for error, completely considered to be European hare (Lepus europaeus),
5. roe deer (Capreolus capreolus),
6. red fox (Vulpes vulpes),
7. „deer”, that applies to red deer (Cervus elaphus),
8. wild boar (Sus scrofa),and
9. otter (Lutra lutra).

Further analyses were carried out with bigger body sized, for traffic safety more dangerous species. Roe deer and wild boar were in first focus, but according to the logic of the respective questions, other species (such as e.g. red fox, badger, and brown hare when studying seasonality) were included, too.

For testing temporal distributions (monthly, and weekly patterns of wildlife roadkills) Kruskal-Wallis test was run (KRUSKAL és WALLIS 1952) with Dunn’s Post-Hoc test (DUNN 1964). As initial spatial approach for creating „quasi hot-spot maps”, I displayed wildlife roadkill data of four relevant species (roe deer, wild boar, European badger, and red fox) at different spatial resolutions (on a basis of 500 m to 10 km segments) from M3 highway.

Impact of presence of wildlife passages, and estimated population density on wildlife roadkill frequencies were studied in two approaches for the same four species as before (M3 highway, 2002-2009).

In the **first approach** I took a look on the Game Management Units which are surrounding the observed road. I split up the motorway accordingly to the borderlines of the mentioned Management Units (both on left and right side of the highway). The estimated population density data of the GMU's were applied to the appropriate adjacent road sections. Each assessed road sections got exactly two population estimation data per year, one from the left and the other from the right side, which were aggregated into one representative (arithmetic mean). Data of wildlife roadkills were summarized within each segment. Due to the unequal length of different road-segment a relative roadkill-number was needed to count, as well. With the relative roadkills I was able to test the correlation between those and the estimated population density. Spearman's Rank correlation was run (SPEARMAN 1904). A factor called "underpass" was implemented, as well. The parts of the M3 highway which were built before 2002 does not include wildlife passes. Younger highway sections were already constructed under the obligation of establishing such mitigation measures such as underpasses. The factor "underpass" has a value of "yes" if the respective road section is on the newly created part of the M3 and "no" if it takes place within the stretch was built earlier – without any wildlife passage. I used Man-Whitney U-Test (MANN és WHITNEY 1947) to determine the influence of wildlife passage's (underpasses) presence on the relative roadkill.

The **second approach** based on the main idea to keep the WVC data in an integer form and to deal comparatively sized spatial benchmarks (lengths). Doing so, the whole M3 highway was divided into 500 meters long segments. Roadkill data were summarized within these segments for each year, and species. Data with incomplete year were excluded (year 2002 between 114 km and 234 km). The underpass-factor was implemented here, as well, the same way as before. Suiting the population estimation data to the 500 metres segments was more difficult as in the first approach. Since the estimation data are deriving of the GMUs. If one or more GMU-borderline cut through the line of a 500 meters segment, the typical value was computed by using arithmetic mean, weighted by the length of the different GMU – M3 intersections. For the testing the previously written variables a Generalized Linear Mixed Model was built. Its response variable was the wildlife roadkill (as integer). The “underpass” and the “species” were factors, with 2 and 4 levels, respectively. The estimated game densities played a role of a covariate in the model. The effect of the years was handled as random effect. All possible interactions between were included into the model.

Spatial patterns of wildlife roadkills, and their influencing factors were studied by GIS methods, too. Transferring the wildlife roadkill database into GIS environment was a difficult task and was carried out applying the following steps: 1: database clearing, preparations (ESRI ArcMap Model Builder); 2: harmonisation of roadkill data and SMM road data (ESRI ArcMap Model Builder); 3: Joining roadkill data and SMM road data onto SMM road coverages (ESRI ArcMap Linear Referencing Tools); 4: check, corrections, re-check.

Conventional geometrical calculation methods were not suitable for calculations of spatial distribution of roadkills, therefore I have applied OKABE’s SANET 4 tool OKABE et al. (2006). For distance-related calculations I used the method of „Euclidean Distance”. area ratios were calculated by help of „Diversity Calculator” BUJA (2009), for other GIS-related calculations „Hawth Analysis Tools” BEYER (2004) was used.

For studying spatial patterns of roe deer, and wild boar I have placed 1000-1000-700 sample points on M3, M7, and M1 highways, respectively, a way, that any two points were closer than 200 meters. This resulted in a sampling of my entire study area. For every event, and for all 2700 non-even point I have calculated the following measures: 1: **ratio of natural vegetation** within a 1 km radius (based on Corinne Land Cover: considering CLC 2.4.3., 3.2.1., 3.2.4., and 4.1.1. categories as natural vegetation); 2: **distance to nearest forest**; 3: **distance to nearest settlement**; 4: **network distance to nearest exit road** (where fencing finishes).

Independency of distributions of event, and non-event points were tested by Chi-square test (PEARSON 1900) together with Bonferroni-Z intervals (BYERS et al. 1984). For measuring differences between expected (supply) and observed values, Ivlev-index (IVLEV 1961) was applied.

For handling, managing, processing, and analysing data I have used the following software: Microsoft Office Excel and Access 2007, Google Earth, MapSource, ArcGIS 9.3, SPSS Statistics 17.0, PASW 18.0 (SPSS Inc.), GraphPad InStat 3.05, GraphPad Prism 6 Demo, and R 2.12.

3. RESULTS

Started by 2000 until the end of 2011 there were 29548 carcasses (roadkilled animals) found along highways of Hungary (annual average 2462.3 ± 817.1 (SD); minimum: 969; maximum: 3408)). This figure includes all domestic, and wild species, and the categories „unidentifiable", and „others" are incorporated, too. Wildlife roadkill is more than 40% of it, exactly 12146 carcasses (annual average 1012.2 ± 426.3 (SD); minimum: 257; maximum: 1507).

Brown hare and red fox roadkills make more than the 80% among the mentioned nine categories of wildlife roadkills, which means almost 10000 roadkills annually. Eurasian badger and roe deer have more, than 5% per each. In spite it only consists of 2.1% of all annual roadkills, among the 5 groups not mentioned yet, wild boar has a special importance due its large body weight, which is a higher concern to traffic safety. There were 100 European otter roadkills found during the entire study. The „red deer" category showed very rare, exceptional frequency (0.1%, 10 cases).

82.1% of wildlife roadkills belongs to one of our three biggest and oldest highways (M1, M3, and M7). The lowest number of relative wildlife roadkills is found on the M0, significantly less, than on M1, M3, M30, M35, M7, and on M70, while the biggest number we see at M15.

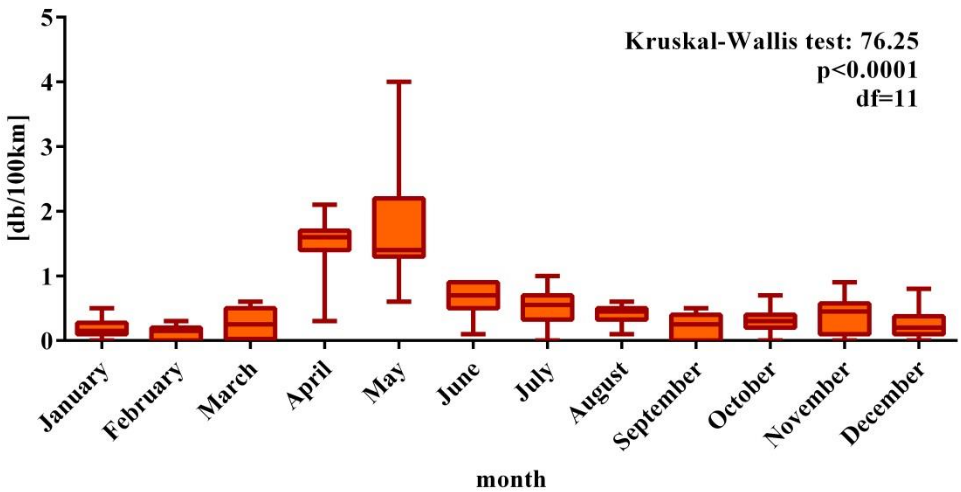
3.1. Temporal patterns

The overall number of animal roadkills on Hungarian highways is tendencially growing since 2000. In 2008, it reached a three-fold level compared to the beginnings. This is in general related to the expansion of Hungarian highway network, which consisted of 600 km of roads in 2000, and exceeded 1300 km in 2011. Relative frequency of annual animal roadkills (per road length unit) shows a delicately decreasing trend since the peak in 2003. In 2000 180.6 carcasses/100 km, in 2003 415.0 carcasses /100 km (peak), whereas in 2008-ban 280.0 carcasses/100 km, and in 2011 258.0 carcasses /100 km drew up the Hungarian picture.

Number of wildlife roadkills multiplied itself almost 5 times from 2000 to 2011 (from 257 to 1337), but this tendency is smashed, too, when I relate it to the expansion of the highway system. In spite there was a 2.5 fold increase in the number of relative annual wildlife roadkills between 2000 (45.0 carcasses/100km) and 2011 (115.1 carcasses/100km), there is, as I wrote, no steady growth. There was a steep increase till 2003 (peak was 143.5 carcasses/100kms), but since 2003 this figure seems to slightly keep decreasing.

The overall temporal pattern of wildlife roadkills shows a typical, two-peak distribution with one peak in spring and one in autumn and with minimums in summer and in winter. There is significantly more wildlife roadkill "produced" A) in April ($p < 0.01$), in September ($p < 0.01$), and in October ($p < 0.001$) compared to January, B) in April ($p < 0.05$), in September ($p < 0.05$), and in October ($p < 0.01$) compared to February, and C) in October compared to December ($p < 0.05$).

The temporal pattern of roe deer roadkills has its minimum in the winter in January and February, from where it starts growing in March, and reaches its top to April-Maj. It remarkably decreases from June to August, and by September until the end of the year it remains on a low level (Figure 1). There were significantly A) lower level found in January and in February compare to April, May, and June; B) and higher levels in April and May, than in September, October, or December; C) lower amount of roadkills in November compare to May.

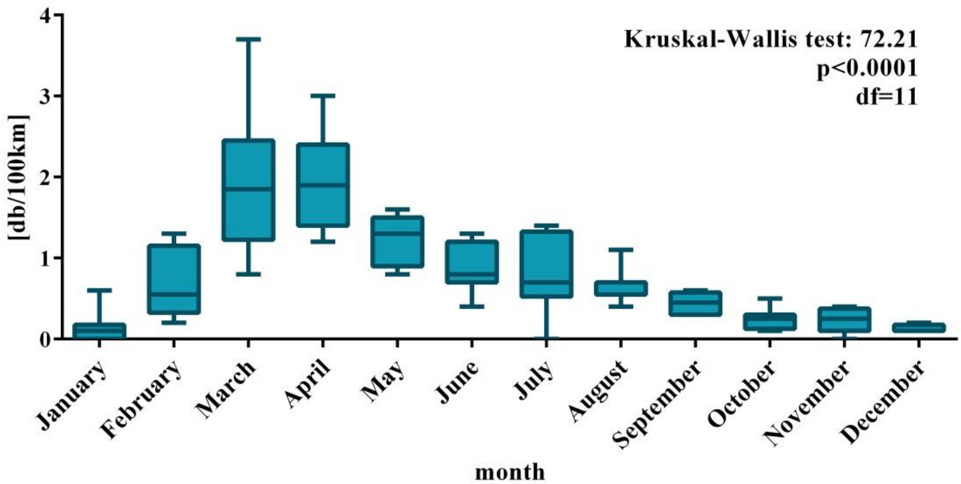


1. Figure. Monthly relative roe deer roadkill frequencies (M3, 2000-2011, n=689)

The minimum of wild boar roadkills is during the winter from December to April, and starts growing in May to reach a local maximum in

June, then decreases to a local minimum in August to reach its absolute peak in October. By November, it starts falling again. I found significantly more wild boar roadkills June and July ($p < 0.05$) and in October and November ($p < 0.01$) compared to March.

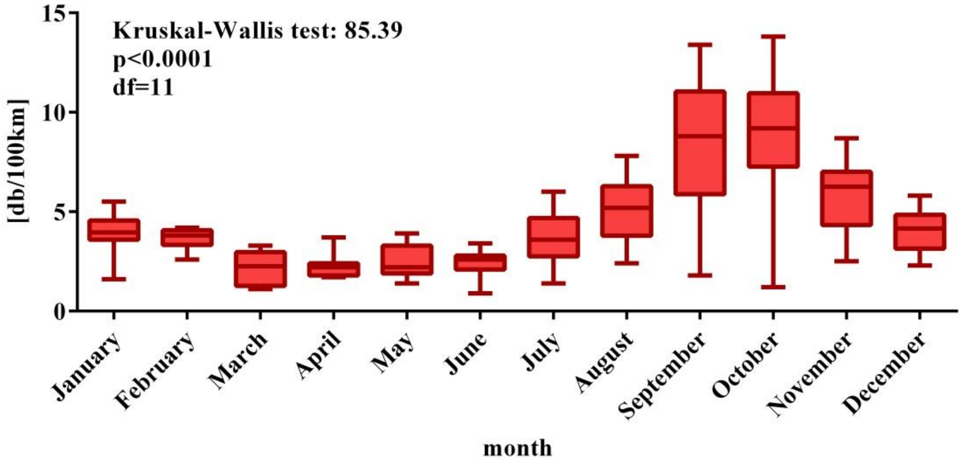
The number of Eurasian badger's roadkills shows a sudden growth from the minimum in December-January throughout February to its peak in March-April, than turns into a steady downward trend from May to the winter (Figure 2). Figures of March, Aprils and May are statistically different from the ones of October, November, and December.



2. Figure. Monthly relative E. badger roadkill frequencies (M3, 2000-2011, n=767)

In case of red fox, the downturn and minimum from March to June is indeed spectacular. Compared to this level, roadkill level of the autumn peak is approximately four times bigger. Roadkills in March, April, May, and June are on a significantly ($p < 0.05$, or in some cases much less) lower level than it is in August, in September, in October, and in November (Figure 3).

Brown hare does not have such definite seasonality as I found in case of previous wild species. However there is an annual peak in spring (April and January are the only month differing statistically), the roadkill level remains almost the same throughout the rest of the year without any bigger trend or fluctuations.



3. Figure. Monthly relative red fox roadkill frequencies (M3, 2000-2011, n=5909)

Wildlife roadkill frequencies changes during the course of the week. I found significantly less roadkills on Wednesdays ($p < 0.05$), Saturdays ($p < 0.05$), and Fridays ($p < 0.05$) than on Sundays, which is approximately of 140% of the Friday's (minimum) level.

75% of WVCs (1561) occurred in darkness (night), 21% (425) in daylight, and only 3% (74) during dusk or dawn. This general share did not change remarkably in average of years, where 64.2% ± 5.3% happened in darkness, 11.4% ± 1.6 % during dusk or dawn, and 24.41% ± 3.4% in daylight (2000-2011, n=2060). There were no WVCs ending with human death or serious injury during dusk or dawn.

3.2. Spatial patterns

I have started the analysis of wildlife roadkills' spatial patterns on the M3 highway. My first quasi-hot-spot graph was created for four species (roe deer, wild boar, Eurasian badger, and red fox) with 500 m spatial resolution. I have developed a map with 10km spatial resolution for the same four species, too (MARKOLT et al. 2009a). These already suggest that spatial distribution of wildlife species among Hungarian highways is not homogeneous. It also differs from random distribution, which I have proved using Network-K Function (MARKOLT et al. 2012a).

I investigated the impact of estimated population density and wildlife passages on spatial distribution of wildlife roadkills on the M3 highway between 2002 and 2009 for four species (roe deer: n=91, wild boar: n=83, Eurasian badger: n=117, red fox: n=1263) (MARKOLT et al. 2012b). The **first approach** shows significant (but very week) correlation between **estimated population density** and roadkill number only for wild boar (rho=0.24, S=3288526, p <<0.0001). No statistically proven correlation were found for roe deer (rho=0.04, S=4062695, p=0.4863), neither for Eurasian badger (rho=-0.03, S=2353978, p=0.5947), nor for red fox (rho=0.10, S=2055462, p=0.1364). Treating data of these four species as one I found no difference in roadkill frequencies whether or not the road section was with **wildlife passage** (Mann- Whitney U test: W=161372; p=0.1972). However, roe deer and wild boar roadkill frequencies are significantly lower on the sections with passages, than on the sections without (Mann- Whitney U test: roe deer: W=11284; p=0.0024; wild boar: W=11629; p << 0.0001). This was not the case for Eurasian badger, where I found no statistical difference (Mann-Whitney U- test: badger: W=9479; p=0.6897). For red fox there is a significant difference (Mann- Whitney U test: red fox: W=7000; p=0.0001), but interestingly in the other way around: higher roadkill rates are on sections with passages (min: 0.0000; 1st quartile: 0.4762; median: 0.9108; average: 1.0038; 3rd quartile: 1.4170; max: 3.6730), and lower roadkill rates on the sections without passages (min: 0.0000; 1st quartile: 0.3172; median: 0.5406; average: 0.6823; 3rd quartile: 0.9418; max: 3.4830).

Table 1 contains the results of the **second approach**'s model. Interactions are marked with colons between the variables. I took a random sample with the size of 5000 elements of the model residuals for model diagnostic purposes. Shapiro-Wilk normality test showed outstandingly significant result (W = 0.3365, p <<0.0001) so the hypothesis of the sample's normality is rejected, so the homogeneity of the variances is not guaranteed.

1. Table: results of the generalized linear mixed model

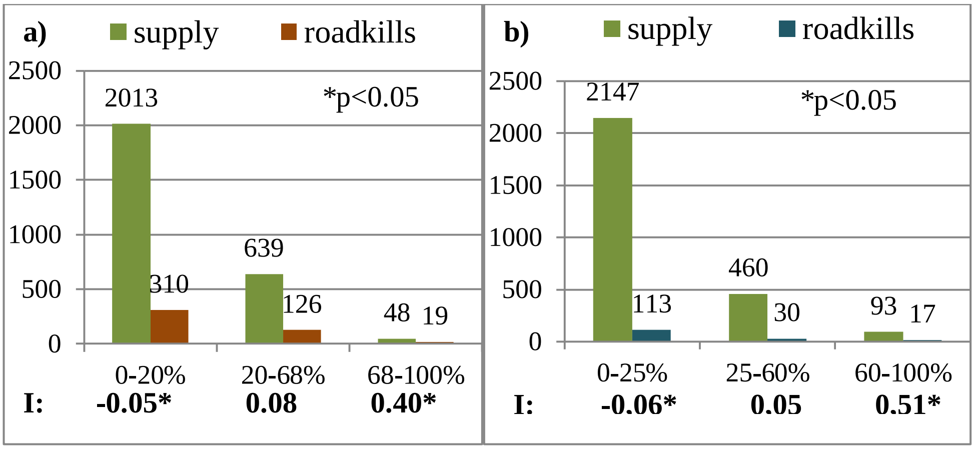
Generalized linear mixed model fit by the Laplace approximation				
AIC	BIC	logLik	deviance	
4396	4519	-2181	4362	
Random effects:				
Groups	Name	Variance	Std.Dev.	
Year	(Intercept)	0.0801	0.28303	

Number of obs.: 10195, groups: year, 8				
Fixed effects:				
	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-3.24530	0.32946	-9.851	< 2e-16 ***
f(spec)r deer	-0.90524	0.59973	-1.509	0.13119
f(spec)fox	1.93775	0.33237	5.830	5.54e-09 ***
f(spec)w boar	-0.24740	0.40382	-0.613	0.54010
f(u pass)yes	0.65127	0.36743	1.772	0.07631
density	0.31467	0.55437	0.568	0.57029
f(spec)r deer:f(u pass)yes	-0.77949	0.74994	-1.039	0.29862
f(spec)fox:f(u pass)yes	-0.31369	0.39546	-0.793	0.42765
f(spec)w boar:f(u pass)yes	-3.57180	0.76896	-4.645	3.40e-06 ***
f(spec)r deer:density	-0.04463	0.57585	-0.078	0.93822
f(spec)fox:density	-0.11626	0.56891	-0.204	0.83807
f(spec)w boar:density	0.43345	0.57353	0.756	0.44979
f(u pass)yes:density	-3.64149	1.15201	-3.161	0.00157 **
f(spec)r deer:f(u pass)yes:density	3.48142	1.16773	2.981	0.00287 **
f(spec)fox:f(u pass)yes:density	3.52944	1.16609	3.027	0.00247 **
f(spec)w boar:f(u pass)yes:density	10.80316	2.08914	5.171	2.33e-07 ***
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1				

„f(spec)”: species factor
„f(upass)”: underpass factor,
„density”: estimated population density

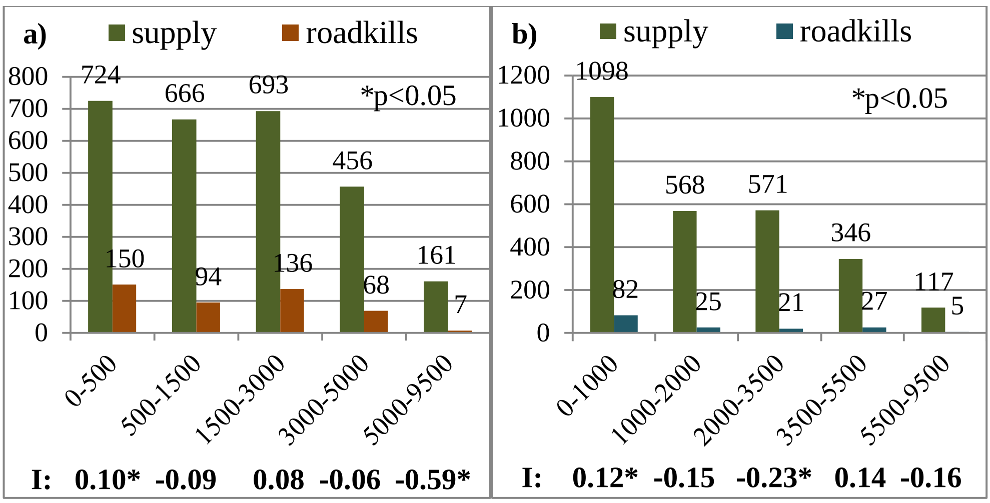
Further factors influencing the spatial distribution of roadkills were analysed involving GIS methods for two species, which mean special concern to traffic safety (roe deer, wild boar) based on the data registered on M1, M3, and M7 highways.

In case of roe deer, if the ratio of natural vegetation within 1 km was 0-20%, roadkill level slightly, but significantly decreased, whereas if this rate was 68% or more, it remarkably increased roadkill levels (Figure 4/a). Results for wild boar were similar: 0-25% rate of natural vegetation within 1 km had small, significant decreasing impact, while 60-100% rate definitely increased roadkill frequencies of the respective section (Figure 4/b).



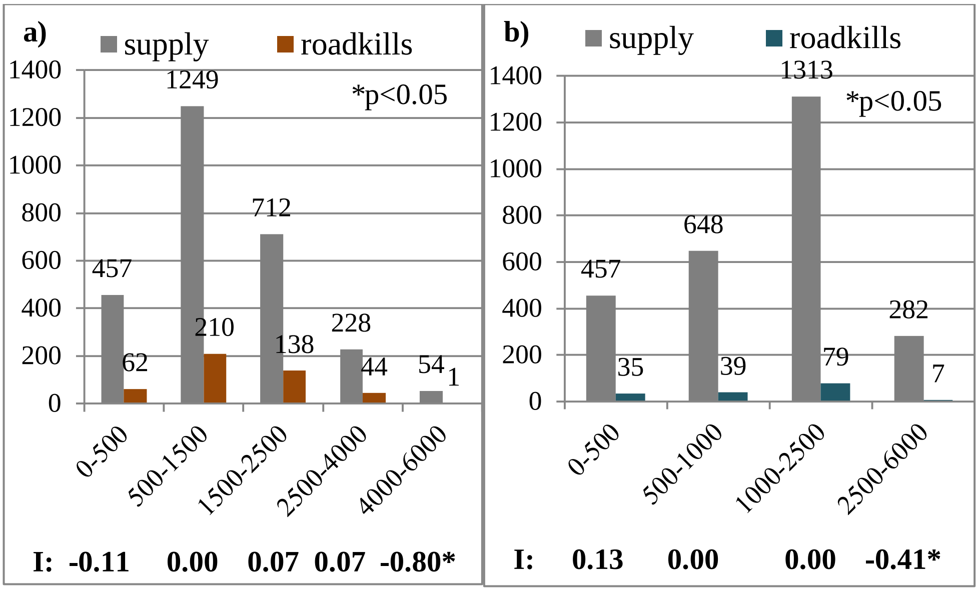
4. Figure. Distribution of control points (supply), and event points (roadkills) according to ratio of natural vegetation within r=1 km sample area, and Ivlev's indices (M1, M3, M7, 2000-2010)
a): Roe deer (n_{supply}=2700, $n_{roadkill}$=455); b): Wild boar (n_{supply}=2700, $n_{roadkill}$=160)

If the proximity of closest forested area was less, than 500m, roe deer roadkills showed slight, but significant increase. If it was more than 5kms strong fall was overserved in roadkill level (Figure 5/a). Wild boar had similar tendencies: 1 km or less delicately increased, while 2.5-3 km decreased the roadkill frequencies (Figure 5/b).



5. Figure. Distribution of control points (supply), and event points (roadkills) according to proximity of forested areas, and Ivlev's indices (M1, M3, M7, 2000-2010)
a): Roe deer (n_{supply}=2700, $n_{roadkill}$=455); b): Wild boar (n_{supply}=2700, $n_{roadkill}$=160)

When distance to closest settlement was more than 4 km, it remarkably decreased roe deer roadkill frequencies (Figure 6/a). For wild boar this threshold was at 2.5 km, which caused decrease (Figure 6/b).



6. Figure. Distribution of control points (supply), and event points (roadkills) according to proximity of exitpoints, and Ivlev's indices (M1, M3, M7, 2000-2010) a): Roe deer (n_{supply}=2700, $n_{roadkill}$=455); b): Wild boar (n_{supply}=2700, $n_{roadkill}$=160)

In case of roe deer, if the proximity to closest exit road was between 0.5 and 2.5 km it slightly increased roadkill values of the respective road sections, while 7 km or bigger distance decreased it. For wild boar there was no distance class found that would have significantly positive impact, but the proximity to closest settlement equal or over 7 km strongly decreased wild boar roadkill frequencies.

3.3. New scientific results

1. I have described the involvement of Hungarian middle/big sized terrestrial fauna, the group of involved species, and their degree of involvement into the conflict with transportation (highway) infrastructure. I have defined the conflict species of main traffic safety risks.

2. I described the temporal wildlife roadkill patterns of traffic risking conflict species on Hungarian highways.
    a. Where the overall picture shows a two peaked (April, September-October) distribution.
    b. Roe deer, Eurasian badger, and brown hare have more roadkills in spring compared to other seasons.
    c. Wild boar and red fox has an autumn-peak. Wild boar shows a local peak of roadkills in early summer, too.
    d. Remarkably more wildlife roadkills are occurring on Sundays, than in the rest of the week. The biggest difference is between Fridays, and Sundays.
3. I have prepared the first roadkill maps of M3 highway with multiple spatial resolutions (5000m to 10000m).
4. I proved that spatial distribution of wildlife roadkills on Hungarian highways is not randomly distributed.
5. I have detected the impact of the surrounding area's characteristics on roe deer and wild boar roadkills, in particular:
    a. High rate of natural vegetation within 1 km and proximity of forest patches both increased roadkill frequencies for both species.
    b. I found significantly less roadkills where closest settlement was 4 km or further for roe deer, and at least 2.5 km for wild boar.
6. I proved, that population density is not mainly responsible for roadkill levels.
7. I proved that presence of passage may decrease roadkill frequencies of roe deer and wild boar.
8. I have identified the decreasing impact of exitroad's distance on roe deer and wild boar roadkill frequencies.

4. CONCLUSIONS AND SUGGESTIONS

Annually an average of 71.898 ± 18.997 (SD) millions HUF (minimum 47.840, maximum: 107.676 million HUF) damage in property occurs on Hungarian highways due to WVCs according to statistics of police.

The absolute number of wildlife roadkills in Hungary is year after year increasing, but the relating it to road length it turns to a slightly decreasing trend (MARKOLT et al. 2010b). This decrease in fauna loss means direct improvement in traffic safety, and keeping my second hypothesis at once.

More than 90% of the wildlife roadkills happened on one of M1, M3, or M7, since these are our oldest highways. Roadkill frequency relative to road length is highest on M3 among these 190.7 ± 60.7 (SD) wildlife roadkill/year/100km, but the differences are not significant. The same measure for M15 compared to M7 is significantly higher (282.1 ± 50.5 (SD) wildlife roadkill/year/100km), of which 82% is brown hare, 7% is only red fox, and roe deer is of 5%. Compare to the Hungarian average of 30-35% of brown hare share among all wildlife roadkills, this 82% is more than two-fold difference, which probably derives from local habitat features.

According to SMM's roadkill database Hungarian middle/big sized terrestrial fauna is generally involved into the conflict with transportation (road) infrastructure, especially those species, which are not effectively excluded by protective fencing (answer for my first study question). Red fox and brown hare share on 80% of all roadkills.

Those species can be considered as main risks for traffic safety, which may cause serious damages due to their body weights, and the probability of a collision with them is remarkable. These are in first line roe deer, wild boar, but red fox, Eurasian badger, and brown hare can be included, too (answer for my second study question).

Due to these results I keep my first work hypothesis.

4.1. General temporal patterns

The overall seasonal pattern of wildlife roadkills show a two peaked (April, September-October) distribution with minimum levels in winter (MARKOLT et al. 2010b) that suits well to results found by GRILO et al. (2009).

I found significant difference in weekly distribution of wildlife roadkills, too. I haven't found similar researches in the international scientific literature, since this is not an ecological question. Still, due to traffic safety considerations, it is important to know, that during Sundays there is approximately 140% bigger chance to hit a wildlife species by car on a highway, than on Fridays. Behind this tendency I assume traffic reasons as in the following: according to weekly traffic pattern based on a whole year traffic counting (M3, Gödöllő, 2008) Fridays have significantly the highest traffic volume (approximately 51500 vehicle/day) compared to the rest of the week, whereas Saturdays and Sundays are with significantly lover traffic volumes (38750, and 37200 vehicle/day, respectively) compared to all other days. Thus, traffic volume peak, and wildlife roadkill minimum coincide (Friday), just like minimum traffic volume and the peak of wildlife roadkill (Sunday). This is in line with the tendency pictured by SEILER (2005) in a moos roadkill study, stating, that bigger traffic would only cause bigger roadkills until certain limit, because exceeding that limit, not roadkill maximizes, but barrier effect of the road (so the wild will not attempt crossing on a road, where the traffic is so big that cars go after each other). Furthermore, weekend-traffic may incorporate bigger share of unexperienced drivers (who rarely drive, but then bigger distances, e.g. commuters), who therefore may be less probable to avoid an emergency situation. Also, tired travellers arriving home from actively spent weekend may also raise the probability Sunday afternoon-evening roadkills.

My results show approximately three times more roadkills by night, than in daytime, and during dusk or dawn together. This does not fit to the results of HAIKONEN és SUMMALA (2001) where dusk came with outstandingly high deer roadkill frequencies, so this is not an universal result for all wildlife species. In my case police statistics did not make it possible to study species specific daily patterns.

This way my third study question was answered generally, and on species specific levels, too. Therefore my third work hypothesis is kept.

4.2. Spatial patterns

My first quasi-hot spot maps with different spatial resolutions (MARKOLT et al. 2010a, MARKOLT et al. 2010c) already suggested that spatial distribution of wildlife species among Hungarian highways is not homogeneous. It also differs from random distribution, which I have proved using Network-K Function (MARKOLT et al. 2012a) for M1, M3 and M7 highways. This coincides with previous expectations and other Hungarian and international studies (CLEVENGER et al. 2003, CSERKÉSZ et al. 2013, GUNSON et al. 2011, RAMP et al. 2005, SEILER 2005). This also answers my fourth study question. Therefore my fourth work hypothesis is kept, as well.

The estimated population density of respective wildlife species seemed to significantly influence wildlife roadkill frequency in case of wild boar only, but this influence was very week. This result could be transformed to the statement, as: „where there is no or just very limited number of wild boar, there roadkill consequences are not expected, and everywhere else is possible.” Roe deer, Eurasian badger, and red fox densities did not seem to impact roadkill frequencies. Thus the answer for my fifth study question is no. It also means, that for roads surrounded by protective fencing I think theory of SEILER (2005), according to population density definitely influences roadkill frequencies, is not applicable (or only on a very principal level: you should only count on a roadkill, where the given species has occurrences). Considering the fact, that the four species I investigated are country-wide spread, this statement has even less importance.

I found the same result using two different approaches when I was studying the impact of wildlife passages on wildlife roadkill frequencies. Roe deer and wild boar roadkills were significantly lower on road sections with underpasses, than on sections without. This was not the case for Eurasian badger, where I found no statistical For red fox there was a significant difference, but interestingly in the other way around: higher roadkill rates are on sections with passages, and lower roadkill rates on the sections without passages. This result seems to be confusing, but GRILO et al. (2009) found the same. According to their explanation passages were built on good habitats, therefore not the presence of passages, but the bigger wildlife activity due to the habitat’s good quality causes the increase in roadkill volumes. This argument may be valid for our case, too, but I believe efficiency of protective fencing is responsible for this trend, too. Where protective fencing works effectively, quality of the surrounding habitat (just like density of surrounding species) should not be able to influence roadkill levels. We saw, that the influence of density was generally not confirmed, but together with passages it already raised roadkills, we must conclude, that protective fencing is not that effective in proximity of passages. This is supported by my practical observation, according to which where continuity of the protective fencing breaks (due to crossing structures, passages, etc.), errors on the fencing leading to dysfunction are more frequent, and that lowers the exclusive power of the fencing.

Exclusive power of fencing is species specific. My earlier studies and experience showed that red fox and badger use fencing errors very effectively, and can easily find a way through. I have photographically proved that 15*15 cm mesh sized fencing is not necessarily a barrier to fox. I saw many times brown hare footprints in the snow criss-crossing the fencing. Where fencing is not properly lowered to ground, badger may easily dig under, etc. In case of roe deer and wild boar smaller mistakes of the fencing would not necessarily mean so big risk, but there are bigger mistakes (major water erosion in embankment under the fencing, service doors left open, fencing cut), that may let these bigger species getting it.

The answer to my sixth study question is complex. Passage's impact lowering roadkill volumes was confirmed for roe deer, and wild boar. Protective fencing seems to be more effective tool for these two species, than for others. Therefore for these two species it is crucial to have proper design and practical implementation of fencing, especially at interchanges. Distance from express road was detectable for both of these species.

On road sections, where the rate of natural vegetation within 1 km is at least 68% (for roe deer), or minimum 60% (for wild boar) I found bigger roadkill volumes, than it would have been expected based on the control sites. This factor is describing the micro environment of road (so not the habitat!). Where the close environment of the road is not covered by vegetation, wildlife roadkill volume will reduce. This result was well known for roads without protective fencing, and is present in the management practice, but is a new result for the fenced Hungarian highways. Furthermore, this result, considering the actual quality of Hungarian protective fencing, questions the point of view of, that highways' both sides should be forested (JĘDRZEJEWSKI et al. 2009), in order ensure functioning it as a green corridor. Based on my results, in the current situation it would increase roadkill risks on the respective sections (Unless protective fencing would be improved. In that case turning highway sides to green corridors would not even be only acceptable, but wished).

As a control to natural vegetation's, and forest patch proximity's impact, I investigated the impact of proximity to closest settlement. The results seem to be surprising, and are similar for roe deer, and wild boar. I found significantly less roadkills where closest settlement was 4 km or further for roe deer, and at least 2.5 km for wild boar. Most of the roadkills happened on sites, where settlements were not more than 2.5 km far for those species. This result is hard to understand in itself, but according to me it (for roe deer strongly, for wild boar moderately) underlines the importance of exit roads, i.e. exit roads are usually found close to settlement.

The answer for my seventh study questions is yes, since I found significant differences in all categories. Since I have identified factors that are influencing the spatial pattern of wildlife roadkills, my last work hypothesis will be kept, too.

4.3. Species specific evaluation

48.6% of wildlife roadkills is red fox, which means in average 52.5 ± 12.9 (SD) carcasses/100 km) annually, and so this is the most frequently "roadkilled" wildlife species. BARTHELMESS és BROOKS (2010) found far lower number of fox road kills on non-fenced, local roads (0.05 ± 0.03 (SD) carcass/week which is ~2.6 ± 1.56 (SD) carcass/year). In a more similar study to mine, GRILO et al. (2009) found annually 20 fox carcass/100 km and 5 badger carcass/100 km on (not completely fenced) highways. The difference between these and my results may be of methodological nature: Hungarian database does not base on estimation, but complete count, whereas estimations may often seriously underestimate. Further explanation can be the role of fox in Hungarian ecosystems, where, is spite of situation on the study areas of the cited literature, fox did not have any natural competitor in Hungary until golden jackal's return (ARNOLD et al. 2012). This high share of fox among wildlife roadkill species may seem to be surprising based on the common opinion, that carnivores less tend to victimize to traffic than herbivores, or omnivores (BARTHELMESS és BROOKS 2010, FORD és FAHRIG 2007). Country wide spread, and dysfunctions of protective fencing may both be partly explaining it.

According to GRILO et al. (2009) fox parents that are feeding young were most vulnerable to road-related mortality. This time in Hungary starts in March-April, and may last until the end of summer. In spite of this I found downturn from early spring to early summer in fox roadkills (2.2-2.5 carcass/100 km/year), that only start increasing in July, and reaches its peak in September-October (8.3 and 8.9 carcass/100 km/year, respectively). This is the time of family boundaries are opening up, and dispersal of young. Therefore according to my results young dispersing foxes are the most vulnerable group of foxes, because looking for new sites increases risk, and new sites might include unknown dangers (e.g., highly trafficked roads).

I didn’t find any correlation between population density and roadkill volume for red fox. I think this may also be due to fox is a common spread species all over Hungary (hard to find are with very limited fox occurrences). Passages’ presence did not decrease, but increase fox roadkill frequencies. In general to reduce fox roadkill volumes, good protective fencing may have a strong effect (fence lowered and dug into ground, small mesh size).

The second most frequent wildlife species in roadkills is the brown hare (31.8%, annually 37.0 ± 23.2 (SD) carcass/100 km). Brown hare is common spread, in Hungary, and can easily cross the protective fencing. Brown hare roadkills are persisting throughout the whole year without any bigger fluctuations, except for the peak in spring. The lowest number of roadkills was found in January, the biggest is April, when the volume is approximately twice as big as in the rest of the year. The peak coincides with brown hare’s mating season.

Between 2004 and 2011 767 Eurasian badger carcasses were registered (6.3% of all). March-April is the absolute peak of badger road kills (2.0 carcass/100 km/year), then it steadily decreases. From October to January there is only a very minimal volume of approximately 0.1-0.2 carcass/100 km/year that signalises the time of inactivity. I found no evidences of correlation between population density, and badger roadkills in spite of the observation, that badger easily digs under the fencing, and crosses it. Impact of passages was not identified, either. Both of these could be explained by the field experience, that badger often uses drainage under highways. This would explain as well, why such a commonly spread species as badger is only having 6% share of all wildlife roadkills. In order to reduce badger roadkill volume, it has a special importance to lower and dig the bottom of the fencing to ground; it is not enough to fix it to the ground surface.

5.7% of all wildlife roadkills are roe deer road kills, which predominantly occur in April-May (1.4 and 1.7 carcass/100 km/year annually). This peak is in times of territory fights, which brings big behavioural changes for roe deer. Common view (and the warning very often appears in media in middle-end of summers), that roe deer's mating season causes high traffic safety risks. Since the roe deer roadkill volumes in summer, after a very steep fall, do not even reach half of the volumes in spring, this theory is not applicable for Hungarian highways. PERIS és MORALES (2004) investigated temporal patterns animal mortality (individuals drawn to a canal), and found May, as well, to be the most frequent mortality time for roe deer. In line with this I conclude, that roe deer is highly vulnerable in times of territory fights. Zoological descriptions sometimes express it the way, that "testosterone overwhelms roe deer's brain", which makes bucks to attack competitors, or objects being similar to competitors, or even may attach humans. This may explain my results, and the one found by PERIS és MORALES (2004). I did not find correlation with population densities, but I proved that passages may decrease roe deer roadkill volumes. Exit roads have special importance for roe deer. which result is in line with the main result of (CSERKÉSZ et al. 2013). In spite roe deer is responsible only for 5.7% of wildlife roadkills, such WVCs may have much more serious consequences than a WVC with e.g. red fox, therefore efforts must be taken in order to avoid, lower, mitigate this frequency. Considering the strong seasonality and the dependency of exit roads (interchanges), seasonal mitigation methods may be advices and effective to handle the main conflict points.

256 wild boar roadkills means 2.1% of wildlife roadkills. This is not a great number, but it is still adequate to investigate wild boar roadkill patterns due to the level of damage in property may be very high by its big body mass. Common thinking usually refers to wild boar's mating season (later autumn, early winter), and later autumn winter hunting as main reason increasing roadkill volume. this would mean, that roadkill frequency should increase from October to December, and then, as hunting finish get back to lower levels. Contrary to this, my results suggest minimal roadkill levels from December to April, which start increasing in May, to a local peak in June. Then decreasing again, and after reaching its minimum in August, it peaks in October. Then, in November starts decreasing again. The local peak in June may be explained by the increasing activity caused by the bigger

feed requirements due to sounders' establishment. Wild boar is the only species, where I found correlation between population density and roadkill frequency, but its low level makes it impossible to draw any conclusions on it. Presence of underpasses reduced the volume of wild boar roadkill, and I managed to detect the impact of exit roads, as well (even if this impact was weaker than in case of roe deer). Based on all of these it seems mitigation measures for wild boar is one of the most difficult tasks: improving the quality of protective fencing, and avoiding its entering at exit roads would be basics. Additionally, it is not enough to base on a short period of the year (as it was for roe deer), since May to November should be covered "temporarily". Texas gates are internationally recommended to keep away wildlife at exit roads, but this is not a realistic alternative in Hungary.

Out of the rest of the nine wildlife groups marten sums up to 3.7%, the groups of otter, „polecat", and deer" groups together only reaches 1.7% of all wildlife roadkills. During these 12 years there were only 10 collisions with red deers, which is luckily too low number of concluding any patterns. Risk of red deer collision on the studied highways during the study time based on my results is insignificant. Important to mention the 100 otters victimized to traffic during the study time. Otter is strictly protected in Hungary, so the annually almost 10 otter road kills is a big number. Otter roadkills show no seasonal pattern, therefore mitigation measures cannot be based on it. Since otter habitats are strongly related to water, otter roadkill volume could be reduced by special attention to the quality of the protective fencing in proximity of water bodies.

4.4. General suggestions

My results show that Hungarian middle/big sized terrestrial fauna is generally involved into the conflict with transportation (road) infrastructure, that confirms my first hypothesis. This involvement can be caught in habitat fragmentation and in road mortality, as well. The Hungarian highways act as an almost total barrier for the middle/big sized terrestrial fauna due to protective fencing, the wide road surfaces, and due to the traffic. This, depending on the species may cause local problem, or even can threat survival of a population.

A roadkill provides explicit data about occurrence of species involved. CSATHÓ és CSATHÓ (2009), for example, found several first occurrences (proving specimen) to his study area. Protective fencing around highways is meant to keep out wildlife, but in spite of this almost all middle/big sized mammal can be found in SMM's roadkill database (MARKOLT et al. 2010b). Therefore, roadkill databases of road managers provide occurrence wildlife occurrence. For species, that are surely well identified my road controllers, roadkill database is suitable for monitoring (along highways). Therefore I recommend georeferenced roadkill data to regularly be joined (eventually integrated) to other similar fauna databases (such as NBmR, Vadonlese).

For rare, strictly protected species I recommend establishing a national protocol, where roadkilled specimen would be handed over to one of the national scientific institutions for further analysis instead of annulling it. Its basis is the recognition of the species by the road controller, which may be ensured by trainings.

In order to reduce wildlife roadkill volume of the main conflict species, I see three fields. The first is the protective fencing, because it seems to be not enough effective in exclusion of the three most often roadkilled species (red fox, brown hare, Eurasian badger). Changing this situation (by reducing the mesh size, lowering, and digging the fencing to ground, proper culvert design) would most probably result in remarkable fall in roadkills, and supposedly would be reducing wild boar roadkills, too. The second factor is the exit roads, which seems to have a crucial role in case of roe deer, and wild boar (the two most concerning species from traffic safety point of view). Considering the current Hungarian situation, and knowing, that wide application of texas gates is fully unrealistic, the systematic solution must be found somewhere else. Repellent methods used over the whole year seem to not be a good solution due to habituation, but in case of strong seasonality for roe deer, temporal/seasonal (April-May) repellent methods might be effective around the main conflict hotspots. The third field if fast identification and elimination problems found around the protective fencing (wrong implementation, vandalism, door left open, eroded embankment of highway, improper implementation and/or maintenance of culverts, etc.), which would probably avoid many road kills.

5. AUTHOR'S PUBLICATION RELATED TO THE SUBJECT OF THE DISSERTATION

5.1. Article in scientific journal with impact factor

MARKOLT F., SZEMETHY L., LEHOCZKI R., HELTAI M. (2012): Spatial and temporal evaluation of wildlife-vehicle collisions along the M3 Highway in Hungary. *North-Western Journal of Zoology*, 8 (2) 414-425 p. **(IF 2012: 0,706)**

5.2. Article in scientific journal with no impact factor

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5.3. Article in Hungarian journal

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5.4. Presentation on international conference

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5.5. Presentation on Hungarian conference

MARKOLT F., SZEMETHY L., LEHOCZKI R., HELTAI M. (2012): A térinformatika alkalmazási lehetőségei a vadelütések vizsgálatában. In: TŐZSÉR, J. & ALTBÄCKER, V., eds. *Animal welfare, etológia és tartástechnológia. Különszám.* A III. Gödöllői Állattenyésztési Tudományos Napok előadásainak és posztereinek összefoglaló kötete. 2011. Október 14-15. 2011 Gödöllő. Szent István Egyetem MKK Állattenyésztés-tudományi Intézet.

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6. AUTHOR'S PUBLICATION METHODOLOGICALLY RELATED TO THE SUBJECT OF THE DISSERTATION

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