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Deer on the railway line: spatiotemporal trends in mortality patterns of roe deer

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Abstract: Traffic-related mortality of free-ranging animals is among the most commonly observed human–wildlife conflicts. These conflicts pose serious threats to human safety as well as having great economic consequences. Although considerable attention has been paid to the role of roads in affecting free-ranging animals, the effects of railways have been less studied. Our study provides initial insights into the spatial and temporal variability of the roe deer–train collisions at 4 selected railway sections in the Czech Republic. Using data on 69 roe deer–train collisions collected during 2009, we tested the effects of railway section length, train frequency, relative abundance of roe deer, and time of year (by month) on collision probability. The number of roe deer–train collisions was influenced by train frequency (i.e. the higher the number of trains passing through individual study sections, the higher the number of collisions) and the time of the year (i.e. the highest number of collisions occurred in winter, particularly in February). Future research efforts should focus on describing roe deer behavior and movement patterns along the railways as well as the mortality factors related to the accidents. Such findings will help to identify hotspots of future accidents and to design suitable mitigation measures.

Key words: Animal–train collisions, traffic mortality, Czech Republic

1. Introduction

To meet the demands of an increasing human population and resulting economic development, the volume of traffic has rapidly increased in past decades (Groot Bruinderink and Hazebroek, 1996; Frair et al., 2008). Simultaneously, better wildlife management and conservation measures have also led to an increase in the populations of large mammalian herbivores, both in density and distribution, throughout Europe (Apollonio et al., 2010). The increase in population size and density of these animals is now creating problems of human–wildlife conflict in various forms (Redpath et al., 2013). One widely occurring form of human–wildlife conflict is traffic-related mortality of ungulates, which is commonly observed throughout Europe (e.g., Rolandsen et al., 2011).

Populations of wild ungulates have been increasing throughout the Czech Republic over the last decades, and roe deer (*Capreolus capreolus*) is the most common, occupying open agricultural lands as well as forested areas (Červený, 2009). Considering the intensity and location of railway traffic and the high abundance and density of ungulates in the Czech Republic, frequent deer–train collisions are to be expected (Modafferi, 1991; http://www.cd.cz). Nonetheless, there is little existing research that has investigated the role of railways in affecting the populations of wild ungulates in the Czech Republic (Havlín, 1987; Jankovský and Čech, 2008; Kušta et al., 2011) and only a few studies have focused on this issue worldwide (e.g., Baofa et al., 2006). On the other hand, a large number of studies address the issue of mortality of wildlife due to road traffic (e.g., Langbein and Putman, 2005; Dussault et al., 2006; Gonzáles-Gallina et al., 2013).

Theoretically, roads and railways should have similar ecological impacts on wildlife (Canters et al., 1997; Joyce and Mahoney, 2001). Besides direct mortality of animals, roads and railways can affect wildlife in numerous different ways: by causing habitat loss and fragmentation, creating barriers to movement and behavioral modifications, increasing dispersal of exotic species, and, thereby, reducing long-term survival and population viability (Trombulak and Frisell, 2000). Animal–vehicle collisions also pose a serious threat to human safety and can have significant economic consequences as a result of medical costs and the costly measures adopted to prevent accidents, such as wildlife fences along roads (Groot Bruinderink and Hazebroek, 1996; Ascensão et. al., 2013). Although

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collisions with trains may be less threatening to humans, they are certainly important from a wildlife management perspective and might even be more common than collisions on roads (Van der Grift, 1999).

In this primarily exploratory study, we aimed to examine the spatial and temporal patterns of roe deer–train collisions on 4 selected railway sections in the Czech Republic. We chose roe deer because it is the most numerous ungulate species and is important from a management perspective (both for hunting and habitat conservation). Specifically, we tested the effect of train frequency on roe deer–train collisions, assessed the temporal variability of collisions at each individual railway section, and, finally, determined the spatial variability of collisions across railway sections.

2. Materials and methods

2.1. Study area

The study was restricted to 4 selected railway sections in the Czech Republic with known occurrence of roe deer (Červený, 2009). The railway sections Plzeň–Horažďovice (hereinafter "section 1"; length: 60 km; 410 m a.s.l.) and Bělčice–Závišín (hereinafter "section 2"; length: 4.5 km; 520 m a.s.l.) run through the southwestern part of the Czech Republic. The sections Obrataň–Jindřichův Hradec (hereinafter "section 3"; length: 15.2 km; 660 m a.s.l.) and Dobrá Voda u Pelhřimova–Hříběcí (hereinafter "section 4"; length: 6 km; 650 m a.s.l.) are located in the south of the country (Figure 1).

2.2. Data collection

We calculated the train frequency (i.e. the number of trains passing per month through individual study sections) based on the Czech Railway's timetable for 2008–2009 (http://www.cd.cz/en/domestic-travel/timetable/line-timetables/index.php). We acquired the hunting statistics (http://eagri.cz/public/web/mze/lesy/myslivost/) on roe deer (i.e. animals killed per 100-ha area around the individual sections during 2009) as a proxy for the relative abundance of the species near the individual study sections. We used this dataset as it provides the most reliable indicator of roe

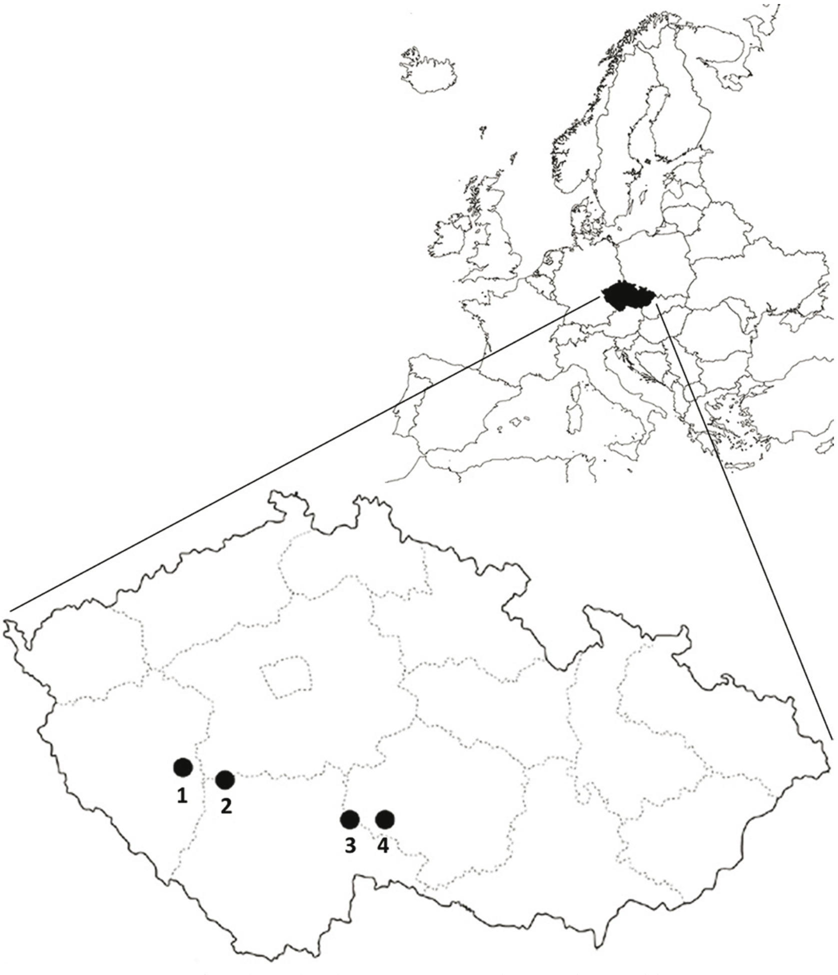

Figure 1. Location of 4 selected railway sections in the Czech Republic.

deer densities in the Czech Republic (Bartoš et al., 2010). Data on train kills were collected opportunistically during 2009 from train drivers who were required to record the locations and dates of the roe deer–train collisions while passing through the individual study sections. These locations were identified and marked based on the distance markers placed along tracks, which are used by the Czech Railway for distance indication. We also performed round trips along each study section twice per month throughout the study period in order to record any other roe deer–train collisions missed by the drivers and to map the surrounding habitats around each railway section. The habitats surrounding the collision locations were categorized as predominantly field/meadow, forests, or shrubland by section. The recorded locations were later checked for redundant duplication of recording, and only unique instances were selected for analyses.

2.3. Statistical analyses

We first estimated the relationship between the number of collisions and the spatial characteristics of individual study sections (i.e. section length, train frequency, and relative abundance of roe deer). We tested for correlations using Pearson's correlation coefficients (r) between each of these variables, in pairs. To test what predicts the probability of roe deer–train collision, we regressed train frequency per month in the individual study sections and months against number of collisions. We designated month as the temporal scale variation because the collision data and train frequency were collected and measured at this scale. However, we aimed to relate results by month to roe deer lifecycle and management measures. The winter season lasts from December to April, calving occurs from May to June, and rutting occurs during July and August. The hunting season lasts from May to September for bucks and from September to December for does and fawns. Deer are also given supplementary feed from September until April (Bartoš et al., 2010).

We used generalized linear mixed-effects models (GLMMs) with a Poisson error structure (Zuur et al., 2009) to identify the predictors of collision probability. Train frequency (i.e. number of trains passing per month through individual study sections) and month were treated as fixed effects and section identity as a random effect (to account for repeated measurements of roe deer–train collisions from the same railway sections). The models were fitted using the *glmer* function in R and estimated with the Laplace approximation. Model selection was performed using the ANOVA function and Akaike's information criterion (AIC) to compare the fit of individual and combined variables, with ΔAIC > 10 indicating that the model was unlikely to perform better than the model with the lowest AIC (Burnham and Anderson, 2002). All statistical analyses were performed in R 3.0.2 statistical software (R Development Core Team, 2009) with the *lme4* (cran.r-project.org/package=lme4) package.

3. Results

3.1. Spatial trends

A total of 69 roe deer–train collisions were recorded across the 4 selected railway sections during 2009. The highest number of collisions was recorded at section 1 (n = 36), and 11 accidents were recorded at each of sections 2, 3, and 4.

The relative abundance of roe deer was highest at section 2 and lowest at section 4. Sections 1, 2, and 3 were predominantly field/meadow, whereas section 4 was mostly forested (Table 1). The number of collisions was positively correlated with the length of the railway section ($r^2 = 0.89$, $P < 0.04$) and the train frequency ($r^2 = 0.88$, $P < 0.04$), whereas the number of collisions and relative abundance of roe deer were not correlated ($r^2 = 0.313$, $P < 0.6$). The sections with a higher proportion of field/meadow habitats (sections 1, 2, and 3) were also the ones with a higher number of collisions, whereas section 4, dominated by forest, had fewer recorded collisions (Table 1).

A comparison of tested GLMMs, including AIC and ΔAIC values, is shown in Table 2. The best model (judged by the lowest AIC value) included train frequency as a fixed effect and section identity as a random effect. Nevertheless, the difference in AICs between this simpler model and a

Table 1. Spatial characteristics of individual railway sections surveyed for this study.

	Number of trains passing per week	Relative abundance of roe deer*	Surrounding habitats (%)		
			Field/meadow	Forest	Shrubland
Section 1	452	1.61	84	10	6
Section 2	170	2.17	85	5	10
Section 3	156	1.67	49	37	14
Section 4	132	1.06	23	69	8

*Animals killed per 100-ha area around the individual sections during 2009.

Table 2. Model comparison for factors potentially influencing the probability of roe deer–train collisions.

Model	Fixed effects	Random effects	AIC	ΔAIC
1	Train frequency	Railway section	144	0
2	Month + train frequency	Railway section	152	8
3	Month	Railway section	160	10

AIC: Akaike's information criterion; ΔAIC: $AIC_i - AIC_{min}$.

more complex model that also included month as a fixed effect was only 8 points, showing the simpler model to be only a slightly better relative fit than the more complex one (Table 2). Moreover, the ANOVA test did not show any significant difference between the 2 models ($P > 0.2779$). On this basis we decided to use the more complex model. The estimated coefficients and standard errors for the variables of the final model are shown in Table 3.

While accounting for the random variation due to railway section, the train frequency (i.e. number of trains passing per month through individual study sections) had a positive effect on the number of roe deer–train collisions (0.84 ± 0.00; $P < 0.0017$; Table 3).

Table 3. Results of the final generalized linear mixed effects model for the effects of month and train frequency on the occurrence of roe deer–train collisions.

	Estimate ± std. error
Fixed effects	
Intercept	–0.99 ± 0.64
May	0.36 ± 0.65
June	0.40 ± 0.64
July	0.36 ± 0.61
August	0.65 ± 0.61
September	0.69 ± 0.76
October	–0.33 ± 0.71
November	–0.25 ± 0.70
December	–0.38 ± 0.76
January	–0.33 ± 0.76
February	0.12 ± 0.58*
Train frequency	0.84 ± 0.00***
Random effect	Variance ± std. error
Segment	0.78 ± 0.47

*: Significant at 0.05; ***: Significant at 0.001.

3.2. Temporal trends

The number of collisions was highest in winter, especially in the month of February (Figure 2), and the month of February also emerged as significant in the final GLMM ($P < 0.0191$; Table 3). The effect of the remaining months was not significant (Table 3). However, this trend was not consistent over the sections as the collisions occurred throughout the year across sections and varied in number (Figure 2).

4. Discussion

We show that, even within a short sampling period, a large number of roe deer–train collisions were recorded. This finding in itself reemphasizes the importance of this issue and calls for more attention to be paid to wildlife–train collisions by researchers and wildlife management authorities. Our results suggest that the train frequency (i.e. number of trains passing through individual railway section per month) influences the probability of roe deer–train collisions. The effect of traffic frequency on the probability of accidents has already been shown in other studies (e.g., Seiler, 2004; Hussain et al., 2007; Danks and Porter, 2010). Our study concurs with these, as the number of roe deer–train collisions was positively correlated with the traffic frequency (Belant, 1995; Joyce and Mahoney, 2001). A higher train frequency for roe deer means that the deer encounter more trains per time unit, which would constantly agitate the animals, inciting flight and erratic movements and thus resulting in more collisions.

Our analyses revealed that the number of collisions was highest in winter and the most statistically significant month was February. Winter is generally the lean period in terms of food availability, and quality and presence of snow combined with scarcity of food affects the movement of ungulates (Marchand, 1996). Ungulates are forced to cover larger distances in winter in order to find food and snow-free areas or those with little snow where they can dig easily. Such areas can usually be found along roads and railways (Bowman et al., 2010; Rea et al., 2010). This could be an explanation for the increased frequency of deer–train collisions in our study areas, as deer may move more during winter months. February is one of the months when

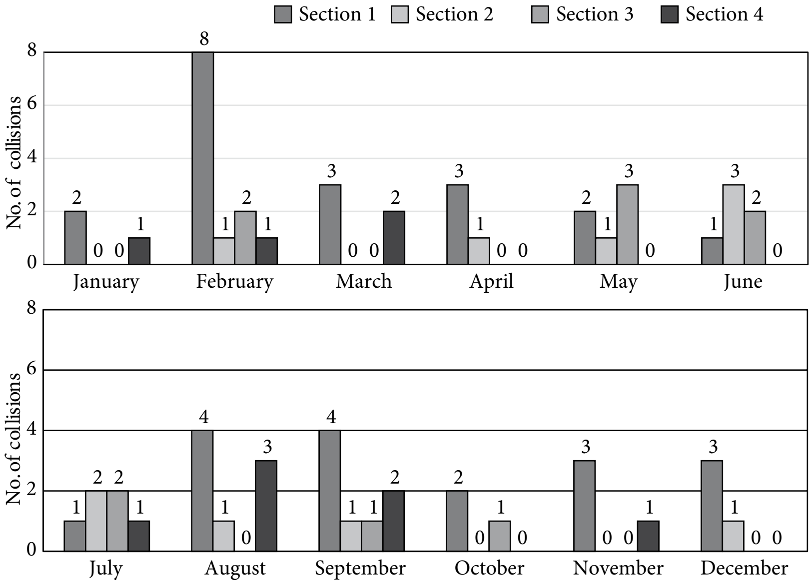

Figure 2. Bar plots showing spatial and temporal patterns of roe deer–train collisions between selected railway sections in the Czech Republic during 2009. The numbers above the bars represent the counts of collisions for each railway section during the particular month. Zero indicates that no collisions were recorded in that period.

deer are provided extensively with supplementary feed across the Czech Republic. Such practices are known to alter density and distribution of animals as well as increase direct and indirect interactions between individuals (Putman and Staines, 2003). Consequently, reactions to supplementary feeding could explain the higher number of collisions during winter, especially if feeding sites are close to railways and supplementary feeding increases direct competitive interactions between individuals.

An increase in deer–vehicle collisions in winter has also been observed for other deer species such as red deer (*Cervus elaphus*) and moose (*Alces alces*) in Norway (Gundersen and Andreassen, 1998; Meisingset et al., 2013) and mule deer (*Odocoileus heminonus heminonus*) in the United States (Myers et al., 2008). Studies from British Columbia in Canada (Child et al., 1991), northern Sweden (Lavsund and Sandegren, 1991), and Finland (Haikonen and Summala, 2001) also reported a peak in deer–vehicle accidents in midwinter. However, in other studies, collisions have been observed to peak in summer, e.g., roe deer in Slovenia (Pokorny, 2006) and moose in Quebec (Dussault et al., 2006) and Newfoundland (Joyce and Mahoney, 2001). This indicates that local factors and species biology likely affect the probability of accidents.

There are other factors that are known to affect the likelihood of deer–vehicle collisions, such as habitat characteristics around the traffic infrastructure (Seiler, 2003). Habitat features are known to determine the habitat selection patterns of ungulates, and roe deer are known to prefer open agricultural landscapes (Cederlund et al., 1980). In our study areas, railway sections with a high proportion of open fields (i.e. 1, 2, and 3) had higher roe deer density and frequent collisions. A high proportion of fields in sections 1, 2, and 3 corresponded with higher human population density, which, in turn, corresponded to higher train frequency in these sections.

Overall, human inhabitation and resulting changes in the landscape affect the likelihood of collisions (Cederlund et al., 1980; Nielsen et al., 2003). Our study provides an initial but crucial insight on the issue, but additional information is clearly needed. More sampling is required across railway sections to get a broader picture of the issue over time. In addition, studies on roe deer movement and behavior around the railway tracks are also needed to understand the causes and patterns of collisions in more detail. Countrywide studies are required in order to develop a nationwide policy of mitigation measures to minimize deer–train collisions. More accurate information building on our study would contribute to making sure that these policies, such as train speed limits in areas with higher train frequency stretching across different habitat types, are both appropriate and effective.

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