Identification of Local Factors Causing Clustering of Animal-Vehicle Collisions on Roads

Tomáš Bartonička[1], Richard Andrášik[2], Martin Duľa[1,3], Jiří Sedoník[2], Michal Bíl[2]

[1]Department of Botany and Zoology, Masaryk University, Kotlářská 2, 61137 Brno, Czech Republic

[2]CDV Transport Research Centre, Líšeňská 33a, 63600 Brno, Czech Republic

[3]Mendel University in Brno, Institute of Forest Ecology, Zemědělská 3, 61300 Brno, Czech Republic

Corresponding author: Tomáš Bartonička, Department of Botany and Zoology, Masaryk University, Kotlářská 2, CZ-611 37 Brno, Czech Republic, email: bartonic@sci.muni.cz

Highlights

- The proper selection of sites where the environmental factors are determined is crucial.
- Collisions in clusters are caused by local factors which have to be identified.
- Collisions outside clusters take place randomly.
- The correct determination of local factors will result in better mitigations.

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Abstract

Numbers of animal-vehicle collisions (AVCs) are on the increase in many countries, despite measures applied to reduce the risk of these collisions. Effective measures reducing the risk of AVC require the defining of high-risk locations on roads where AVCs occur repeatedly. Furthermore, traffic accident data may contain incomplete and erroneous values, which make its exploration and understanding an extremely demanding task. We therefore applied a novel kernel density estimation method KDE+, which is not influenced by missing data, for identification of AVCs hotspots along roads. Our data set consists of almost 600 AVCs from the Czech road network. Estimated hotspots consist of AVCs which are non-randomly distributed and thus mostly occurred due to a local factor. The remaining AVCs occurred randomly and therefore were likely induced by a global factor. Our main goal was to identify the local factors and their effect on the non-random occurrence of AVCs. We compared the two fundamentally different types of occurrence of AVCs and arrived at the environmental factors influencing the non-random distribution of AVCs. The results indicate that the hotspot identification method followed by the selected data mining methods is able to identify factors causing local clustering of AVCs.

Keywords

Traffic Collision, Hotspot-Selection Method, Environmental Factors, Clustering

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Introduction

Vehicles are the most widespread and popular way of transport involved in moving people and goods. The mobility and transport of humans are dependent, however, on the quality and density of the road network. The number of registered vehicles, as well as the length of the road network, is continuously increasing, which facilitates the mobility of people. It limits the safe movement of animals through the countryside which is becoming more fragmented (e.g. Oxley et al. 1974, Adams and Geis 1983).

Animal-vehicle collisions (AVCs) are primarily handled in those cases, when the consequences are fatal for humans, or lead to significant damage to vehicles. The number of AVCs is increasing in Europe, which has a major impact on road safety. Large mammals, mainly ungulates, are the main group involved in the conflict and most of the accidents are caused by roe deer (*Capreolus capreolus*), red deer (*Cervus elaphus*), daim (*Dama dama*) and moose (*Alces alces*) (e.g. Waechter 1979, Groot-Bruinderink and Hazebroek 1996, Haikonen and Summala 2001). Wild boar (*Sus scrofa*) is an increasing problem mainly in Mediterranean areas and Central European countries (Carbaugh et al. 1975, Williams and Wells 2005, Gonser et al. 2009). The sharp increase in AVCs observed over the last decade has been attributed to two main causes: the geographic and demographic expansion of ungulate populations and the increase in the length of the road network and the speed of vehicles (Rossel et al. 2013). A series of technical measures enhanced road safety, but also prevented the conflict with game which is in the interest of hunting associations (e.g. Malo et al. 2004).

Roads and adjacent landscaping negatively affect important habitats and degrade them (Meffe et al. 1997). It concerns not only forest fragmentation, but also bio-corridors between other habitats such as water bodies, streams or linear vegetation, i.e. windbreaks or bank vegetation (Bennett 1999). They are then permanently disconnected. When animals are moving on a long section of a road, AVC risk is lower than when they move in a narrow corridor, connecting a road body. Increased attention is paid to these risky sections because most of the studies clearly demonstrated an increased mortality in such places (Andrews 1990, Bennett 1991, Georgii et al. 2011) and several measures were proposed to reduce the risk of AVCs (Harris and Gallagher 1989, Harris and Scheck, 1991).

Many projects involve the implementation of specific mitigation measures, including structures keeping wildlife away (e.g. Clevenger et al. 2003). In addition to the construction of culverts and bridges for the animals, roads are fenced at places of frequent AVCs (Forman and Alexander 1998), audio and optical signal systems to discourage animals from crossing roads (Rowden et al. 2008), speed limits or installing information and warning signalization (e.g. Al-Ghamdi and AlGadhi, 2004) or thermal sensors can draw the attention of drivers to the presence of large animals (Hirota et al. 2004) were tested. Specific additional signalization and verge management, which consists of cutting existing vegetation into strips along both sides of the road and eliminating obstacles to prevent animals from finding refuge beside the roads and making them more visible to drivers are applied (Johnson 2008). Despite many of the above-mentioned measures and placed constructions, traffic accidents caused by animals are on the rise (Iuell et al. 2003). Moreover, wildlife overpasses and green bridges, constructions that provide effective mitigation are very expensive (Glista et al. 2009). Although the constructions should lead to a reduction in the risk of collisions and mortality, this has not been the case. The error might be in the system that identifies sections of roads where AVCs occur, because hotspots are often determined separately for different taxonomic groups (Iuell et al. 2003, Glista et al. 2009), by different numbers of observers, with a different frequency and duration of the surveys (Teixeira et al. 2013). As a consequence of different methodology, some carcasses may be missing and the total mortality may be underestimated when there is a long time interval between consecutive controls and/or many soft and small-bodied species with short persistence times of carcasses decay (Gerow et al. 2010, Guinard et al. 2012).

The aim of this study is to present an approach based on an innovative kernel density estimation method (KDE+ method, Bíl et al. 2016) which is able to precisely identify places where AVCs aggregate into clusters. Finally, we compared the surroundings of AVCs in clusters and of these with spatially random occurrence to find out whether environmental characteristics differ between them and if some factor may predict the presence of hotspots.

Material and methods

The data on AVCs came from the Police of the Czech Republic from the period October 2006 – December 2011. The Police of the Czech Republic use Garmin Geko 201 with a maximum error up to 25 m. 599 randomly selected AVCs were consequently enriched by the information as to which species of large mammal caused an accident.

Measured variables

We determined for each of the AVC the presence or absence in clusters according to the KDE+ method (Bíl et al. 2013). We also gathered information on: (i) factors connected to an animal – mammal species (wild boar, roe and red deer, other mammals such as fox or hare), (ii) traffic factors – road width, road category, presence or absence of a middle belt and guardrails, and (iii) environmental factors (Table 1).

Variables which describe road segments (ii) were obtained by spatial and attribute querying from GIS layers provided by The Road and Motorway Directorate. Environmental variables (iii) were obtained from digitalized GIS layers such as the boundary of forest and green areas, rivers, landcover – industry areas, building areas – and an ortophotomap provided by the State Administration of Land Surveying and Cadastre (SASD). The extent of the digitalized layers was equal to the buffer of 300 meters around each AVC. New digitalized features were drawn in scale 1:1000 from WMS orthophoto map (provided by SASD). The intensity of the traffic comes from a transport census in 2010.

Statistical methods

First, we studied the relationship between AVCs and the date and time of the collision. We considered 24 time intervals for each month representing the time of day (xx:00 – xx:59, where xx goes from 00 to 23). We therefore had 12 times 24 cells. We consequently counted the number of records belonging to a particular cell. Assuming that an AVC could occur equally likely in any cell, we would expect N/(12*14) AVC in a particular cell, where N is the total number of AVC in question. For each cell, the exact binomial test (Hollander et al., 2014) was applied to examine whether the real number of AVCs was significantly greater than the expected number of AVCs.

Second, we analyzed the influence of explanatory variables on clustering separately by the use of the odds ratio (OR; Simon, 2001). The confidence interval of OR was also calculated to examine the significance of the dependency between an explanatory variable and clustering. All possible partitions into two groups were taken into account regarding continuous variables or categorical variables with more than two categories. Options with the highest ORs were studied.

The third step in our analysis was to work with all explanatory variables at the same time. We categorized each continuous variable and then applied a multiple correspondence analysis (MCA; Abdi et al., 2007) to reduce dimensionality in the data. As a result, we obtained several new variables called dimensions, which are linear combinations of original explanatory variables. We then constructed a logistic regression model with dimensions as explanatory variables and presence in a cluster as a dependent variable. We finally reconstructed the meaning of the original variables through the coefficients of the logistic regression model and relations known from MCA.

In the end, we were able to express how many times the clustering is more likely in the case that an original explanatory variable has a particular value. If the confidence interval (95 %) is greater than 1, the clustering of AVCs is affected positively by the particular value of an explanatory variable. In contrast, when the confidence interval is lower than 1, the clustering of AVCs is affected negatively and collisions occur more likely at random (Tab. 4). All the computations were performed in software R (R Development Core Team, 2008).

Results

Time, date and animal pattern

Our data sample consists of 599 records containing 164 (27.4 %) AVCs which occurred in clusters (Fig. 1). Most of the AVCs were with roe deer (63.8 %, 382), followed by wild boar (30.1 %, 180), red deer (3.0 %, 18) and other mammals such as fallow deer, foxes and hares (3.2 %, 19).

AVCs are strongly affected by the relative sun height above or below the horizon. It is therefore natural that the time of the day when AVC occurred changes over the course of the year. The majority of AVCs involving roe deer were the most frequent in May around twilight and dusk. In contrast, AVCs with wild boar involved occurred mostly in November and October in the same parts of the days (Fig. 2). The majority of all recorded AVCs occurred in the night time (79 %), i.e. between dusk and dawn.

We applied the exact binomial test to each cell (Fig. 2). Regarding roe deer, we determined that four AVCs and more in a particular cell indicate significantly more AVCs than expected. In other words, highlighted cells (Fig. 2) express time periods in which AVCs are more likely to occur than expected. A similar outcome was also achieved for wild boar. However, the threshold of AVC indicating the significant difference equals three. Concerning both roe deer and wild boar, the numbers of AVC were significantly greater during the night time.

Effect of variables on clustering

Odds ratio (OR) method was used to separately examine the influences of the variables onto the clustering of AVCs. The 95 % confidence interval of OR was calculated to test the statistical significance of the obtained results. As OR can be calculated only for 2x2 contingency tables, only binary variables could be tested directly. Concerning continuous variables or categorical variables with more than two categories, we examined all possible partitions of the AVCs and studied only the partition with the strongest influence. Examining the road category resulted, for example, in three tests. We determined that when the forest was nearer than 350 m, the odds of clustering is more than six times greater than in the opposite case (Table 2).

Probability of clustering

We categorized continuous explanatory variables from Table 1 and performed MCA. As a result, we obtained three dimensions explaining 93.83% of the inner variability of the dataset (Table 3).

We consequently constructed a logistic regression model with three explanatory variables (three dimensions) and the presence in a cluster as a dependent variable. Only the first and the third dimensions were significant in this model (Table 3). We were then able to estimate the probability of clustering at any location where the explanatory variables are known. Furthermore, we reconstructed the meaning of original variables through the coefficients of the logistic regression model and relations known from MCA (the dimensions are linear combinations of original variables).

The meaning of an original variable X taking a particular value x (e. g. X – road class, x – 1st class) can be expressed as $o(X = x) = p/(1 - p)$, where p is the probability of clustering under the assumption that $X = x$. Number $o(X = x)$ quantify how many times clustering is more likely when $X = x$ compared to the case $X \neq x$ (e. g. clustering is 1.06 times more likely for the 1st class roads than in the case of other roads). Also the 95 % confidence intervals (CI) were computed for each $o(X = x)$. Hence, we divided the presence of a particular attribute (X

= x) into three groups (Figure 3): positively affects clustering (CI above number one), no effect on clustering (CI contains number one), negatively affects clustering (CI below one). The distance from the forest and bank vegetation was found as a very important factor controlling the presence of clusters of animal-vehicle collisions, while in open areas AVC clusters were absent.

Discussion

Temporal patterns of wildlife mortality are well known for a long period of time and have been summarized in several studies (e.g. Langton 1989; Smith and Dodd 2003). Such peaks of mortality are related to the diurnal or annual animal movements as has also been suggested by our results.

Also spatial crash pattern (AVC cluster positions along roads) is reasonable to monitor for longer period of time, as follows from the above mentioned cases. For instance, such a significant spatial association was found between multiyear hotspots and wetlands (Garrah et al. 2015). Santos et al. (2015) have suggested that the numbers of hotspots are negatively correlated with an increasing time interval between surveys, due primarily to missing genuine hotspots. The sampling interval and the accuracy of hotspots identification are affected, among other things, by carcasses persistence rate on the road (Teixeira et al. 2013). Our models, however, are only based on large mammal-vehicle collisions whose carcasses have the highest persistence of all.

Additionally road mortality surveys often determine work separately for different taxonomic groups. Different sampling for each taxonomic unit only enhances the variability between taxons and complicates the generalization in the determination of the hotspots on the basis of local characteristics. Such results underscore the notion that multiple years and adding multiple taxons are necessary to identify locations where the greatest conservation good can be achieved.

Conservation strategies for wildlife focus on the integration of animal species into landscapes endangered by human activities, therefore the measures to minimize infrastructure and landscape fragmentation impacts must necessarily be taken (Iuell et al. 2003). The majority of road-kill studies have been carried out on a local scale with variable buffer sizes around the location points (Malo et al., 2004; Seiler 2005; Grilo et al. 2009). Unfortunately this concept has brought high heterogeny to the datasets. We therefore applied a new statistical concept and methodologies when not only one collision but clusters of animal-vehicle collisions were taken against other collisions, which were not located within a cluster and were randomly distributed (Bíl et al. 2013). In our study we first established genuine hotspots (AVCs which were clustered in time and space), and then explained their presence by environmental characteristics.

Factors potentially responsible for the occurrence of AVCs are usually divided into three groups i.e. a) connected with animal behaviour and species ecology (sex, age, dispersal, habitat utilisation, migratory, etc.), b) traffic factors (vehicle speed, visibility, density, etc.) and 3) environmental factors (such as the presence of natural corridors, adjacent habitats, fragmentation) (e.g. Davenport and Davenport 2006). Whereas habitat variables have been related to road fatalities elsewhere (e.g. Clevenger et al., 2003; Malo et al., 2004; Seiler, 2005) our results mirror those from other studies. Roadside vegetation coverage (Seiler, 2005) and the presence of corridors (streams and forest edges) can be more important in explaining not only the limited AVCs distributed elsewhere but in explaining AVC's aggregation into clusters. In the road-kill models, the forest habitat is an important prerequisite for large mammal-vehicle collisions in Europe (Almkvist et al., 1980, Kofler and Schulz, 1987) as well as in the USA (Finder et al., 1999, Hubbard et al., 2000). The short distance to a forest (less than 350 m) was also the most important explanatory factor in our survey, again followed by the length of a forest edge. In general, these variables increase the chance of the presence of cluster of AVCs. Moreover, not only the presence of these features but their co-occurrence with other variables at same locality was determining to explain road-kill patterns. We found that the presence of a stream was only significant when clusters of AVCs were of the closed habitat type. In contrast, the correlation between clusters of AVCs and the presence of streams has not been detected outside the forest.

Habitat corridors may potentially moderate some of the worst effects of habitat fragmentation (Bennett, 1999), but their importance can only come from the core habitats that they are connecting. On the one hand, the edges between habitat types are fundamental structures in landscape functioning, and hence are of central importance in conservation biology (Lidicker, 1999). The high ratio of edge to area, on the other hand, might be detrimental to species using the corridor (Weldon and Haddad, 2005). Human activity in the agricultural landscape can create abrupt forest edges or windbreaks. The result is a preference for a falsely attractive habitat and a general avoidance of high-quality but less-attractive habitats. Moreover, the edges of the growths are widely used for animals to move and do experience corridors as habitat sinks or ecological traps (King et al., 2009).

The second category of factors influencing the numbers and likelihood of AVCs comprises traffic density and vehicle speed. Increasing traffic has been held responsible for the growing number of AVCs worldwide (e.g. Newton et al., 1997, Forman and Alexander, 1998). Impact on clustering in the context of different levels of intensity of transport was exactly the opposite and without stratification may remain hidden. It is not surprising that the clustering of AVCs occurs at localities with extremely high traffic intensity. These clusters can be caused by the crossings of migration corridors and highways, when animals cross roads repeatedly on the most suitable sites (Grilo et al., 2012). On roads with less traffic intensity, the seeming safety of the locality used to cross the road is caused by (i) speed of vehicles together with the limiting of other disturbing factors such as less noise, less vibrations, etc. and (ii) the large distance between the vehicles (Forman et al., 2003; Husby and Husby, 2014). At low traffic, animals may not hesitate to enter a roadway and very few individuals may collide with vehicles. However with increased traffic, more animals will be killed. A number of observations suggest that at middle traffic intensity, animals may not hesitate to enter a roadway and many of them may collide with vehicles while attempting to cross (Seiler and Helldin, 2005). On very busy roads, however, approaching animals are more likely repelled by vibrations and noise. Zurcher et al. (2010) support the hypothesis that bats perceive vehicles as a threat and display anti-predator avoidance behavior in response to their presence. If we assume, however, that traffic intensity is a correlated type of road (highway, local road, etc.), a higher density of collisions was found on intermediate roads than on major highways or on local access roads (e.g. amphibians, Kuhn, 1987; small mammals and birds, Oxley et al., 1974; carnivores, Clarke et al., 1998 and ungulates, Skölving, 1987). After the quick appearance of a vehicle, large mammals return back to the point of entry on the road, making the likelihood of collisions increase. Illustrative examples of animal behaviour before a crash can be seen on videos uploaded by the public at the YouTube website. Significantly fewer collisions occurred on minor county roads with reduced speed limits and on unfenced highways with traffic denser than 8,000 vehicles per day (Seiler and Helldin, 2005). Highways with traffic levels above 10,000 vehicles per day are therefore considered an insurmountable barrier for most terrestrial vertebrates (e.g. Rosell Pagès and Velasco Rivas, 1999).

Reducing direct mortality by implementing mitigation measures has become a significant component of many regional and species-specific conservation strategies. However, even if roads sections are mitigated and wildlife perceive cars as a threat or even as predators, mortality will not be erased completely (cf. Seiler and Helldin, 2005) and mitigation measures have to be improved once again with regard to the increasing traffic volume.

On the basis of the KDE+ method applied in this study, we suggest that for any models for identification of factors influencing the non-random occurrence of AVCs the proper selection of places where the factors will be determined is crucial. Two fundamentally different types of such places exist in principle, i.e. places in clusters where AVCs follow a certain spatial pattern and other places on the remaining parts of the roads. Whereas AVCs in clusters concentrate and are caused by local factors which have to be identified, AVCs outside clusters take place only randomly. Correct determination of local factors will result in more successful AVC mitigation.

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Caption:

Figure 1: Total numbers of AVCs and AVCs in the clusters.

Figure 2: The results obtained with the use of the exact binomial test for (a) roe deer and (b) wild boar. The highlighted cells had a significantly greater number of AVC than expected. White cells had a zero number of AVC.

Figure 3: The role of the individual variables for the cluster of AVC presence. The red marked attributes positively affect clustering, black attributes are neutral and green attributes negatively affect clustering. The point estimates and their 95 % confidence intervals are depicted.

Table 1: List of measured variables. Traffic and environmental variables were identified in a 300 meter buffer around each AVC.

Variable	**Metric or categories**
presence in cluster	out of clusters/in a cluster
date of collision	dd.mm.yyyy
time of collision	hh.mm
variables connected to animals	
mammal species	roe/red/fallow deer/wild boar/other
traffic variables	
road width	m
road category	1st/2nd/3rd class
middle belt	yes/no
guardrails	yes/no
environmental variables	
distance to other barrier	m
distance to the forest	m
distance to the linear vegetation	m
distance to the stream	m
distance to the built-up area	m
forest area	%
industrial zone	%
habitat type	closed/semi-closed/open
embankment	yes/no
depression	yes/no
shrubs	yes/no
grass belt	yes/no
bank vegetation	yes/no

Table 2: ORs and their 95 % confidence intervals for variables which significantly influence clustering of AVCs.

Variable	OR	95 % confidence interval	
Distance to the forest < 350 m	6.41	2.54	16.17
Forest area > 0 %	4.81	2.37	9.78
Road width >= 7 m	2.68	1.42	5.07
Distance to the stream < 120 m	2.40	1.62	3.57
1st class road	2.05	1.35	3.11
Distance to other barrier >= 120 m	1.72	1.19	2.50
Shrubs	1.68	1.01	2.81
Depression	1.59	1.07	2.40

Table 3: Explained variance by the first three dimensions in the multiple correspondence analysis (MCA) and the results obtained from the logistic regression.

Variable	Explained variance [%]	Sum of explained variance [%]	Estimate	p-value
Dimension 1	54.26	60.09	- 0.1943	0.0049
Dimension 2	29.45	82.99	–	–
Dimension 3	10.12	93.11	- 0.6684	< 0.0001
Intercept	–	–	- 1.6396	< 0.0001

Fig 1

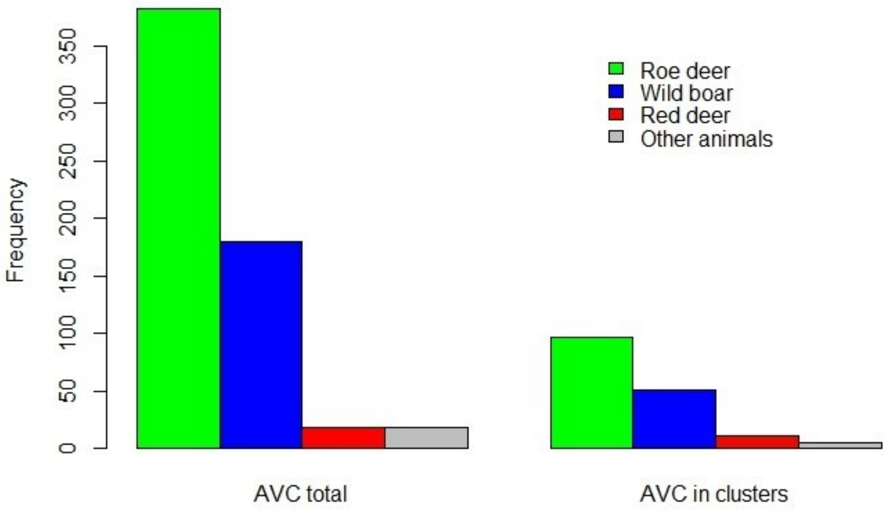


Fig 2

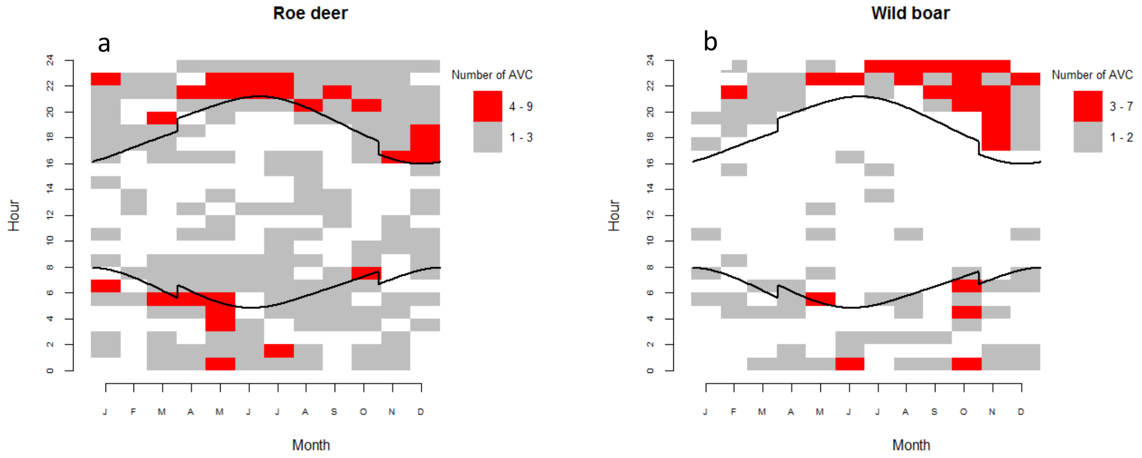
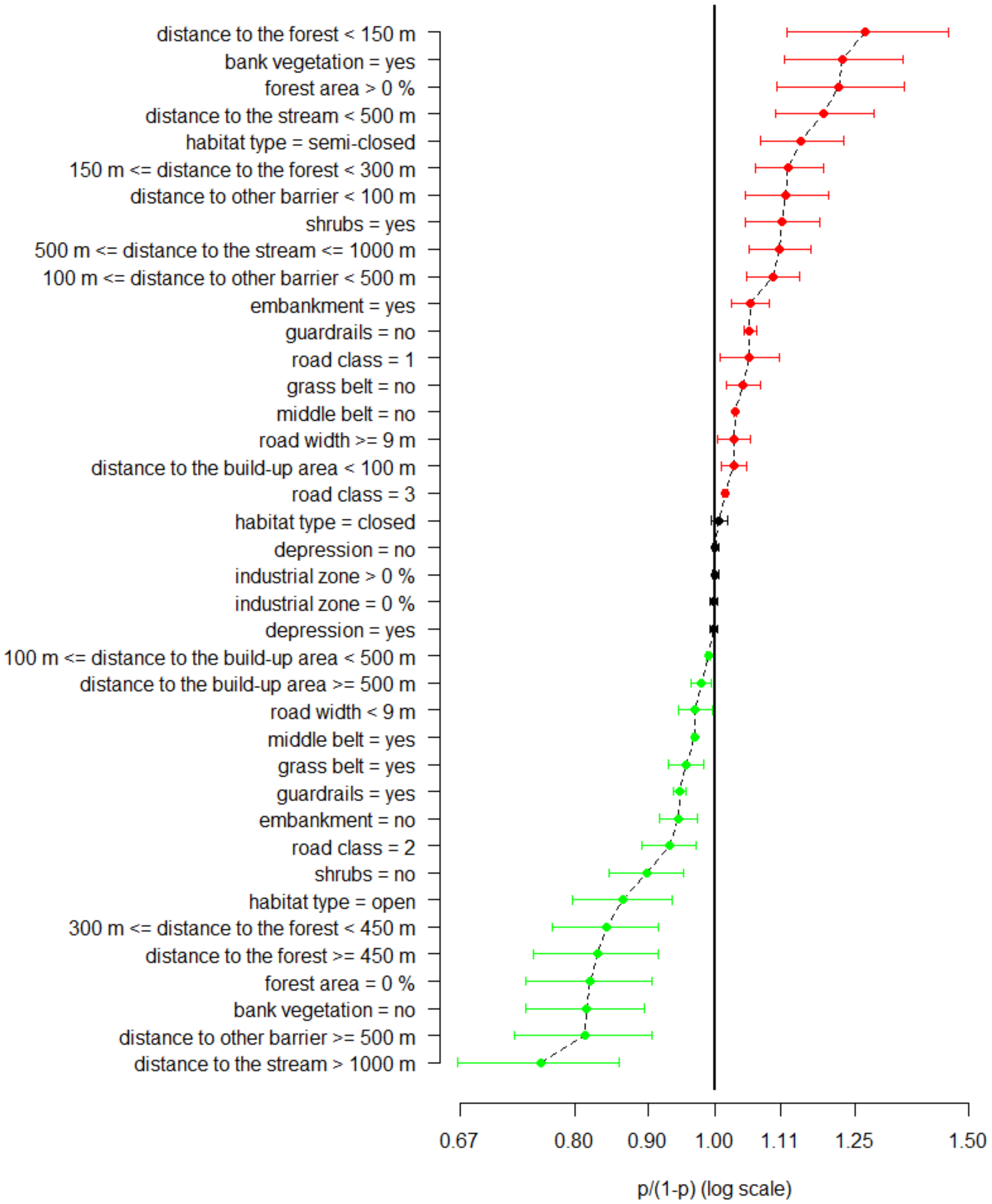

Roe deer
a
Hour
24
22
20
18
16
14
12
10
8
6
4
2
0
J F M A M J J A S O N D
Month
Number of AVC
4 - 9
1 - 3
Wild boar
b
Hour
24
22
20
18
16
14
12
10
8
6
4
2
0
J F M A M J J A S O N D
Month
Number of AVC
3 - 7
1 - 2

Fig 3


distance to the forest < 150 m
bank vegetation = yes
forest area > 0 %
distance to the stream < 500 m
habitat type = semi-closed
150 m <= distance to the forest < 300 m
distance to other barrier < 100 m
shrubs = yes
500 m <= distance to the stream <= 1000 m
100 m <= distance to other barrier < 500 m
embankment = yes
guardrails = no
road class = 1
grass belt = no
middle belt = no
road width >= 9 m
distance to the build-up area < 100 m
road class = 3
habitat type = closed
depression = no
industrial zone > 0 %
industrial zone = 0 %
depression = yes
100 m <= distance to the build-up area < 500 m
distance to the build-up area >= 500 m
road width < 9 m
middle belt = yes
grass belt = yes
guardrails = yes
embankment = no
road class = 2
shrubs = no
habitat type = open
300 m <= distance to the forest < 450 m
distance to the forest >= 450 m
forest area = 0 %
bank vegetation = no
distance to other barrier >= 500 m
distance to the stream > 1000 m
0.67
0.80
0.90
1.00
1.11
1.25
1.50
p/(1-p) (log scale)