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Assessment of roe deer (*Capreolus capreolus* L.) – vehicle accident hotspots with respect to the location of 'trees outside forest' along roadsides

Dominik Seidel*, Nalise Hähn, Peter Annighöfer, Anke Benten, Torsten Vor, Christian Ammer

Department of Silviculture of the Temperate Zones, Faculty of Forest Sciences, University of Göttingen, Büsgenweg 1, 37077 Göttingen, Germany

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ABSTRACT

Animal-vehicle collisions (AVCs) pose a serious threat to human and animal welfare, and result in increasing costs for society. Mitigation efforts have been in the focus of research for decades but have revealed only few generalities on where and why AVCs occur. Uncertainty therefore remains on how to make decisions regarding nature conservation, wildlife and transportation management. In our study, we used GPS data on almost 1000 AVCs between October 2014 and October 2016 involving roe deer (*Capreolus capreolus* L.) in the administrative district of Göttingen, Germany, to identify accident hotspots based on Kernel Density analysis. We then used information from a mapping campaign of trees outside forests (TOF), including hedges, bushes, groves, isolated trees and other non-forest vegetation to investigate whether TOF abundance is larger near accident hotspots when compared to areas showing no hotspots (assumed as reference area). We found that near hotspots, TOF are significantly more abundant than in the remaining reference area. We conclude that future transportation management should consider TOF management as a possible indicator for AVCs.

1. Introduction

Around the globe, animal-vehicle collisions (AVCs) result in significant losses of animal and human welfare, with thousands of people injured or killed, millions of animal fatalities, and billions in economic losses each year (e.g. Danielson & Hubbard, 1998; Hothorn, Müller, Held, Möst, & Mysterud, 2015; Kušta, Keken, Ježek, & Kůta, 2015). In Germany alone, more than 500 AVCs occur per day (Hothorn, Brandl, & Müller, 2012). Here, and in other European countries, deer species (family: Cervidae) and wild boar (*Sus scrofa* L.) are most often involved in serious collisions (Finder, Roseberry, & Woolf, 1999; Lavsund & Sandegren, 1991; Malo, Suarez, & Diez, 2004; Seiler, 2004). Statistics only cover accidents that include injured humans or at least claimable damage on the vehicle (e.g. Biggs, Sherwood, Michalak, Hansen, & Bare, 2004; Gunson, Chruszcz, & Clevenger, 2003; Hussain, Armstrong, Brown, & Hogland, 2007), so estimates suggest a mere 25–60% of all accidents are ever reported (Steiner, Leisch, & Hackländer, 2014). All over Europe, AVCs are of high concern as the number of vehicle-miles travelled is increasing, animal populations are growing and human settlements continue to expand into wildlife habitats (e.g. Gkritza, Baird, & Hans, 2010). The negative effects of AVCs on ecology, economy and public health are therefore likely to increase (e.g. van der Ree, Smith, & Grilo, 2015).

Mitigation efforts have been in the focus of research for decades but so far only few generalities on where and why collisions occur have been revealed (Clevenger, Barrueto, Gunson, Caryl, & Ford, 2015). A US-based study pointed out that mitigation measures based on animal behavior and movement patterns perform best (Romin & Bissonette, 1996). Accordingly, several studies found that most accidents happen in the hours of dusk and dawn and during rut (e.g. Allen & McCullough, 1976; Bruinderink & Hazebroek, 1996; Haikonen & Summala, 2001).

Evidently, a successful mitigation of AVCs requires an understanding of why and where an animal may cross a road. Identifying the spatiotemporal drivers of animal movements may hence provide useful knowledge to prevent accidents. While we have a good understanding of relevant temporal processes (Hothorn et al., 2015; Steiner et al., 2014), the relationship between the spatial landscape structure and AVCs is less clear and more difficult to analyse. Even with similar animal population densities in the surrounding areas, large differences exist in the number of AVCs for adjacent road stretches (van der Ree et al., 2015). This supports the theory that spatial characteristics are of great importance for the issue.

Previous studies addressed landscape configuration measures, such as object type (e.g. forest, field, building etc.), object distance to an accident site, or land-use cover percentages of the total area in a zone of interest around the crash site (e.g. Clevenger et al., 2015). In the past, only few generalities on the effect of landscape elements on AVCs have been identified because many studies used inadequate methods

* Corresponding author.
E-mail address: dseidel@gwdg.de (D. Seidel).

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(inadequate replicates, no inclusion of control sites, etc.) as pointed out by Danielson and Hubbard (1998). Others factors, such as the species-specific behavior, as well as specific road and landscape characteristics contribute to the poor generalization of study findings. More recent studies used sophisticated approaches based on statistics that address the complex landscape configuration as an explanatory variable (e.g. Malo et al., 2004). Others used models of landscape connectivity (e.g. McRae, Dickson, Keitt, & Shah, 2008) or network analysis (Bíl, Andrášik, Svoboda, &,Sedoník, 2016) to understand the relationship between animal movement pattern and accident hotspot location.

We know with a degree of certainty that increased landscape diversity next to the road (e.g. Found & Boyce, 2011; Hubbard, Danielson, & Schmitz, 2000) and the presence of gullies or riparian zones (Finder et al., 1999) increased the chances of an AVC. Also, studies reported that AVCs are not randomly located along roads (Gonser, Jensen, & Wolf, 2009) and landscape structure was correlated with AVC locations, even better than traffic volume (Hubbard et al., 2000) or traffic speed (Gonser et al., 2009). Certain percentages of habitat types in the overall area around a crash site seem to increase the chance of an AVC, and there is evidence that this is consistent across spatial scales (Gonser et al., 2009; Malo et al., 2004). While large-scale patterns, e.g. the regional land use, may determine deer movement patterns, the local-scale environment, e.g. the presence of vegetation near the road, will determine the likelihood of an AVC at a specific site (Clevenger et al., 2015).

This is where the present study wants to provide new insights. We hypothesize that the presence and coverage of trees outside forest (TOF), denoting small groves, tree groups, isolated trees, hedges, bushes and riverside vegetation that are not defined as forests according to the FAO definition (Bellefontaine, Petit, Pain-Orcet, Deleporte, & Bertault, 2002), along a road network are associated with an increased risk of collision with roe deer (*Capreolus capreolus* L.) We assume this would be the case as TOFs reduce the drivers' visibility and reaction time but simultaneously, in agreement with previous studies (e.g. Clevenger et al., 2015; Found & Boyce, 2011; Hubbard et al., 2000), we predict a greater attractiveness of roadsides if TOFs are present.

2. Materials and methods

2.1. Study site

The focus area of the study, measuring a total of about 1118 km^2, was located in the administrative district of Göttingen (51.5413° N, 9.9158° E). The predominant land use in the area is agriculture (≈48%), followed by forest (≈33%; cf. Seidel et al., 2015). The district's climate is characterized by both maritime and continental influences from Western and Eastern Europe, respectively. Average annual temperatures are approximately 8 °C, with annual mean precipitation ranging from 580 mm in the East to 1050 mm in the Southwest (DWD, 2012). European Roe deer can be found throughout the state of Lower Saxony. State-wide annual hunting harvest amounts to almost 130.000 individuals (DJV, 2015–2016).

2.2. Road network, accident data and hot spot identification

The road network information for the district was obtained from the German official topographic map information system (ATKIS). All road types (primary, secondary and tertiary) were included in the analysis.

During the study period of 2014-10-01 00:00 UTC + 1 to 2016-10-17 00:00 UTC + 1, the district police recorded GPS coordinates of 988 accident with roe deer in total. Using ArcMap (10.4.1; ESRI, 2011) accident locations were converted to shape-file format and superimposed onto the road network using the WGS 1984 UTM Zone 32N projection.

2.3. Data on trees outside forest (TOF)

Data on the location and extent of all trees outside forest was obtained from a mapping campaign based on the OpenSource software (QGIS) and the Open Layers plugin Bing aerial maps provided by the Digital Globe Foundation (Digital Glob, Longmont, USA). The data was compiled in 2012 during a study presented by Seidel et al. (2015). A polygon describing the shape and size of each TOF object (n = 61,029) in the administrative district of Göttingen was available from this study in form of a TOF-shape file.

2.4. Hotspot identification and statistics

Points of collision between roe deer and vehicle may either follow a hypothetical random distribution or deviate from this, indicating that the data may be dispersed or clustered. Using Average Nearest Neighbour (ANN) analysis in ArcMap (10.4.1; ESRI, Redlands, California, USA) allows evaluating the data distribution through the index:

$$\mathrm{ANN} = \frac{\overline{\mathrm{D}}_0}{\mathrm{D}_\mathrm{E}}$$

where $\overline{D}_0$ is the observed mean distance between every feature and its nearest neighbour and $\overline{D}_E$ is the expected mean distance for the associated features given a random distribution.

The z-score for the average nearest neighbour statistic is calculated as follows:

$$z = \frac{\overline{\mathrm{D}}_o - \overline{\mathrm{D}}_\mathrm{E}}{\mathrm{SE}}$$

where SE is the standard error. ANN analysis is a succinct method to predict whether data clustering is present. No information is given, however, on the localization of the potential individual clusters (Clevenger, Hardy, & Gunson, 2006).

In order to identify the location of statistically significant clusters we used Kernel Density Estimation (KDE; see Plug, Xia, and Caulfield (2011) for details) implemented in ArcGIS. In KDE, the sum of collision points within a user-defined area surrounding a pixel allows the density of AVCs for each individual pixel in a raster file to be calculated. During KDE in ArcGIS we used a grid cell size of 5 m and a search radius of 200 m, defining which neighbouring roe deer accidents are included in the analysis and computation of hotspots. These parameter settings were chosen to reduce the chances for an overlap of the Kernel Density output across the numerous individual roads, as similarly used and discussed by Stark (2017) and Okabe, Satoh, and Sugihara (2009). More information on using KDE for spatial analysis can be found in Hart and Zandbergen (2014).

To facilitate the analysis we stratified the surroundings of each hotspot according to accident density (from here on called risk zones). The innermost zone around the hotspot center (red zone) is an area of very high accident risk (risk class 1; 107–134 AVC*km^{-2}), the next (orange zone) is risk class 2 (81–107 AVC* km^{-2}), yellow is risk class 3 (54–81 AVC* km^{-2}) and blue is risk class 4 (27–54 AVC* km^{-2}; Fig. 1). The background value is 0–26 AVC* km^{-2}. The numbers refer to the observed time-period of 24 month and 17 days.

Upon identifying areas, which showed an higher risk of collision based on spatial clustering of accidents, the TOF shape-file was clipped to determine the area of individual TOF objects within each zone. A summation of the areas of all TOF objects within each risk zone (km^2* km^{-2}) was then carried out.

To determine a reference value of equal likelihood for TOF objects within the vicinity of roads, including areas where individual accidents occurred, but which were not considered to be significantly clustered, each road was buffered by 200 m on either side. This parameter was chosen due to previous research by Rost (1979), stating that large mammals tend to have lower population densities (avoid areas) within