NORTH-WESTERN JOURNAL OF ZOOLOGY 10 (2): 393-399 ©NwjZ, Oradea, Romania, 2014
Article No.: 141705 http://biozoojournals.ro/nwjz/index.html

The mortality patterns of wildlife-vehicle collisions in the Czech Republic

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Received: 30. September 2013 / Accepted: 15. February 2014 / Available online: 17. October 2014 / Printed: December 2014

Abstract. Wildlife-vehicle collisions (WVCs) have become an issue of growing concern across many countries world-wide. Such collisions can have serious implications for populations of free-ranging animals as well as for human safety and frequently cause considerable material damage. We have examined the national wildlife-vehicle collisions throughout the Czech Republic using the database compiled by the Czech Traffic Police during 2007-2009. Using chi-square goodness of fit tests and Geographic Information Systems software we tested the following hypotheses: (i) WVCs occur with the same frequency throughout the year, (ii) the frequency of WVCs is evenly distributed throughout the day, (iii) WVCs occur with the same probability in summer and winter, and (iv) WVCs occur with the same probability despite differences in surrounding vegetation type along roads. Our analysis revealed significant differences in occurrence of WVCs throughout the year and day. The lowest probability of WVCs was recorded in winter, whereas the highest occurred at the end of spring. The habitats surrounding the roads did not appear to have any significant effect on the number of WVCs. However, we were not able to evaluate proportions of individual mammal species in the WVCs data since this information was not included in the Czech Traffic Police database. In order to design suitable mitigation techniques, it is necessary to further evaluate and examine environmental factors and conditions associated with WVCs in general and for specific WVC hotspots in the Czech Republic.

Key words: car/road accident, game, migration, mortality, transport network.

Introduction

Increasing urbanisation and infrastructural development from the past decades have led to a considerable increase in wildlife-vehicle collisions (hereinafter ´WVCs´, e.g. Montgomery et al. 2012, Meisingset et al. 2013). Such collisions pose a serious threat to populations of free-ranging animals and natural habitats (Gunson et al. 2012), as well as to human safety (Iuell et al. 2003). The ecological effects of roads on environment have been widely documented (e.g. Olsson & Widen 2008, Shepard et al. 2008, Kušta et al. 2011, Neuman et al. 2012, Wang et al. 2013). WVCs are a significant cause of mortality for many free-ranging animals and may affect population density as well as long-term survival and viability (Lao et al. 2010, Neuman et al. 2012, Ascensǎo et al. 2013). In addition, linear features such as roads and highways affect animals in many other ways, such as habitat fragmentation and alteration and modification of animal behavior (Trombulak & Frisell 2000). The rate of WVCs may be related to a number of factors, such as technical aspects of roads, traffic volume, vehicle speed, type and attractiveness of surrounding vegetation type, time of day, or the animals' motivation for crossing the road (Iuell et al. 2003, Morellet et al. 2007, Keken et al. 2011, Sullivan 2011).

It has been documented that the most negative impact of roads on mammal populations is not the mortality of individuals themselves due to collisions with vehicles but rather the fragmentation of their habitat, due to limitations on migration within their home ranges (Trombulak & Frisell 2000). According to Anděl et al. (2005), there is a serious risk that extensive areas of animal occurrence will be permanently cut off, resulting in isolated populations. This could endanger the long-term survival and viability of populations of certain migratory species, especially large mammals. Despite the well-described negative impacts of linear features of infrastructural development on free-ranging animals(e.g. Iuell et al. 2003), the mechanisms that provoke animal responses to roads are often ambiguous or poorly understood (Montgomery et al. 2013).

Animal road crossings are not evenly distributed throughout different spatiotemporal scales (Seiler 2005, Dussault et al. 2006, Danks & Porter 2010). Migratory species can be quite persistent in their use of crossing sites, a fact which should be considered when planning and constructing new roads (Bruggeman et al., 2007). Increasing numbers of WVCs and their often unpredictable effects on animal population development have resulted in several attempts to identify effective mitigation measures (e.g. fencing, warning reflectors, speed limits, efforts to increase driver awareness, over/under-passes etc. (see review in Putman 1997). Nevertheless, no single technique can reliably eliminate WVCs altogether. When selecting the best places to locate mitigation measures, a number of factors become relevant including traffic volume and speed, density of animal populations, driver awareness, time of year/month/day, road attractiveness, integration into surrounding landscape, and roadside vegetation (Litvaitis & Tash 2008).

WVCs are a growing and multifaceted problem also in the Czech Republic. This problem is important because of safety reasons, biodiversity conservation and the economic costs implied. According to Mrtka & Borkovcová (2013) the estimated annual costs related to WVCs exceed €100 million annually in the Czech Republic. To better understand the factors influencing WVCs and to identify hotspots for the future implementation of effective mitigation measures, more knowledge about the location and timing of WVCs is required. Such a country-wide study is still lacking in the Czech Republic. Therefore, the aim of our study was to contribute to the understanding of the temporal dynamics of WVCs in the Czech Republic at daily, monthly and yearly scales in a variety of vegetation types.

Materials and Methods

Study area

Our study was conducted in the Czech Republic (Fig.1), which is a landlocked Central European state with an area of 78 867 km², population of 10 532 770 inhabitants, and population density of 133 inhabitants/km² (Czech Statistical Office 2012) . The climate is moderate, transitional between continental and oceanic. A succession of four seasons is typical. The forests are predominantly coniferous and cover approximately 34% of the country (Czech statistical office 2012) . According to the Road and Motorway Directorate of the Czech Republic, the total length of motorways and other roads in the Czech Republic is 55 654 km. The highway density is 7.1 km/1000 km².

Data collection

We used existing information on WVCs compiled by the Traffic Police of the Czech Republic during 2007-2009(Police of the Czech Republic 2012). The data includes date, time and location of each collision (GPS coordinates). Collisions are recorded only in cases when substantial damage to tangible property occurred, without noting the animal species involved. Nevertheless, data has been published regarding the wild animals most commonly involved in WVCs from the Czech Republic (Mrtka & Borkovcová 2013). These are: *Lepus europaeus* - 144 000 road kills during the study period, *Capreolus capreolus* - 129 000, *Erinaceus* spp. - 32 000, *Martes* spp. - 19 000, *Vulpes vulpes* - 17 000, and *Sus scrofa* - 17 000 (Mrtka & Borkovcová 2013). Regarding the financial costs related to WVCs, the highest average cost per collision (damage only on tangible property, lost on wildlife were not include) was for *Capreolus capreolus* and *Sus scrofa* (Mrtka & Borkovcová 2013, Anděl et al. 2011). Based on these results, we assumed that the data from The Traffic Police represents mainly collisions which have involved *Capreolus capreolus*.

Roads were categorized as following: controlled-access highways (i.e. major highways in the Czech Republic, hereinafter ´highways´) and other roads (i.e. other drivable motorways and freeways). For each study year, highways and other roads with the highest number of WVCs were selected for the analyses (Fig. 1).

Data analyses

We used a chi-square goodness of fit tests (Sokal & Rohlf 1995), with $\alpha < 0.05$ indicating significance in order to:

(i) Test the correspondence between the distribution of WVCs per month with an even distribution (i.e. whether the occurrence of WVCs depends on a month).

(ii) Test the correspondence between the distribution of WVCs within each hour throughout day and an even distribution (i.e. whether the probability of the occurrence of WVCs depends on an hour of the day).

(iii) Test the correspondence between the winter (i.e. October-March) and summer (i.e. April-September) distribution of WVCs during the day (i.e. whether the probability of the occurrence of WVCs in different hours of the day depends on winter/summer season).

(iv) Test whether the probability of WVCs depends on surrounding vegetation type. The distribution of vegetation types where the WVCs occurred were tested against a distribution of vegetation types observed at randomly selected locations (see below for details of this selection). The vegetation types were classified as follows:

(a) Open vegetation on both sides of highway/road (e.g. meadow, field).

(b) Forest on both sides of highway/road.

(c) Open vegetation on one side of highway/road and forest on the other side.

Using ArcGIS 9.3 software, a map of the highways/roads network was created for the Czech Republic from available maps (source: Road and Motorway Directorate of the Czech Republic, http://www.rsd.cz/Mapy) by semi-automatic vectorization to determine the propor-

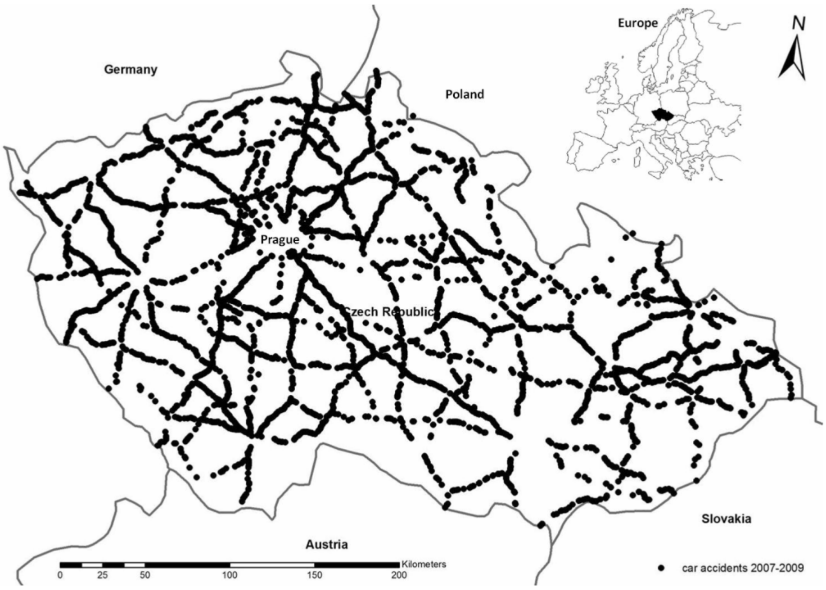

Figure 1. Localization and Map of recorded wildlife-vehicle collisions in the Czech Republic during 2007-2009.

tions of vegetation types. Within the vectorized network, 60 randomly located points were generated for highways and 500 points for other roads using the *Create random points* feature. The number of points was selected so that it reflects the different sizes of the road and highways network (i.e. larger road network than highway network). Points that were generated in urban areas and points in which the location type could not be determined were excluded (0 points for highways and 200 points for other roads). Using the resulting sample sizes (i.e. 60 points for highways and 300 points for other roads), both observed and expected frequencies in the chi-squared tests were greater than 10, which is sufficient for the validity of the test. For each point, the type of habitat was determined by a visual assessment from an orthophoto map (source: Czech National Geoportal INSPIRE, http://geoportal.gov.cz).

All calculations were performed in the Microsoft Excel 2003 software and ESRI ArcGIS 9.3 software.

Results

In total, 50 highways and other roads with 7, 475 WVCs were analyzed for each study year (Fig. 1).

Distribution of WVCs throughout the year

In the case of highways, the distribution of WVCs was significantly different from an even distribution, i.e. the number of WVCs depended on month (χ^2 = 356.000; p = 1 x 10^{-69}). The lowest probability of WVC occurrence was from November to March and the highest probability of WVCs was in April and May.

Similarly, in the case of other roads, the number of WVCs depended on month (χ^2 = 424.936; p = 3 x 10^{-84}). The lowest probability of WVC occurrence was from January to March and the highest probability of WVCs was in April, May, October and November (Fig. 2).

Distribution of WVCs throughout the day

The distribution of WVCs throughout the day differed significantly from an even distribution in both highways (χ^2 = 420,062; p = 3 x 10^{-83}) and other roads (χ^2 = 2,045.616; p = 0).

Distribution of WVCs in winter and summer

The distribution of WVCs during the day in winter differed significantly from the distribution of WVCs during the day in summer both for highways (χ^2 = 1,096.242; p = 4 x 10^{-217}) and other roads (χ^2 = 84.232; p = 2 x 10^{-13}; Fig. 3 and 4).

Probability of WVCs on surrounding habitat types

There were no significant differences in WVC occurrence for both highways (χ^2 = 4.236; p = 0.120) and other roads (χ^2 = 0.201; p = 0.904).

Discussion

Our study was not able to evaluate proportions of individual animal species in the WVCs data since

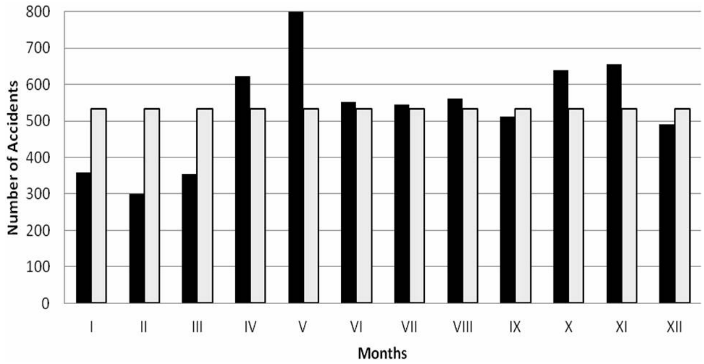

Figure 2. Histogram of the frequency of accidents in each month (dark) and what expected distribution would be (light) – other roads.

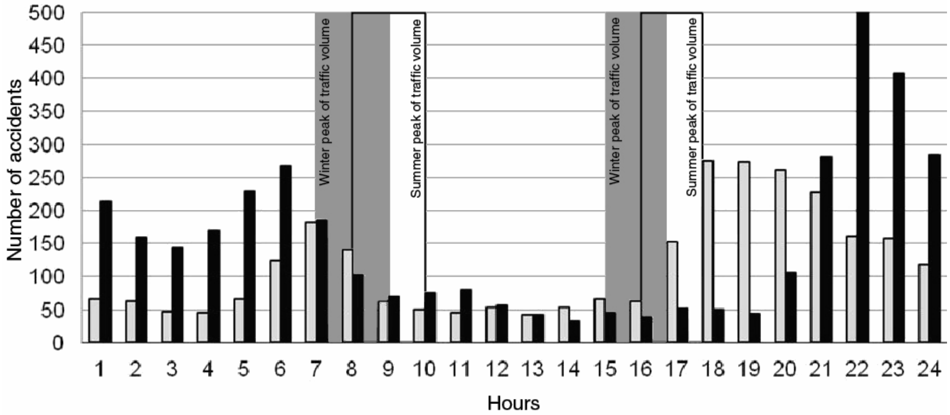

Figure 3. Histogram of the number of wildlife-vehicle collisions throughout the day in winter (light) and in summer (dark) – other roads. Peak of the traffic volume in winter is represented by the white column and peak of the traffic volume in summer is represented by the grey column.

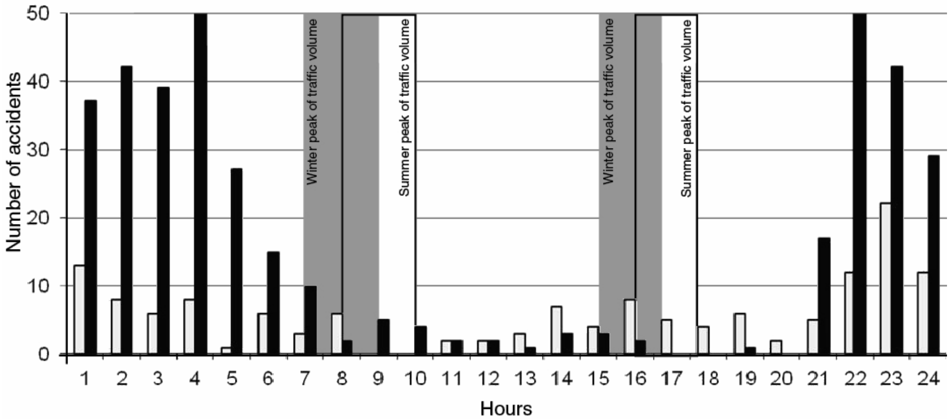

Figure 4. Histogram of the number of wildlife-vehicle collisions throughout the day in winter (light) and in summer (dark) – highways. Peak of the traffic volume in winter is represented by the white column and peak of the traffic volume in summer is represented by the grey column.

this information was not included in the database acquired from the Czech Traffic Police. Therefore, we used results of Borkovcová et al. (2012) in order to determine the most common species subject of WVCs in the Czech Republic, which is *Capreolus capreolus*. *C. capreolus* is the most numerous ungulate species throughout the Czech Republic, occupying open agricultural lands as well as forested areas (Červený 2009).

Our results showed significant differences in the occurrence of WVCs throughout the year as well as day in case of both highways and other roads. The higher occurrence of WVCs in spring and summer might be related to offspring dispersal and the search for new territory, which is also shown in a studies by Sullivan (2011) and Markolt et al. (2012). Spring is also a period of seeking for highly nutritional food resources after the harsh winter period (Van Soest 1994, Van Beest et al. 2010), and therefore, movement activity is higher. The hunting season can also be included as a predictor of WVCs including *C. capreolus* (e.g. hunting season in the Czech Republic lasts from May to September [males], and from September until the end of December [females and juveniles]) which follows the peaks of WVCs at the end of spring and beginning of autumn. Moreover, spring is a period of high tourism pressure in forest habitats and open landscapes, and wildlife can be more disturbed by humans and thus have higher movement activity (Farrell & Tappe, 2007). Our findings on distribution of WVCs throughout the year are in accordance with WVC data from Switzerland (Burnand et al. 1985). There were also two peaks in collisions with roe deer, one in April and May and the second one in October.

Peaks in the number of collisions at varying times of day or night are probably connected to the main activity periods of *C. capreolus*. We also showed that WVCs were not evenly distributed throughout the day, which may be caused by the greater movement activity of the species during their grazing cycles, especially at dusk and dawn. In both cases (i.e. highways and other roads) the highest numbers of WVCs occurred at night with the peaks at dawn and dusk. The highest peak of WVCs occurring during dawn and dusk was also shown in a study of Carbaugh, et al. (1975), conducted on the Allegheny plateau in Pennsylvania across an area with a large deer population, in a deciduous forest area.

Our results also suggested that the occurrence of WVCs during winter and summer was significantly different throughout the day (Fig. 3 and Fig. 4). In both cases the collisions were most frequent at dusk and dawn. According to Hobbs et al. (1981) or Gleason & Jenks (1993), Sielecki (2000) the surrounding habitats along roads are not attractive feeding sites for ungulates in winter, and thus they are not present along roads during winter. This is also confirmed by the study of Bissonette & Hammer (2000), wherein the highest density of ungulates along roads as well as the highest number of collisions were observed in May, whereas the lowest in winter (November–March).

Another factor influencing the probability of WVCs is the volume of traffic (Iuell et al. 2003). It has been shown that high levels of traffic volume may serve as a barrier to wildlife (i.e. mammals do not attempt to cross the road due to the number of vehicles; Jaarsma et al. 2002, Trocmé et al. 2003, Kušta & Keken 2009). Nevertheless, lower traffic volume do not necessarily equate to fewer WVCs, because low-volume roads may present less of a barrier to animals than high-volume roads (Beckmann et al. 2010). However, our data showed that most of the WVCs happened on roads and at times of lower traffic volume (i.e. peaks in traffic volume in the Czech Republic occur between 07:00 AM – 09:00 AM and 03:00 PM – 05:00 PM in winter, while peaks of WVCs in summer occur from 08:00 AM – 10:00 AM and 04:00 PM – 06:00 PM). Peaks in winter WVCs are almost in direct correlation with peaks of traffic volume, because peaks of traffic volume correlate with dusk and dawn.

Our analyses did not reveal any significant effect of habitat type along the road on the number of WVCs. This finding is in contrast with the study of Müller & Berthould (1997) from Switzerland, who reported prevalence of WVCs with *Capreolus capreolus* in open landscapes (such as meadows, pastures and fields) and least occurrence of WVCs in forests. However Recorbet and Désiré (1985) found WVCs to be more frequent in forested areas. Other studies have shown that high density of edge habitat between forest and fields or pastures, and also lower distance to forest, increase the risk of WVCs (Farrell & Tappe, 2007; Found & Boyce 2011). In our study, we did not take into account the ecotone effect because we focused on differences between individual types of habitat forest and field in general, and probably this is the cause for our non-significant results.

Our study provided a first country-wide insight on the WVCs throughout the Czech Republic for a period of three consecutive years. Future research efforts should aim toward examination and evaluation of hotspots of WVCs, determination of environmental conditions and factors related to WVCs in order to implement suitable mitigation techniques (e.g. odor repellents, traffic signs, speed limits, or warning lights or technical measures on roads or in their vicinity). More information is needed on the identity of mammal species killed by vehicles on roads in the Czech Republic in order to determine target species for the mitigation process. Also, more information is needed on the movement, activity patterns and behavior of large mammals around roads, especially *Capreolus capreolus*, as well as evaluation of environmental factors and conditions associated with the occurrence of WVCs in order to elaborate effective mitigation measures.

Acknowledgements. This study was supported by the Ministry of Agriculture of the Czech Republic, Grant No. QJ1220314.

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