The road and landscape features affecting the occurrence of ungulate-vehicle hotspots in Sweden

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Swedish University of Agricultural Sciences, SLU
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Abstract

European ungulate populations are increasing both in number and distributional range, resulting in more ungulate-vehicle collisions (UVC). These UVC cause socio-economic losses and are a growing problem in Sweden. Since 2010, drivers in Sweden are legally obliged to report UVC-accidents to the police. The police usually call upon specially contracted hunters to take care of the killed or injured animal and produce a report. With this information, from police and hunters, it is possible to map the occurrence of UVC and derive predictions on where and when the likelihood for accidents is especially high.

The purpose of this study was to build on already existing data and research on UVC in Sweden and develop predictive models for the spatial occurrence of accident hotspots. I explored and analysed which road, traffic, landscape, ecological and behavioural related attributes correlate with the aggregation of UVC involving roe deer, moose, wild boar, reindeer, and fallow deer respectively and collectively. Using these variables, I created models by logistic regression to predict UVC hotspots that I believe will potentially assist in future management and preventive actions

My results indicate that a combination of road and landscape variables were good predictors of the occurrence of hotspots in all species except in fallow deer. Nevertheless, road characteristics proved to be the most important parameters for predicting the occurrence of hotspots. Three road parameters i.e., Traffic Volume, Speed and Proportion of Unfenced Road had positive correlation to the occurrence of hotspots in all the species' models. Other common variables that were present in at least 50% of the models included areas of open land, exploited land, arable land, minor and major roads and the distance to built-up areas.

Keywords: Ungulate-Vehicle Collisions, Landscape analysis, Hotspots, Moose, Roe deer, Fallow deer, Reindeer, Wild boar

Populärvetenskaplig sammanfattning

Väg- och landskapsegenskaper som påverkar hotspots i viltolyckor i Sverige

Antalet viltolyckor ökar stadigt i Sverige i takt med att klövviltstammar växer och trafiken ökar. Samhällskostnaderna för viltolyckor uppskattas till 10 miljarder SEK per år. Det finns ett stort behov av kostnadseffektiva åtgärder, men dessa förutsätter bättre kunskaper om var och när viltolyckor inträffar. Sedan 2010 är bilförare i Sverige skyldiga att polisanmäla olyckor med klövvilt och stora rovdjur. Polisen brukar kalla in eftersöksjägare för att ta hand om det dödade eller skadade djuret. Med information från polis och jägare är det möjligt att kartlägga merparten av alla viltolyckor och studera eventuella orsakssamband som kan förklarar olyckornas fördelning längs vägnätet. Detta skapar underlag för nya åtgärdsstrategier och riktade åtgärder.

Syftet med denna studie var att utifrån existerande data och forskning om viltolyckor i Sverige och utveckla modeller som kan förutsäga och identifiera olycksdrabbade vägavsnitt, sk. ”olyckshotspots”. Datat omfattar olyckor med rådjur, älg, vildsvin, ren och dovhjort under femårsperioden från 2015 till 2019. De identifierade ”hotspotsen” (vägavsnitt med mer 1 olycka per km och och år) jämfördes med ”cold spots”, där endast en olycka inträffat under femårsperioden. Med hjälp av en statistisk metod (logistisk regression) undersökte jag hur vägstorlek,, stängsling, trafikvolym, och landskapet runt vägen bidrog till att förklara skillnaden mellan hot- och cold spots.

Mina resultat visade att en kombination av väg- och landskapsvariabler gav en mycket god förutsägelse av hotspots hos alla arter förutom dovhjort. Vägegenskaperna var viktigast medan modeller med endast landskapsvariablerna hade en mycket lägre förklaringsgrad. Trafikvolym, hastighet och andelen ostängslad väg hade störst betydelse och relaterade positivt med förekomsten av hotspots för alla arter.

Resultaten antyder att sänkt hastighet och ett välutformat och sammanhängande viltstängsel utgör de mest effektiva åtgärder som kan vidtas vid identifierade olyckshotspots även om investeringskostnaderna är höga. Jag rekommenderar Trafikverket att utreda kostnadseffektiviteten av dessa åtgärder mer ingående.

Nyckelord: Hovdjurfordonskollisioner, landskapsanalys, hotspots, älg, rådjur, dovhjort, ren, vildsvin

Table of contents

List of tables

List of figures

1. Introduction

Although many wildlife populations around the world have faced losses in number and distributional range, most ungulate populations in Europe has experienced the opposite(Valente et al., 2020). European ungulate populations are increasing both in numbers and range, resulting in more human-ungulate interactions as well as, management challenges (Neumann et al., 2020; Valente et al., 2020). Some of these interactions, such as, ungulate-vehicle collisions (UVC) tend to be detrimental to both humans and wildlife, often resulting in injuries and fatalities (Favilli et al., 2018; Neumann et al., 2020) and causing a socio-economic loss of an estimated 10 billion SEK per year (Seiler, unpublished). This is a growing problem in Sweden where the occurrence of UVC has been on the rise since its recording started in the late nineteen seventies (Seiler, 2004), highlighted by the 250% increase of wild boar collisions from 2003 to 2011 (Gren et al., 2015).

Since 2010, drivers in Sweden are legally obliged to report UVC-accidents to the police. The police usually calls upon contracted hunters to take care of the killed or injured animal and produce a report (AB, 2020; Seiler et al., 2019). With this information, from police and hunters, it is possible to map the occurrence of UVC and derive predictions on where and when the likelihood for accidents is especially high. For example, the Swedish transport administration (Trafikverket) produced accident frequency maps using standard Kernel Density Calculations (KDE) with a 1 km search window (Seiler et al., 2019; Trafikverket). They defined hotspots as road sections where more than one accident per km per year has been reported over a 5-year period and at least 4 accidents have been reported for 4 out of those 5 years.

These hotspots have been determined to include approximately 65% of all UVC but cover only 16% of the national road network (Seiler et al., 2019). Thus, aggregation is very helpful in focusing mitigation measures as it allows for resources to be concentrated towards the problem road sections.

Types of Analysis and Applications

Wildlife traffic accident data can be used for several types of analyses and applications. For example, estimating wildlife population indices as a tool, developed by Gren et al., (2015) that estimated the population dynamics of animals. The approach assumed that the change in accident incidents over time was a proxy for the Swedish wild boar population size and determined traffic load as measure of effort whilst estimating the impacts of landscape characteristics. This method was purported to compensate for the inaccuracy that may be present in more traditional models, that use hunting bag statistics. It is often difficult to determine the actual hunting effort e.g., number of hours spent, or hunters present in these traditional methods (Gren et al., 2015). UVC analysis can also be used to calculate cost-benefit estimates of mitigation measures such as fences or passages (Seiler et al., 2016; Seiler et al., 2017). They may also help in providing data to inform car drivers about where and when accidents are frequent and increased attention may be needed (AB, 2020).

The purpose of this study was to build on already existing data and research on UVC in Sweden and develop prediction models for the spatial occurrence of accident hotspots. Previous studies have looked at the clustering of incidents involving roe deer, moose, wild boar, red deer, reindeer and fallow deer indiscriminately (Seiler et al., 2017; Sjölund, 2016). I used UVC data from 2015 - 2019 to identify species-specific hotspots and cold spots and examined the role of external factors (landscape, infrastructure, traffic, and hunting statistics) that may predict for the aggregation of UVC.

The main objectives were to:

1. explore and analyse which road, traffic, landscape, ecological and behavioural related attributes that correlate with the aggregation of UVC involving roe deer, moose, wild boar, reindeer, and fallow deer respectively and collectively.
2. create models which may be used to predict UVC hotspots, potentially assisting future management and preventive actions.

2. Methods

2.1. Data

2.1.1. Study Area

The study was conducted at national level, covering all the counties of Sweden (Figure 1). UVC data of the species of interest was prepared previously as part of an ongoing research project. Data related to road infrastructure, traffic and wildlife was collected from Trafikverket and Jägareförbundet. Landcover characteristics were collected from topographic maps.

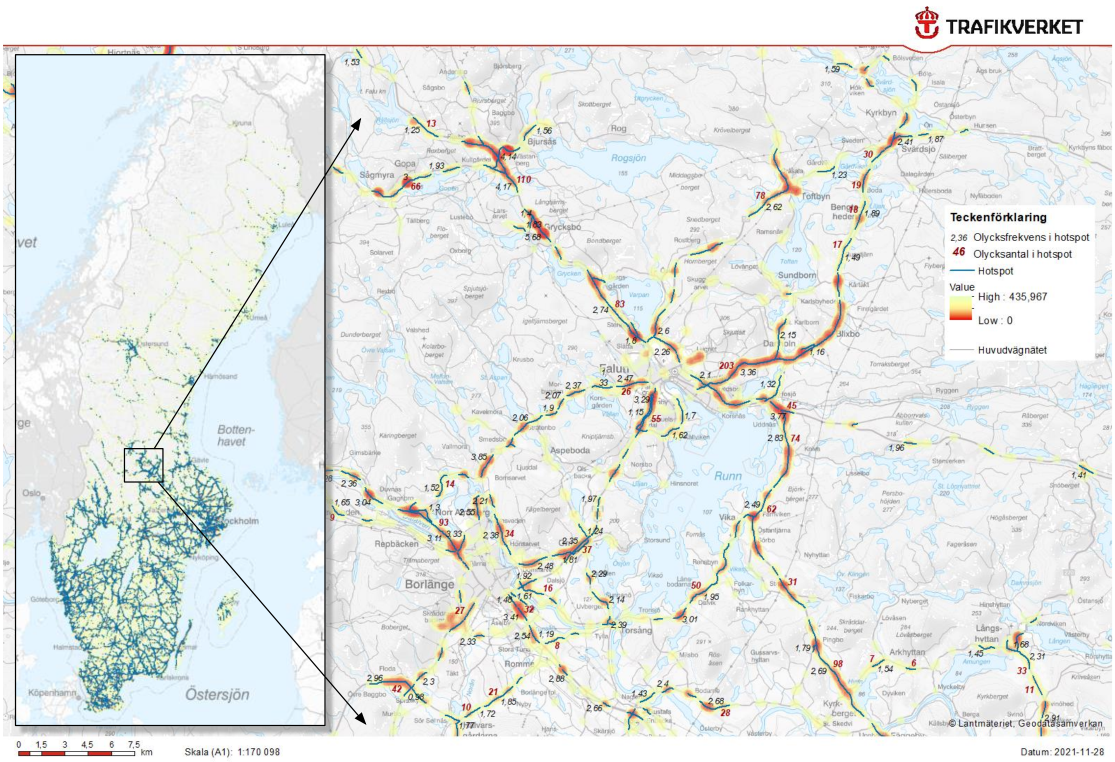

Figure 1: Showing all hotspots in Sweden and a zoom-in on hotspots around Borlänge and Falun for all ungulates combined. Red numbers indicate accident counts, black their frequency per km and year

2.2. Selection of cold spots and hotspots

Regions of high UVC density had already been calculated using a Kernel Density analysis (KDE) as part of another project (Seiler et al., 2019) and provided the base data for all subsequent hotspot analysis that I conducted. Selection of hotspots and cold spots were conducted for each species separately and the combined dataset, as outlined below (Figure 2). All UVCs within urban areas where excluded as this was determined to require a different set of parameters for comparison and was out of the scope of this research project (Bíl et al., 2013).

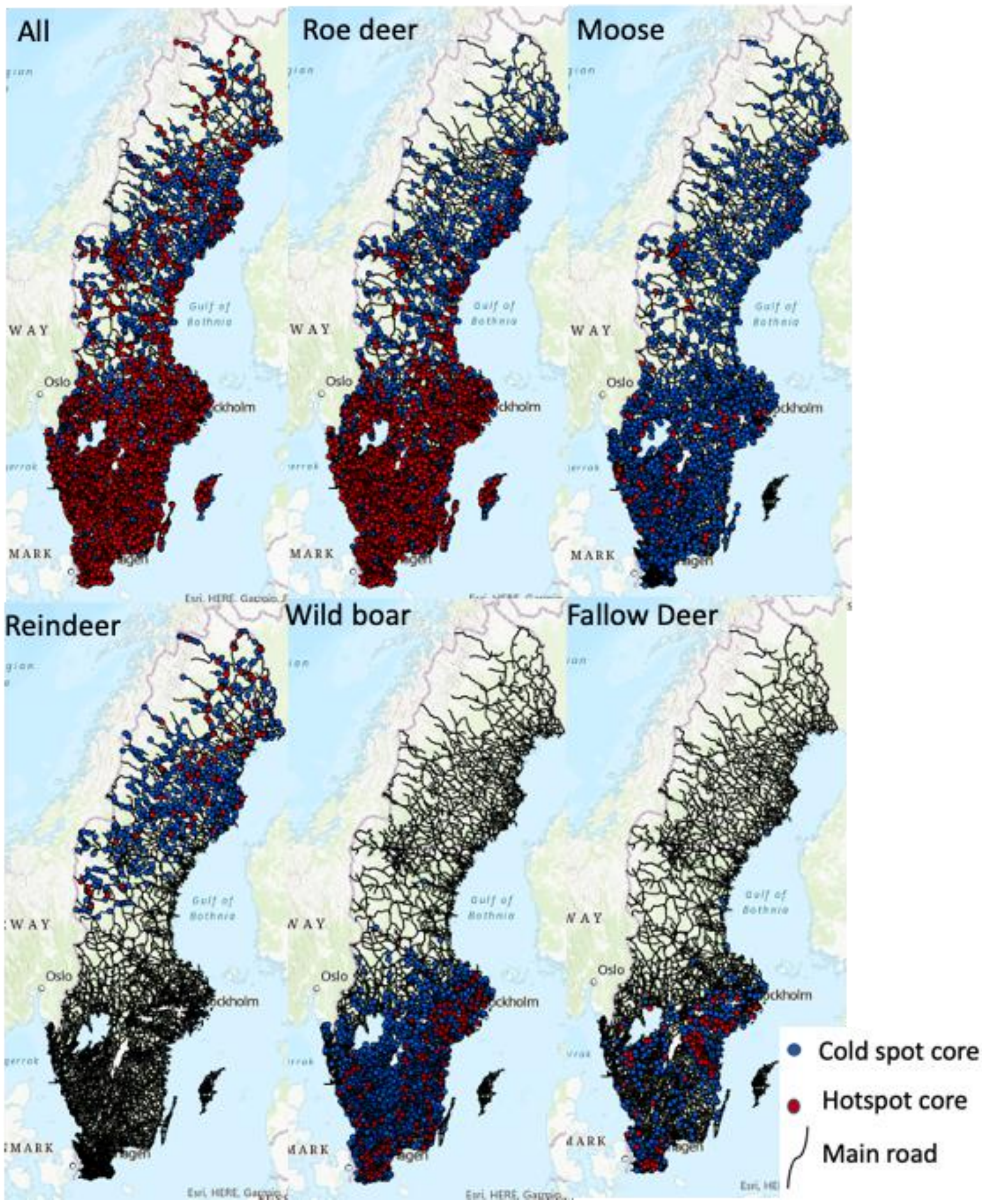

Figure 2: Hotspot and cold spot core distribution by species from study.

The definition of a *hotspot* follows the global threshold of a 1 km stretch of road having at least one accident every year for 4 of a 5-year period (Seiler et al., 2019). It was using this threshold that the KDE analysis was carried out previously. I selected 250 m road sections that emanated from hotspot cores which consisted of the region with the highest kernel value.

I defined a *cold spot* as a 250 m road section centred at one isolated accident during the 5-year period of study, further than 2 km radius from the nearest hotspot road and at least the species-specific minimum distance away from any other accidents e.g., > 700 m for roe deer and >1 km for moose (distances were based on the minimum distance between hotspots). In this, cold spots represented sites where accidents have occurred albeit utterly rare and isolated.

2.3. Road and Landscape Variable Collection

Road and Landscape variables were collected for hotspots and cold spots using road information available from the National Road Database (NVDB) and digital topographic maps (Naturvardsverket; Trafikverket). Logistic regression models were then developed to evaluate differences between hotspots and cold spots for the different species as well as a dataset of all the species combined.

2.3.1. Variable Data Cleaning

After collecting the different road, landscape and hunting bag variables, I conducted all subsequent analyses in JMP statistical software (JMP®). First, I carried out a predictor screening analysis, by species against the response variable "Hotspot". I did this so that I could determine the variables that indicated a significant relationship (determined by the ranking created by the software). The bootstrap analysis included an output of how the individual variable ranked relative to others in being able to predict the occurrence of hotspots. I then eliminated those that did not rank very highly, out of the proceeding analyses. I choose arbitrarily the road variables that ranked 1 - 7 and the landscape variables that ranked 1 - 10. Any variables that ranked lower were excluded from further analysis. I reasoned that any predictors which had higher ranking would not have a substantial impact on the models illustrated by the weaker correlation hotspots.

Following the predictor screening, I then conducted a multivariate pairwise analysis to determine the correlation between the independent (predictor) variables. I did this to avoid multicollinearity in my logistic models (Dormann et al., 2013). I did not allow for any two variables that demonstrated a correlation > 0.7 to be included during the model development (Dormann et al., 2013).

2.3.2. Landscape Variables

Land cover types considered in this study were the areas of WATER, WETLANDS, ARABLE LAND, FORESTS, OPEN LAND, EXPLOITED LAND, MINOR ROAD, MAJOR ROAD and DISTANCE TO BUILT-UP AREA (Table 2). No distinction was made between the different types of forest such as deciduous or coniferous. I measured the proportional cover within 100m, 1km, 2 km and 4km radius around the hotspot and cold spot cores, respectively. The different radii used to measure were: a) the immediate surrounding of the road (100m radius); b) the adjacent landscape (1 km), and c) the wider surroundings, allometrically estimated with respect to the different species average home ranges e.g., 4 km for moose (Cederlund & Okarma, 1988; Olsson et al., 2011) and 2 km for wild boar (Beasley et al., 2013),1km for roe deer (Elofsson & Häggmark, 2021; Szemethy et al., 1998).

I obtained Hunting data at county level from two time periods i.e., 2010 - 2014 and 2015 - 2019, in effect creating a fourth scale of measurement. The hunting data was included in the landscape model as a proxy for species abundance (Neumann et al., 2020).

2.3.3. Road Variables

Road attributes were collected for the 250m road sections of the cold and hotspots. The attributes included in the analysis were the PRESENCE OF BRIDGE, PRESENCE OF FENCE, MAIN ROAD CROSSINGS, MAXIMUM SPEED (numerical and categorical), TRAFFIC VOLUME, PRESENCE OF POWERLINE, UNFENCED PROPORTION OF ROAD and WATER CROSSING for which I carried out a summary statistical analysis (Table 3).

2.4. Stepwise Regression

I used the forward stepwise multiple logistic regression to build the best models based on the lowest AICc. Through an iterative process that required screening of the candidate models, I ensured that the models only included non-highly correlated predictor variables.

2.5. Model Ranking

I compared between different models performance using two different parameters namely; the receiver operating characteristics (ROC) and it’s area under the curve (AUC) (Sarang, 2018). I tiered the models according to the AUC values, as this showed how well they were able to distinguish between cold spots and hotspots. Values <0.7 meant the models were unacceptable to predict the occurrence of hotspots, 0.7 - 0.8 were “ acceptable”, 0.8 - 0.9 were “ good” and 0.9 - 1 were “ excellent” (Sarang, 2018).

3. Results

I collected a total of 9,085 cold spots and 4,171 hotspots for all datasets (Table 2). The hotspot to cold spot ratios were different for each species' dataset i.e., approximately 1:1 for *ALL*, 1:1 for *ROE DEER*, 1:23 for *MOOSE*, 1:4 for *FALLOW DEER*, 1:4 for *REINDEER* and 1:9 for *WILD BOAR.*

Table 1: Total number of cold and hot spots selected for analysis for each species

SPECIES	COLD SPOT	HOTSPOT
ALL	2385	2016
ROE DEER	2275	1688
MOOSE	2069	89
FALLOW DEER	458	122
REINDEER	343	80
WILD BOAR	1555	176

3.1. Predictor variables

After the predictor screening and ranking, 9 road variables remained (Table 3) namely, PRESENCE OF BRIDGE, PRESENCE OF FENCE, MAIN ROAD CROSSINGS, MAXIMUM SPEED (numerical and categorical), TRAFFIC VOLUME, PRESENCE OF POWERLINE, UNFENCED PROPORTION OF ROAD and WATER CROSSING.

In terms of the landscape variables there were 11 left (Table 4), and these were ARABLE LAND AREA, DISTANCE TO BUILT-UP AREA, EXPLOITED LAND AREA, FOREST LAND AREA, HUNTING BAG STATISTICS (2010 - 2014 and 2015 - 2019), MAIN ROAD AREA, MINOR ROAD AREA, OPEN LAND AREA, WATER BODY AREA and WETLAND AREA.

Table 2: The selected top ranking predictor landscape variables used for Stepwise Regression. Variables were selected among other potential variables after a predictor screening analysis.

VARIABLE	CODES	DESCRIPTION
ARABLE LAND AREA	ARABLE	Area in hectares of arable land around the cold and hot spot cores, collected within radii of 1 km , 2 km and 4 km
DISTANCE TO BUILT-UP AREA	DIST_TO_BUILTUP	The distance in metres to the nearest built-up area from the from the cold and hot spot cores
EXPLOITED LAND AREA	EXPLOITED	Area in hectares of exploited land around the cold and hot spot cores, collected within radii of 0.1 km, 1 km , 2 km and 4 km
FOREST AREA	FORESTS	Area in hectares of forest around the cold and hot spot cores, collected within radii of 0.1 km, 2 km and 4 km
HUNTING BAG STATISTICS (2010-14)	HUNT_1014	Hunting bag statistics of the different species (ALG =moose, DVH = fallow deer, RAD = roe deer and VSN = wild boar) for the period 2010 to 2014.
HUNTING BAG STATISTICS (2015-19)	HUNT_1519	Hunting bag statistics of the different species (ALG =moose, DVH = fallow deer, RAD = roe deer and VSN = wild boar) for the period 2015 to 2019.
MAIN ROAD AREA	MAINRD	Area in hectares of main roads around the cold and hot spot cores, collected within radii of 0.1 km, 1 km , and 4 km
OPEN LAND AREA	OPEN	Area in hectares of open land around the cold and hot spot cores, collected within radii of 0.1 km, 1 km , 2 km and 4 km
MINOR ROAD AREA	OTHERRD	Area in hectares of minor roads around the cold and hot spot cores, collected within radii of 0.1 km, 1 km , 2 km and 4 km
WATER BODY AREA	WATER	Area in hectares of water bodies around the cold and hot spot cores, collected within radii of 1 km , 2 km and 4 km
WETLAND AREA	WETLAND	Area in hectares of wetlands around the cold and hot spot cores, collected within radii of 0.1 km, 1 km , 2 km and 4 km

Table 3: The selection top ranking predictor road variables used for Stepwise Regression. Variables were selected among other potential variables after a predictor screening analysis.

VARIABLE	CODE	TYPE OF DATA
PRESENCE OF BRIDGE	BRIDGE	Binary
PRESENCE OF FENCE	FENCE	Binary
MAIN ROAD CROSSINGS	MAIN	Numerical, count
MAXIMUM SPEED	SPEED	ordinal: Low (40, 50, 60), High (70,80, 90) and High(100, 110), Very High(120) in km/h
MAXIMUM SPEED CATEGORIES	SPEED	Ordinal: No Data, LOW, MEDIUM, HIGH
TRAFFIC VOLUME	TRAFFIC	
PRESENCE OF POWER LINE	POWER_BIN	Binary
UNFENCED PROPORTION OF ROAD	UNFENCED	Numerical, percentage
WATER CROSSING	WATER	Binary

3.2. Ranking of Models using AUC

According to the AUC scores (Table 5) for Roe deer and the All-ungulates the mixed and road models were the highest ranking and equally good. The mixed model was the best for reindeer and the least was the road model. Whilst in wild boar the mixed model was the best and the worst was the landscape model. Finally, for the moose and fallow deer the road models were the best and the landscape models ranked lowest.

Table 4:The AUC scores of all the models developed and coded red for the highest and blue for the lowest values. Where 0.7 - 0.8 were "acceptable", 0.8 - 0.9 were "good" and 0.9 - 1 were "excellent". AUC_Land =the AUC for the landscape model, AUC_Road = AUC for the road model and AUC_Mixed = AUC for the mixed model

SPECIES	AUC_LAND	AUC_ROAD	AUC_MIXED
ROE DEER	0,8	0,91	0,92
ALL	0,8	0,91	0,92
REINDEER	0,79	0,78	0,87
WILD BOAR	0,75	0,86	0,88
MOOSE	0,67	0,89	0,87
FALLOW DEER	0,61	0,66	0,65

In general, for all datasets, the landscape models were the worst at distinguishing between the hotspots and cold spots. With the road and mixed models, it depended on the species which type performed better.

3.3. Model Variables

TRAFFIC VOLUME, PROPORTION OF UNFENCED ROAD and MAXIMUM SPEED of the road were important for all species models. TRAFFIC VOLUME and PROPORTION OF UNFENCED ROAD where in all instances positively correlated to the occurrence of hotspots (See Table 5 and Appendix II). MAXIMUM SPEED categories where in most cases positively correlated except for the Wild Boar model which showed a negative correlation from lower high speeds (100 and 110Km/h) to the highest speed (120km/h) (See Appendix II).

Similarly results showed that several different landscape variables were good predictors of hotspots and that there was a species variability for some and commonality for others (Table 5). The most common variables (i.e., included in 50% of the models) were the MAIN ROAD AREA (Moose, Reindeer, Roe Deer and Wild Boar), MINOR ROAD AREA (ALL, Fallow Deer, Moose, and Roe Deer), *DISTANCE TO BUILT-UP AREA* (ALL, Moose, Roe Deer, and Wild Boar) and *OPEN LAND AREA* (Roe Deer, ALL and Wild Boar).

Table 5: Variables that were included in the landscape, mixed and road models for each species. The cells highlighted in green indicate that the variable was present in at least 3 different species' models within landscape, mixed or road models. (See Appendices I and II for model parameters)

	Landscape Model						Mixed Model						Road Model					
VARIABLE	All	Fallow Deer	Moose	Reindeer	Roe Deer	Wild Boar	All	Fallow Deer	Moose	Reindeer	Roe Deer	Wild Boar	All	Fallow Deer	Moose	Reindeer	Roe Deer	Wild Boar
ARABLE LAND AREA				x			x			x		x						
DISTANCE TO BUILT-UP AREA	x		x		x	x			x		x	x						
EXPLOITED LAND AREA	x			x			x		x	x		x						
FENCE									x		x		x		x		x	x
HIGH SPEED										x	x				x		x	x
HUNTING BAG STATISTICS			x			x			x		x	x						
MAIN ROAD AREA			x	x	x	x				x	x							
MAIN ROAD CROSSING							x						x				x	
MEDIUM - HIGH SPEED									x		x	x						
MEDIUM SPEED													x				x	x
MEDIUM/HIGH - HIGH SPEED													x	x	x			
MINOR ROAD AREA	x	x	x		x			x		x	x							
OPEN LAND AREA	x				x	x	x				x	x						
PROPORTION OF UNFENCED ROAD							x	x	x		x	x	x		x	x	x	x
TRAFFIC VOLUME							x		x	x	x	x	x	x	x	x	x	x
WATER BODY AREA	x	x			x			x	x									
BRIDGE																	x	x
FOREST AREA						x												
LOW -MEDIUM SPEED																x	x	
LOW/MEDIUM - MEDIUM/HIGH SPEED																	x	
LOW/MEDIUM - HIGH SPEED										x								
LOW/MEDIUM - MEDIUM/HIGH SPEED								x			x							
MEDIUM-HIGH SPEED																	x	x
WATER CROSSING																x		
WETLAND AREA						x						x						

The results of the mixed models (see Table 5 and Appendix II) were that TRAFFIC VOLUME, and MAXIMUM SPEED of the road were important for all species models and positively correlated to the occurrence of hotspots for all datasets except in the fallow deer model where there was a negative correlation. PROPORTION OF UNFENCED ROAD was significant for all groups except for Reindeer and in all cases demonstrated a positive relationship with the occurrence of hotspots. Of all variables that were accepted into the different models, most were common among at least 50% of the species' models. Less common variables included WETLAND AREA that was important only for Wild Boar, WATER BODY AREA that was present only in the Moose and Fallow Deer models and the PRESENCE OF FENCE for Moose and Roe Deer.

4. Discussion

4.1. Important results of the study

My analysis showed that a combination of road and landscape variables predict the occurrence of hotspots in all the species except fallow deer. Nevertheless, road characteristics can be concluded to be an important parameter to predict the occurrence of hotspots. In terms of application, this means that UVC aggregation can be mitigated more easily as it involves parameters that are within the direct jurisdiction of the Transport Administration. The importance of road parameters was evident even in the landscape models, as they included the areas of minor and major roads at different scales. These findings are similar to other Animal-Vehicle Collisions studies conducted around the world (Colino-Rabanal et al., 2010; Seiler et al., 2016; Tanner et al., 2017).

4.2. Road Characteristics

Traffic volume was the most significant predictor in all the different species models, both in the road and mixed models. Showing a positive correlation between the volume of vehicles on a road section and the occurrence of UVC, this has been recorded in other studies (Bíl et al., 2020; Seiler, 2004, 2005; Sjölund, 2016). It is logical that the most accidents would occur where the most traffic goes through, simply by increasing the odds.

All species had some level of maximum speed as predictors of hotspots, the general trend being that as the maximum speed of the road increased the higher the likelihood of UVC aggregation. Other studies have shown that higher speeds tend have a negative correlation with UVC occurrence (Seiler, 2004; Seiler et al., 2016). However, my results did not show such a trend except in the wild boar, where there was an inverse relationship when the speed limit increased from 100 km/h towards the highest speed of 120 km/h. Reducing speed limits on roads may be an option to curb this trend but is probably impractical (Seiler et al., 2016). A study by Seiler (2005) showed that a reduction of the speed limit to 50 km/h from 70 km/h on roads with the traffic volume of 8 000 ADT would decrease the number of moose accidents with 50%. However, this reduction would also mean that more time is spent on the road by commuters leading to other socioeconomic losses and there might be a higher proportion of motorists who might not adhere to such low speed limits (Seiler et al., 2016). Therefore, I posit that of the 3 top road variables the easiest to manage for Trafikverket would be the fencing.

The presence of a fence and/or the unfenced proportion of the road were both positively correlated to the occurrence of hotspots for all the data sets. It would seem that the presence of fences that do not fully cover the road may aggravate instead of mitigate the incidence of UVCs, a cause of concern considering fences are the primary mitigation strategy currently in use (van der Ree et al., 2015). This may be as a result of the funnelling effect of fences, where the animals not being able to cross the road on the fenced portion move along it and take opportunity wherever they find a gap in the fencing (Sjölund, 2016; van der Ree et al., 2015). In this respect, the models are different from the findings of Sjölund (2016) who found that the UVC clusters were characterized by higher traffic and speed limits and a lack of fencing. This difference may be a factor that becomes clearer at a finer species scaling and broader distribution scope, as my study covered all of Sweden whilst Sjölund’s focused on the South and did not discriminate between species. Other studies have shown similar ineffectiveness of fences (Huijser et al., 2016).

However, it is possible that it is not that fences are fundamentally ineffective or problematic but that their use can be improved (Seiler et al., 2016). Van der Ree et al (2015) give guidance on aspects to be considered in the use of fencing namely: species specific design; using non-traditional fencing such as dense plantings and other food or shelter sources for animals, coupling fences with species-specific right-of-way escape mechanisms; consideration of fence lengths that reduce the rate of collisions e.g., fences that consider the extent of species’ habitats or other attributes of importance.

4.3. Landscape Characteristics

Even though the landscape model results show that landscape features on their own are not enough to predict the aggregation of UVC, many of the variables were still present in the mixed models showing their importance. For example, Open land and Hunting bag statistics both were present in both mixed and landscape models. Below I outline the landscape features that were included in multiple species mixed models.

a. Exploited land and distance to built-up areas (all ungulates, roe deer, fallow deer, moose, reindeer, wild boar)
b. Arable land (all ungulates, reindeer, wild boar)
c. Open Land (wild boar, roe deer, all ungulates)
d. Minor Road area (roe deer, reindeer, fallow deer)
e. Hunting bag Statistics (moose, roe deer, wild boar)

The mixed model demonstrated that as smaller arable land area the greater the occurrence of hotspots. For some ungulates such as wild boar, arable lands are feeding sites but they prefer small and narrow fields versus more open land (Gren et al., 2015). Arable Land and Forest Land areas were highly negatively correlated at all scales. This means that the less arable land in an area often means the larger forest cover present. Arable land and open areas allow for better visibility than forest areas (Gren et al., 2015). I reason that the high accident incidence in areas with less arable land would then be a result of low visibility for both ungulates and drivers. Wild boar are more likely to be in regions with a mix of forest and open areas as large pockets of open land are less attractive to them (Beasley et al., 2013). Conceivably, the highest number of accidents would then be in areas that are intermediate between forest and open areas but with a leaning towards larger arable areas. Feeding sites may also be a determining factor but are unregistered (Gren et al., 2015).

For moose, roe deer and wild boar there was a positive relationship between hunting bag statistics and occurrence of hotspots. The hunting bag statistics is a proxy for species abundance (Neumann et al., 2020; Seiler, 2005). As observed by Neumann et al. (2020), for moose the best statistical fit had a 2-year time lag, similarly the moose model in my study had a stronger correlation with the hunting bag statistics of the period 2010 - 2014. The county scale was used and this might be the best for moose because that is the scale of overarching management plans. However, a finer scale e.g., at parish level might have been used for the other species (Neumann et al., 2020). The use of this scale was primarily for the sake of convenience as this was readily available, admittedly the coarse scale may explain why the predictor was not significant for fallow deer. Perhaps this might have helped to strengthen the fallow deer landscape and/or mixed models to acceptable AUC score levels.

Future Research

In my definition of cold spot areas, I opted to discriminate the analysis to areas that were known to have had accidents but that for some reason over the period under study did not accumulate. Instead of choosing a control area where no accidents had occurred over the study period. Whilst on one hand this might have skewed the analysis by not considering regions that may represent “real” cold spots, by having no accidents at all; on the other hand, I believe it made the data more robust as it certainly did not include areas that were outside of the distribution of the focal species. In this way I was certainly comparing high UVC accident occurrence regions with low UVC occurrence within the species distribution. However, it might be useful to test this hypothesis by carrying out the analysis with both cold spots where only an individual accident has occurred and where no accident has occurred over a 5-year period to examine if the results are comparable.

Another possible way that the study could have been refined by, would be to define the hotspots clusters by the KDE+ method (Bíl et al., 2019). A modified Kernel Density Estimation (KDE) method was developed to distinguish between road sections with a clustering of UVCs higher than other parts of the road network and is called the KDE+ method (Bíl et al., 2013; Bíl et al., 2014). Bíl et al (2013) determined the statistical significance of the clustering by using a Monte Carlo hypothesis testing which involved multiple simulations with the same number of randomly selected UVCs. These simulations were to test if the clusters were indeed non-random. Furthermore, by determining the degree of significance of each cluster, they were able to compare the strength of clusters with each other. This type of analysis is important because it allows for faster identification of UVC clustering which means quicker mitigation and management decisions and actions by the transport administrations (Bíl et al., 2013; Bíl et al., 2014).

5. Conclusions

I used logistic regression modelling to examine which road, traffic, landscape, ecological and behavioural related attributes that correlated best with the aggregation of UVC involving roe deer, moose, wild boar, reindeer, and fallow deer respectively and collectively in Sweden. I created three different model types i.e., landscape, road, and mixed models. The mixed models were the best performing models of all and the road parameters the most important predictors of UVC hotspots. The three most important parameters explaining UVC hotspots were "traffic volume", "maximum speed on the road section" and the "proportion of fencing along the road section".

The results of this study indicate that there might be a need to carry out further cost-benefit analysis of current mitigation strategies such as how and where fences should be used. In this study, I show that shorter fences are positively related to the aggregation of hotspots. This may be linked to the funnelling nature of fencing which may be leading animals onto one segment of the road that results in multiple collisions i.e., hotspots. I urge the transport administration to investigate this further.

The models may be improved by redefining cold spots as road sections that are within the species distribution but where no accident has occurred. In terms of the hotspots these too may be optimized by only considering statistically significant clustering using the KDE+ method.

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Appendix I: Logistic Model Parameters

Whole model results of the selected Landscape, Road and Mixed models for all species i.e., All (Combined species dataset), Fallow deer, Moose, Reindeer, Roe deer and Wild boar.

Model	Model Criteria	All	Fallow deer	Moose	Reindeer	Roe deer	Wild boar
Landscape	-LogLikelihood	663,01	5,2	17,7	39,25	605,7	60,81
	DF	6	2	4	3	8	7
	ChiSquare	1326	10,39	35,39	78,51	1211,4	121,61
	Prob>ChiSq	<,0001*	0,0055 *	<,0001	<,0001	<,0001*	<,0001*
	Lack of Fit DF	4394	575	2153	419	3954	1557
	Lack of Fit - LogLikelihood	2372	290,4	353,2	165,9	2097,6	489,49
	Lack of Fit ChiSquare	4744,1	580,8	706,4	331,8	4195,2	978,98
	Lack of Fit Prob>ChiSq	0,0001*	0,425	1	0,999	0,0038*	1
	AICc	4758,1	592,4	716,4	339,9	4213,3	995,07
	BIC	4802,8	605,4	744,8	356	4269,8	1037,8
	Observations (or Sum Wgts)	4401	580	2158	423	3963	1565
	AUC	0,8	0,61	0,67	0,79	0,8	0,75
Mixed	-LogLikelihood	1258,6	10	98,96	62,57	1094,4	160,17
	DF	16	4	8	8	14	10
	ChiSquare	2517,3	19,99	197,9	125,1	2188,8	320,35
	Prob>ChiSq	<,0001*	0,0005 *	<,0001	<,0001 *	<,0001*	<,0001*
	Lack of Fit DF	4257	572	2066	405	3550	1494
	Lack of Fit - LogLikelihood	1681,8	286,5	259	136,3	1352,5	362,27
	Lack of Fit ChiSquare	3363,6	573	518	272,6	2704,9	724,54
	Lack of Fit Prob>ChiSq	1	0	1	1	1	1
	AICc	3397,8	585,9	536,1	291,1	2735	746,72
	BIC	3505,8	607,6	586,7	326,8	2827,6	805,02
	Observations (or Sum Wgts)	427	578	207	414	3565	1505
	AUC	0,92	0,65	0,87	0,87	0,92	0,88
Road	-LogLikelihood	983,83	4,97	84,48	24,39	920,97	104,21
	DF	7	2	5	4	10	7
	ChiSquare	1967,65	9,93	168,96	48,78	1841,93	208,42
	Prob>ChiSq	<,0001	0,007'	<,0001	<,0001	<,0001	<,0001
	Lack of Fit DF	1955	448	1254	290	2059	1044
	Lack of Fit - LogLikelihood	1313,04	263,5	251,12	136,61	1267,3	399,79
	Lack of Fit ChiSquare	2626,09	527,01	502,23	273,22	2534,6	799,58
	Lack of Fit Prob>ChiSq	<,0001	0,006	1	0,753	<,0001	1
	AICc	3929,26	565,1	559	359,1	3348,08	888,63
	BIC	3980,11	577,95	592,79	379,08	3416,71	931,89
	Observations (or Sum Wgts)	4274	544	2075	414	3811	1668
	AUC	0,91	0,66	0,89	0,78	0,91	0,86

Appendix II: Logistic Model Results

Mixed, Road and Landscape model parameters for each significant variable (p<0.05). Insignificant variables have been excluded from the tables.

Model	Species	*Variable*	*Scale*	*Estimate*	*Std Error*	*ChiSquare*	*Prob>ChiSq*
Mixed	All	Intercept	N/A	-8,69E+00	4,62E-01	3,55E+02	<,0001*
Mixed	All	**Arable Land Area**	2 km	-5,79E-04	1,87E-04	9,59E+00	0,0020*
Mixed	All	**Exploited Land Area**	2 km	4,71E-02	3,31E-03	2,03E+02	<,0001*
Mixed	All	Main Road Crossing	N/A	2,39E+00	6,77E-01	1,25E+01	0,0004*
Mixed	All	**Traffic Volume**	N/A	2,36E-03	1,01E-04	5,40E+02	<,0001*
Mixed	All	**Open Land Area**	1 km	9,63E-03	2,65E-03	1,32E+01	0,0003*
Mixed	All	**Open Land Area**	100 m	7,48E-01	1,13E-01	4,36E+01	<,0001*
Mixed	All	**Proportion of Unfenced Road**	N/A	4,75E-02	4,14E-03	1,32E+02	<,0001*
Mixed	Fallow Deer	Intercept	N/A	-2,41E+00	3,95E-01	3,74E+01	<,0001*
Mixed	Fallow Deer	Low/Medium -Medium/High Speed	N/A	-2,77E-01	1,09E-01	6,48E+00	0,0109*
Mixed	Fallow Deer	**Minor Road Area**	100 m	2,24E-03	1,04E-03	4,70E+00	0,0302*
Mixed	Fallow Deer	**Proportion of Unfenced Road**	N/A	7,96E-03	3,69E-03	4,65E+00	0,0311*
Mixed	Fallow Deer	Water Body Area	4 km	5,10E-04	1,94E-04	6,90E+00	0,0086*
Mixed	Moose	Intercept	N/A	-7,94E+00	1,14E+00	4,84E+01	<,0001*
Mixed	Moose	**Distance to Built-up Area**	N/A	-6,25E-05	2,93E-05	4,56E+00	0,0327*
Mixed	Moose	**Exploited Land Area**	4 km	-5,04E-03	1,51E-03	1,11E+01	0,0009*
Mixed	Moose	Fence	N/A	1,28E+00	4,76E-01	7,28E+00	0,0070*
Mixed	Moose	**Hunting Bag Statistics**	2010-14	6,54E+00	2,20E+00	8,86E+00	0,0029*
Mixed	Moose	**Medium - High Speed**	N/A	1,96E+00	2,68E-01	5,33E+01	<,0001*
Mixed	Moose	**Traffic Volume**	N/A	3,85E-04	4,92E-05	6,12E+01	<,0001*
Mixed	Moose	**Proportion of Unfenced Road**	N/A	3,74E-02	1,11E-02	1,13E+01	0,0008*
Mixed	Moose	Water Body Area	1 km	-1,26E-02	5,47E-03	5,31E+00	0,0212*
Mixed	Reindeer	Intercept	N/A	-7,58E+00	1,05E+00	5,20E+01	<,0001*
Mixed	Reindeer	**Arable Land Area**	4 km	-5,89E-03	1,77E-03	1,11E+01	0,0009*
Mixed	Reindeer	**Exploited Land Area**	100 m	4,09E+00	8,71E-01	2,21E+01	<,0001*
Mixed	Reindeer	Main Road Area	1 km	9,27E-04	2,00E-04	2,14E+01	<,0001*
Mixed	Reindeer	low/Medium -High Speed	N/A	1,30E+00	6,08E-01	4,59E+00	0,0321*
Mixed	Reindeer	High Speed	N/A	3,26E+00	1,21E+00	7,23E+00	0,0072*
Mixed	Reindeer	**Traffic Volume**	N/A	6,68E-04	2,21E-04	9,12E+00	0,0025*
Mixed	Reindeer	**Minor Road Area**	1 km	1,76E-04	6,44E-05	7,49E+00	0,0062*
Mixed	Roe Deer	Intercept	N/A	-1,67E+01	1,27E+00	1,74E+02	<,0001*
Mixed	Roe Deer	**Distance to Built-up Area**	N/A	-8,14E-05	1,52E-05	2,86E+01	<,0001*
Mixed	Roe Deer	Fence	N/A	3,12E+00	7,62E-01	1,67E+01	<,0001*
Mixed	Roe Deer	**Hunting Bag Statistics**	2015-19	1,44E+00	1,74E-01	6,86E+01	<,0001*
Mixed	Roe Deer	Main Road Area	1 km	2,81E-04	6,09E-05	2,12E+01	<,0001*
Mixed	Roe Deer	Main Road Area	100 m	2,02E-02	3,75E-03	2,90E+01	<,0001*
Mixed	Roe Deer	Low/Medium -Medium/High Speed	N/A	1,50E+00	2,14E-01	4,93E+01	<,0001*
Mixed	Roe Deer	**Medium - High Speed**	N/A	3,93E+00	4,05E-01	9,40E+01	<,0001*
Mixed	Roe Deer	**Medium - High Speed**	N/A	6,25E+00	7,71E-01	6,57E+01	<,0001*
Mixed	Roe Deer	High Speed	N/A	4,63E+00	9,27E-01	2,49E+01	<,0001*
Mixed	Roe Deer	High Speed	N/A	5,88E+00	8,89E-01	4,37E+01	<,0001*
Mixed	Roe Deer	**Traffic Volume**	N/A	2,00E-03	1,07E-04	3,47E+02	<,0001*
Mixed	Roe Deer	**Open Land Area**	100 m	7,65E-01	1,16E-01	4,34E+01	<,0001*
Mixed	Roe Deer	**Minor Road Area**	1 km	1,80E-04	2,24E-05	6,46E+01	<,0001*
Mixed	Roe Deer	**Proportion of Unfenced Road**	N/A	9,63E-02	1,24E-02	6,01E+01	<,0001*

Mixed	**Wild Boar**	Intercept	N/A	-9,94E+00	1,47E+00	4,54E+01	<,0001*	
Mixed	**Wild Boar**	**Arable Land Area**	100 m	-4,19E-01	1,17E-01	1,28E+01	0,0003*	
Mixed	**Wild Boar**	**Distance to Built-up Area**	N/A	-1,31E-04	5,07E-05	6,65E+00	0,0099*	
Mixed	**Wild Boar**	**Exploited Land Area**	4 km	-3,88E-03	1,44E-03	7,26E+00	0,0071*	
Mixed	**Wild Boar**	**Hunting Bag Statistics**	2015-19	1,71E+00	2,18E-01	6,17E+01	<,0001*	
Mixed	**Wild Boar**	**Medium - High Speed**	N/A	1,63E+00	1,92E-01	7,20E+01	<,0001*	
Mixed	**Wild Boar**	**Traffic Volume**	N/A	4,00E-04	4,94E-05	6,57E+01	<,0001*	
Mixed	**Wild Boar**	**Open Land Area**	1 km	-2,29E-02	7,64E-03	8,95E+00	0,0028*	
Mixed	**Wild Boar**	**Open Land Area**	4 km	2,12E-03	7,80E-04	7,39E+00	0,0066*	
Mixed	**Wild Boar**	**Proportion of Unfenced Road**	N/A	5,68E-02	1,38E-02	1,71E+01	<,0001*	
Mixed	**Wild Boar**	Wetland Area	100 m	1,56E+00	6,12E-01	6,52E+00	0,0107*	
Landscape	**ALL**	Intercept	N/A	-2,76E+00	1,54E-01	3,21E+02	9,55E-72	
Landscape	**ALL**	Exploited Land Area	2 km	5,09E-02	3,02E-03	2,85E+02	6,22E-64	
Landscape	**ALL**	**Distance to Built-up Area**	N/A	-5,35E-05	8,11E-06	4,35E+01	4,31E-11	
Landscape	**ALL**	**Minor Road Area**	100 m	2,58E-03	4,10E-04	3,94E+01	3,46E-10	
Landscape	**ALL**	**Open Land Area**	100 m	5,92E-01	9,60E-02	3,81E+01	6,89E-10	
Landscape	**ALL**	**Open Land Area**	2 km	2,71E-03	6,32E-04	1,84E+01	1,76E-05	
Landscape	**ALL**	Water Body Area	1 Km	4,26E-03	1,20E-03	1,25E+01	4,09E-04	
Landscape	**Fallow Deer**	Intercept	N/A	-1,74E+00	1,71E-01	1,04E+02	2,36E-24	
Landscape	**Fallow Deer**	Water Body Area	4 Km	4,93E-04	1,91E-04	6,65E+00	9,90E-03	
Landscape	**Fallow Deer**	**Minor Road Area**	100 m	2,22E-03	1,02E-03	4,79E+00	2,86E-02	
Landscape	**Moose**	Intercept	N/A	-4,62E+00	5,93E-01	6,07E+01	6,49E-15	
Landscape	**Moose**	**Main Road Area**	100 m	2,93E-03	8,59E-04	1,16E+01	6,43E-04	
Landscape	**Moose**	**Distance to Built-up Area**	N/A	-7,67E-05	2,84E-05	7,27E+00	7,01E-03	
Landscape	**Moose**	**Minor Road Area**	100 m	2,73E-03	1,07E-03	6,57E+00	1,04E-02	
Landscape	**Moose**	Hunting Bag Statistics	2010-14	3,36E+00	1,70E+00	3,90E+00	4,83E-02	
Landscape	**Reindeer**	Intercept	N/A	-5,20E+00	5,43E-01	9,17E+01	1,03E-21	
Landscape	**Reindeer**	Exploited Land Area	100 m	4,45E+00	8,26E-01	2,90E+01	7,18E-08	
Landscape	**Reindeer**	**Main Road Area**	1 Km	8,50E-04	1,63E-04	2,71E+01	1,98E-07	
Landscape	**Reindeer**	Arable Land Area	4 Km	-3,69E-03	1,32E-03	7,85E+00	5,08E-03	
Landscape	**Roe Deer**	Intercept	N/A	-3,23E+00	1,99E-01	2,65E+02	1,78E-59	
Landscape	**Roe Deer**	**Minor Road Area**	1 Km	2,65E-04	1,84E-05	2,08E+02	3,23E-47	
Landscape	**Roe Deer**	**Distance to Built-up Area**	N/A	-1,31E-04	1,37E-05	9,17E+01	1,02E-21	
Landscape	**Roe Deer**	**Main Road Area**	1 Km	2,67E-04	4,11E-05	4,22E+01	8,04E-11	
Landscape	**Roe Deer**	**Open Land Area**	2 km	4,67E-03	7,56E-04	3,82E+01	6,46E-10	
Landscape	**Roe Deer**	**Minor Road Area**	100 m	1,54E-03	4,21E-04	1,33E+01	2,61E-04	
Landscape	**Roe Deer**	**Open Land Area**	100 m	3,54E-01	9,77E-02	1,31E+01	2,94E-04	
Landscape	**Roe Deer**	**Main Road Area**	4 Km	1,28E-05	3,66E-06	1,22E+01	4,73E-04	
Landscape	**Roe Deer**	Water Body Area	1 Km	3,16E-03	1,30E-03	5,91E+00	1,50E-02	
Landscape	**Wild Boar**	Intercept	N/A	-2,29E+00	4,76E-01	2,31E+01	1,52E-06	
Landscape	**Wild Boar**	Hunting Bag Statistics	2010-14	1,07E+00	2,01E-01	2,83E+01	1,03E-07	
Landscape	**Wild Boar**	**Distance to Built-up Area**	N/A	-1,69E-04	4,63E-05	1,33E+01	2,67E-04	
Landscape	**Wild Boar**	Forest Area	100 m	3,62E-01	1,11E-01	1,07E+01	1,08E-03	
Landscape	**Wild Boar**	Forest Area	4 Km	-3,66E-04	1,12E-04	1,06E+01	1,14E-03	
Landscape	**Wild Boar**	Wetland Area	100 m	1,55E+00	5,16E-01	9,07E+00	2,60E-03	
Landscape	**Wild Boar**	**Open Land Area**	4 Km	1,44E-03	4,91E-04	8,66E+00	3,26E-03	
Landscape	**Wild Boar**	**Main Road Area**	4 Km	-1,59E-05	6,74E-06	5,59E+00	1,80E-02	
Road	**All**	Intercept	N/A	-7,25E+00	4,96E-01	2,14E+02	<,0001*	
Road	**All**	Main Road Crossing	N/A	4,45E+00	1,13E+00	1,55E+01	<,0001*	
Road	**All**	Medium Speed	N/A	6,33E-01	1,01E-01	3,96E+01	<,0001*	
Road	**All**	**Medium/high - High Speed**	N/A	-2,89E+00	6,44E-01	2,01E+01	<,0001*	
Road	**All**	**Traffic Volume**	N/A	2,84E-03	1,09E-04	6,78E+02	<,0001*	
Road	**All**	**Proportion of Unfenced Road**	N/A	7,70E-02	9,26E-03	6,91E+01	<,0001*	
Road	**All**	**Fence**	N/A	2,25E+00	6,38E-01	1,24E+01	0,0004*	
Road	**All**	**Medium/high - High Speed**	N/A	2,24E+00	6,36E-01	1,24E+01	0,0004*	
Road	**Fallow Deer**	Intercept	N/A	-1,55E+00	1,40E-01	1,22E+02	<,0001*	
Road	**Fallow Deer**	**Medium/high - High Speed**	N/A	4,89E-01	2,10E-01	5,41E+00	0,0200*	

Road	**Moose**	Intercept	N/A	-7,19E+00	8,54E-01	7,09E+01	<,0001*	
Road	**Moose**	**Medium/high - High Speed**	N/A	2,07E+00	2,66E-01	6,08E+01	<,0001*	
Road	**Moose**	**Traffic Volume**	N/A	2,95E-04	3,27E-05	8,12E+01	<,0001*	
Road	**Moose**	**Proportion of Unfenced Road**	N/A	3,44E-02	1,09E-02	9,93E+00	0,0016*	
Road	**Moose**	**High Speed**	N/A	2,03E+00	7,81E-01	6,74E+00	0,0094*	
Road	**Moose**	**Fence**	N/A	1,16E+00	4,64E-01	6,19E+00	0,0128*	
Road	**Reindeer**	Intercept	N/A	-4,30E+00	1,43E+00	9,00E+00	0,0027*	
Road	**Reindeer**	Low -Medium Speed	N/A	8,11E-01	2,07E-01	1,54E+01	<,0001*	
Road	**Reindeer**	Traffic Volume	N/A	8,28E-04	1,91E-04	1,88E+01	<,0001*	
Road	**Roe Deer**	**Fence**	N/A	2,95E+00	6,58E-01	2,01E+01	<,0001*	
Road	**Roe Deer**	Intercept	N/A	-8,03E+00	6,61E-01	1,47E+02	<,0001*	
Road	**Roe Deer**	Low/medium - Medium/high Speed	N/A	1,23E+00	2,00E-01	3,79E+01	<,0001*	
Road	**Roe Deer**	Medium Speed	N/A	8,60E-01	1,11E-01	6,00E+01	<,0001*	
Road	**Roe Deer**	Medium-High Speed	N/A	1,66E+00	3,72E-01	2,00E+01	<,0001*	
Road	**Roe Deer**	**Traffic Volume**	N/A	2,05E-03	8,77E-05	5,48E+02	<,0001*	
Road	**Roe Deer**	**Proportion of Unfenced Road**	N/A	8,58E-02	1,06E-02	6,53E+01	<,0001*	
Road	**Roe Deer**	Main Road Crossing	N/A	2,83E+00	7,48E-01	1,43E+01	0,0002*	
Road	**Roe Deer**	Bridge	N/A	-6,00E-01	2,38E-01	6,34E+00	0,0118*	
Road	**Roe Deer**	Low -Medium Speed	N/A	2,37E-01	1,02E-01	5,33E+00	0,0210*	
Road	**Roe Deer**	**High Speed**	N/A	1,54E+00	7,01E-01	4,85E+00	0,0277*	
Road	**Wild Boar**	Intercept	N/A	-1,57E+01	3,06E+00	2,62E+01	<,0001*	
Road	**Wild Boar**	Medium-High Speed	N/A	1,11E+00	1,92E-01	3,34E+01	<,0001*	
Road	**Wild Boar**	**Traffic Volume**	N/A	3,48E-04	4,03E-05	7,45E+01	<,0001*	
Road	**Wild Boar**	**Proportion of Unfenced Road**	N/A	1,18E-01	3,12E-02	1,43E+01	0,0002*	
Road	**Wild Boar**	Bridge	N/A	2,91E+00	1,20E+00	5,92E+00	0,0149*	
Road	**Wild Boar**	**High Speed**	N/A	-1,64E+00	7,04E-01	5,43E+00	0,0198*	
Road	**Wild Boar**	**Fence**	N/A	2,17E+00	9,49E-01	5,23E+00	0,0222*	
Road	**Wild Boar**	Medium Speed	N/A	3,29E-01	1,54E-01	4,58E+00	0,0323*	

Appendix III: Summary Statistics of Road Variables

Summary statistics of all road features used for the stepwise logistic regression analyses. Where units used were (N) = count of the variable was used, km/h =kilometres per hour and (AADT) = annual average daily traffic. Not all variables were selected in the final models.

SPECIES		**Moose**		**ALL**		**Fallow Deer**		**Roe Deer**		**Reindeer**		**Wild Boar**	
VARIABLES		**COLD**	**HOT**	**COLD**	**HOT**	**COLD**	**HOT**	**COLD**	**HOT**	**COLD**	**HOT**	**COLD**	**HOT**
POWERLINE (N)	**NO_POWERLINE**	2017	85	2354	1950	449	118	2245	1646	339	74	1521	175
	POWERLINE	52	4	31	66	9	4	30	42	4	6	34	1
BRIDGE/WATER CROSSINGS (N)	**BRIDGE, NO_WATER**	57	7	35	91	19	6	32	103	9	5	30	1
	BRIDGE, WATER	35	1	34	44	10	2	26	47	4	1	27	2
	NO_BRIDGE, NO_WATER	1744	74	2080	1685	377	102	1974	1381	304	74	1315	151
	NO_BRIDGE, WATER	233	7	236	196	52	12	243	157	26	0	183	22
FENCE/WATER CROSSINGS (N)	**FENCE**	86	8	23	130	36	6	39	114	6	4	67	2
	UNFENCED	1983	81	2362	1886	422	116	2236	1574	337	76	1488	174
	NO_WATER	1801	81	2115	1776	396	108	2006	1484	313	79	1345	152
	WATER	268	8	270	240	62	14	269	204	30	1	210	24
MAXIMUM SPEED (km/h)	**NO DATA**	2	0	5	4	1	0	6	6	0	1	3	2
	HIGH	137	6	62	175	51	10	62	159	42	24	87	9
	LOW	68	0	57	96	13	1	79	107	12	10	29	3
	MEDIUM	1862	83	2261	1741	393	111	2128	1416	289	45	1436	162
MAXIMUM SPEED (km/h)	**40**	3	0	1	6	1	0	5	5	0	0	1	1
	50	46	0	42	59	9	1	55	59	7	6	20	1
	60	19	0	14	31	3	0	19	43	5	4	8	1
	70	1285	14	1856	1020	289	68	1786	769	108	10	1195	70
	80	375	36	264	513	72	32	222	462	83	16	174	67
	90	202	33	141	208	32	11	120	185	98	19	67	25
	100	113	2	47	130	38	8	40	113	38	20	61	6
	110	21	4	11	44	12	2	17	40	4	4	20	3
	120	3	0	4	1	1	0	5	6	0	0	6	0
TRAFFIC VOLUME (AADT)	**Mean**	1047	4652	301	2006	1946	2739	419	2715	479	975	1220	3195
	Std Dev	2221	5039	708	3945	3474	3169	898	4399	732	941	2710	2830
	Min	9	449	6	11	10	150	8	30	6	30	11	191
	Max	32558	43724	13392	91150	25040	16856	13414	77340	5732	4533	34900	17017
UNFENCED PROPORTION OF ROAD (m)	**Mean**	94	93	99	93	89	95	97	92	97	93	94	100
	Std Dev	31	32	16	33	42	27	22	33	21	34	32	4
	Min	-113	-101	-101	-108	-105	-100	-106	-108	-109	-100	-106	58
	Max	100	100	100	100	100	100	100	100	100	100	100	100
MAIN ROAD CROSSINGS (N)	**Mean**	0	0	0	0	0	0	0	0	0	0	0	0
	Std Dev	0	1	0	1	0	0	0	1	0	0	0	0
	Min	0	0	0	0	0	0	0	0	0	0	0	0
	Max	8	5	2	11	4	2	2	11	3	1	5	2

Appendix IV: Summary Statistics of Landscape Variables

Summary statistics of all the variables used in the stepwise regression analyses by species cold spots and hotspots. The areas were calculated in hectares for all variables and within different buffer zones around the cold and hotspots specifically, 100 m, 1 km, 2 km, and 4 km (indicated as "Scale" in the table). DISTANCE TO BUILT-UP AREA was calculated in metres and HUNTING BAG STATISTICS as the number of successful hunts of a given species within a county per 5-year period (2010-2014 and 2015-2019).

VARIABLE		SPECIES	COLD				HOT			
	SCALE		Std Dev	Mean	Min	Max	Std Dev	Mean	Min	Max
ARABLE LAND AREA	100 m	Moose	0,72	0,44	0	2,91	0,73	0,44	0	2,72
	100 m	ALL	0,78	0,51	0	2,92	0,82	0,68	0	2,9
	100 m	Fallow Deer	0,9	0,86	0	2,95	0,9	0,9	0	2,82
	100 m	Roe Deer	0,81	0,62	0	2,92	0,81	0,74	0	2,9
	100 m	Reindeer	0,39	0,13	0	2,79	0,4	0,17	0	1,55
	100 m	Wild Boar	0,89	0,73	0	2,91	0,9	0,68	0	2,84
	1 km	Moose	55,3	41,37	0	279,19	53,64	51,17	0	226,9
	1 km	ALL	65,19	43,3	0	295,16	67,65	65,89	0	296,3
	1 km	Fallow Deer	73,17	85,19	0	284,39	62,24	83,09	0	254,2
	1 km	Roe Deer	67,69	53,36	0	295,16	67,06	74,54	0	292
	1 km	Reindeer	20,44	7,82	0	147,04	17,69	10	0	94,65
	1 km	Wild Boar	69,7	64,7	0	288,24	65,92	78,23	0	245,6
	2 km	Moose	194,45	150,06	0	1079,8	192,43	178,61	0	917,5
	2 km	ALL	236,8	152,53	0	1177,6	247,96	235,74	0	1184
	2 km	Fallow Deer	268,54	313,81	0	1126,8	215,94	302,48	0	946,2
	2 km	Roe Deer	246,74	186,95	0	1177,6	246,72	268,45	0	1133
	2 km	Reindeer	50,55	22,34	0	349,28	49,95	27,06	0	277,5
	2 km	Wild Boar	250,8	230,46	0	1187	231,76	289,92	0	994
	4 km	Moose	674,42	535,2	0	4225	689,03	660,63	0	3092
	4 km	ALL	844,73	557,25	0	4609,4	905,19	852,12	0	4367
	4 km	Fallow Deer	949,37	1139,01	1,93	4326	821,46	1119,65	5,21	3472
	4 km	Roe Deer	887,87	679,94	0	4609,4	906,35	967,31	0	4408
	4 km	Reindeer	144,55	71,6	0	788,9	152,94	71,08	0	780,5
	4 km	Wild Boar	885,01	838,68	0	4515,9	798,89	1068,58	34,78	4100
DISTANCE TO BUILT UP AREA	N/A	Moose	7076,93	6290,6	0	68807	4601,46	3804,84	77,78	29747
	N/A	ALL	7223,7	7767,31	0	60691	4600,67	3732,67	0	57162
	N/A	Fallow Deer	2255,4	2996,98	0	11197	2373,33	2823,11	38,63	10598
	N/A	Roe Deer	5129,38	5830,44	0	53077	2909,16	2865,83	0	39493
	N/A	Reindeer	11051,5	15164,2	0	55429	10869,4	14487,9	0	48819
	N/A	Wild Boar	2780,37	3620,98	0	32835	1946,16	2400,66	0	10773
EXPLOITED LAND AREA	100 m	Moose	0,16	0,37	0,12	1,84	0,24	0,45	0,14	1,42
	100 m	ALL	0,14	0,35	0	1,69	0,21	0,44	0,01	1,8
	100 m	Fallow Deer	0,21	0,42	0	1,76	0,2	0,43	0,21	1,62
	100 m	Roe Deer	0,15	0,37	0	2,19	0,23	0,46	0	1,9
	100 m	Reindeer	0,13	0,35	0	1,04	0,24	0,5	0,22	1,41
	100 m	Wild Boar	0,15	0,37	0,12	1,49	0,19	0,38	0,2	1,53

	1 km	Moose	9,28	12,63	1,55	113,48	15,92	19,01	2,53	103,6
	1 km	ALL	4,16	9,69	0,73	55,34	11,29	16,28	2,52	105
	1 km	Fallow Deer	10,92	15,35	3,64	100,41	7,44	14,8	5,34	61,03
	1 km	Roe Deer	4,57	10,91	1,92	71,16	14,52	18,83	3,39	127,9
	1 km	Reindeer	5,11	7,7	0,73	48,77	7,48	12,7	3,91	50,94
	1 km	Wild Boar	8,83	13,73	4,01	126,49	7,9	15,85	6,17	53,32
	2 km	Moose	33,13	45,06	5,28	376,97	54,24	68,05	14,5	357,1
	2 km	ALL	15,53	33,6	3,43	339,47	41,31	58,46	6,69	462,7
	2 km	Fallow Deer	39,46	56,56	14,31	330,14	29,7	55,68	27,52	244,1
	2 km	Roe Deer	16,53	38,15	3,3	339,47	50,9	67,55	12,01	430,5
	2 km	Reindeer	18,37	23,55	3,43	213,1	22,74	35,37	10,08	170,8
	2 km	Wild Boar	30,99	50,89	13,42	468,51	30,06	60,43	24,85	263,2
FOREST AREA	100 m	Moose	0,85	1,86	0	2,96	0,84	1,71	0	2,91
	100 m	ALL	0,89	1,81	0	3,14	0,84	1,42	0	2,91
	100 m	Fallow Deer	0,89	1,34	0	2,94	0,9	1,29	0	2,89
	100 m	Roe Deer	0,89	1,66	0	3,14	0,81	1,32	0	2,94
	100 m	Reindeer	0,71	2,04	0	2,9	0,77	1,63	0,04	2,83
	100 m	Wild Boar	0,93	1,57	0	2,93	0,92	1,55	0	2,89
	2 km	Moose	221,71	815,11	6,76	1203,3	204,64	779,54	224,8	1203
	2 km	ALL	246,17	832,66	11,75	1203,3	257,08	714,08	12,51	1200
	2 km	Fallow Deer	266,58	658,32	16,9	1159,5	230,69	651,03	103	1141
	2 km	Roe Deer	251,96	802,28	11,75	1191,7	256,49	671,25	13,97	1130
	2 km	Reindeer	195,27	855,15	99,66	1177,5	191,01	820,63	281,3	1177
	2 km	Wild Boar	260,71	754,34	12,5	1160,3	241,47	647,22	62,94	1112
	4 km	Moose	809,42	3279,88	76,37	4713	796,14	3078,41	1031	4322
	4 km	ALL	920,61	3325,08	62,19	4711,6	983,55	2910,61	77,85	4529
	4 km	Fallow Deer	958,2	2685,29	95,43	4347,3	901,84	2570,5	308,5	4176
	4 km	Roe Deer	952	3230,17	62,19	4653,2	980,51	2760,94	78,11	4519
	4 km	Reindeer	740,24	3449,91	251,73	4578,2	694,95	3366,83	986	4548
	4 km	Wild Boar	953,69	3033,34	86,74	4540,2	910,46	2587,38	187,6	4444
HUNTING BAG STATISTICS	2010-14	Moose	0,07	0,28	0,06	0,38	0,06	0,29	0,12	0,38
	2010-14	Fallow Deer	0,41	0,44	0	1,05	0,37	0,56	0	1,05
	2010-14	Roe Deer	0,35	0,56	0,01	0,97	0,28	0,66	0,01	0,97
	2010-14	Wild Boar	0,45	0,71	0	1,54	0,44	1	0,18	1,54
	2015-19	Moose	0,06	0,23	0,05	0,33	0,05	0,23	0,12	0,3
	2015-19	Fallow Deer	0,58	0,67	0	1,47	0,52	0,87	0	1,47
	2015-19	Roe Deer	0,35	0,58	0,01	1,25	0,28	0,69	0,01	1,25
	2015-19	Wild Boar	0,52	1,04	0	2,03	0,49	1,42	0,44	2,03
MAIN ROAD AREA	1 km	Moose	1281,41	2741,18	1322,4	14517	2723,49	3517,4	2003	20822
	1 km	ALL	685,38	2446,03	1224	8335,4	1941,1	3186,02	1334	20814
	1 km	Fallow Deer	2025,73	3390,35	1491	16509	1585,84	3229,71	2002	13487
	1 km	Roe Deer	774,15	2556,17	1293,8	9260,9	2201,46	3491,15	1355	26204
	1 km	Reindeer	680,84	2285,38	1224	9073,2	1473,74	3109,01	2002	9812
	1 km	Wild Boar	1549,95	2982,8	1301	19595	1877,01	3155,65	2001	20677
	4 km	Moose	14642,9	23707,9	4767,2	124560	17860	29491,1	8197	1E+05
	4 km	ALL	11048,6	20317,1	4440,9	196939	18874,2	29751,9	4829	2E+05
	4 km	Fallow Deer	19425,1	31991,9	6753,3	146779	16548,8	30914,6	8627	1E+05
	4 km	Roe Deer	11258,6	22424,2	4605,2	196939	20991,6	32988,4	7232	2E+05
	4 km	Reindeer	6781,14	13473,5	4440,9	70981	10686,5	17022,1	8028	56752
	4 km	Wild Boar	15328,8	27888,2	5622,1	150085	17080,4	31828,1	8354	1E+05

	100 m	Moose	60,79	213,43	194,57	1022,4	174,02	249,67	198,1	1164
	100 m	ALL	25,12	204,39	185,98	622,69	130,8	235,19	190,4	1457
	100 m	Fallow Deer	122,66	241,56	197,89	1092,2	104,85	229,88	194,9	1043
	100 m	Roe Deer	31,92	206	192,54	878,14	151,01	245,64	190,2	1743
	100 m	Reindeer	27,84	203,82	197,14	544,48	125,3	234,14	197,2	879,7
	100 m	Wild Boar	70,91	218,2	189,86	1035,5	84,62	219,23	189,9	1071
OPEN LAND AREA	100 m	Moose	0,37	0,36	0	2,69	0,39	0,47	0	1,69
	100 m	ALL	0,38	0,35	0	2,8	0,43	0,52	0	2,84
	100 m	Fallow Deer	0,42	0,46	0	2,16	0,39	0,48	0	1,83
	100 m	Roe Deer	0,4	0,4	0	2,8	0,43	0,56	0	2,65
	100 m	Reindeer	0,43	0,39	0	2,88	0,49	0,7	0,03	2,09
	100 m	Wild Boar	0,38	0,4	0	2,27	0,38	0,43	0	1,95
	1 km	Moose	19,36	24,6	0,42	263,47	18,27	30,99	2,43	105,4
	1 km	ALL	17,72	21,02	0,91	224,44	21,1	32,69	1,16	221,2
	1 km	Fallow Deer	18,59	32,72	3,43	122,85	15,95	33,46	7,54	79,5
	1 km	Roe Deer	17,11	23,49	1,1	260,28	21,55	36,18	1,15	210,5
	1 km	Reindeer	31,15	21,08	0,93	263,07	28,14	35,49	4,08	170,3
	1 km	Wild Boar	17,11	29,33	1,85	164,95	16,57	34,23	7,51	92,9
	2 km	Moose	72,02	92,13	3,71	968,6	65,71	114,29	10,92	355
	2 km	ALL	65,76	77,01	1,87	1040,5	71,01	116,9	6,23	889,7
	2 km	Fallow Deer	62,55	122,33	21,19	437,29	61,44	131,86	33,72	384,8
	2 km	Roe Deer	57,82	84,33	6,63	835,25	74,25	129,5	11,45	857,7
	2 km	Reindeer	128,32	78,96	7,12	1040,5	93,28	108,27	13,67	532,4
	2 km	Wild Boar	55,83	108,29	12,42	526,77	64,11	136,64	34,94	487,1
	4 km	Moose	273,9	352,24	28,45	4090	233,05	425,58	68,4	1197
	4 km	ALL	259,58	309,87	28,45	3954,1	253,12	431,48	36,25	3820
	4 km	Fallow Deer	213,4	470,5	130,54	2072,6	198,97	491,78	125,1	1213
	4 km	Roe Deer	211,33	329,15	29,77	2951,3	251,77	474,39	36,25	2450
	4 km	Reindeer	522,9	322,04	30,78	4074	377,99	384,2	58,39	2200
	4 km	Wild Boar	188,64	410,43	50,43	1866,5	227,29	526,36	140,4	1839
MINOR ROAD AREA	1 km	Moose	2987,41	5351,55	0	24923	3342,13	7083,27	127,7	16549
	1 km	ALL	2236,88	4368,93	0	20156	2909,19	6647,21	0	25107
	1 km	Fallow Deer	2856,47	6155,26	521,77	32240	2593,67	6429,39	1535	16764
	1 km	Roe Deer	2135,86	4974,04	0	20156	3262,32	7203,95	591	39066
	1 km	Reindeer	2325,87	2887,24	0	17667	2797,78	4900,45	277,8	14775
	1 km	Wild Boar	2475,05	5942,06	450,97	22767	2410,26	6539,28	1780	20408
	2 km	Moose	9884,95	20968,9	0	83410	10642,6	26942,2	7202	59357
	2 km	ALL	7413,66	17533,1	0	68142	9679,8	25076,1	0	87096
	2 km	Fallow Deer	9422,54	24695,7	6654,2	100942	8001,2	25553,4	13830	73510
	2 km	Roe Deer	6735,56	19597,1	157,33	58910	10937,4	27489,1	5701	2E+05
	2 km	Reindeer	6896,97	10556,5	0	53578	6774,27	14394,6	2246	40776
	2 km	Wild Boar	7842,07	24118,3	5740,9	76284	7315,38	26706,3	10777	55937
	4 km	Moose	34555,5	82489,7	383,31	275440	36302,2	97681	15565	2E+05
	4 km	ALL	27688,8	71981,7	150,86	235851	33239,4	95521,8	648,2	3E+05
	4 km	Fallow Deer	29545,8	97641,2	23237	348417	26421,8	98497	60009	2E+05
	4 km	Roe Deer	25069,2	79416,3	303,31	235851	35187,1	103626	30954	3E+05
	4 km	Reindeer	21618,8	42137,3	72,79	187432	20830,6	44287,1	4507	1E+05
	4 km	Wild Boar	25800,9	96562,6	32771	267602	28222	105884	58276	2E+05
	100 m	Moose	85,47	65,07	0	580,13	103,16	95,92	0	405,6
	100 m	ALL	77,89	55,8	0	580,13	101,57	89,78	0	639,5
	100 m	Fallow Deer	95,49	76,41	0	614,62	95,19	96,45	0	389,4
	100 m	Roe Deer	85,78	66,54	0	515,9	101,95	92,38	0	713,5
	100 m	Reindeer	73,12	51,63	0	344,6	129,18	108,14	0	619,1
	100 m	Wild Boar	83,28	64,89	0	560,52	85,35	70,52	0	338,5
WATER BODY AREA	1 km	Moose	31,32	20,22	0	212,13	22,55	13,63	0	107,5
	1 km	ALL	31,24	20,31	0	204,5	28,87	18,3	0	204,9
	1 km	Fallow Deer	25,62	13,43	0	207,3	20,17	13,84	0	70,13
	1 km	Roe Deer	31,77	20,22	0	188,96	29,22	17,02	0	204,9

	1 km	Reindeer	39,79	33,83	0	204,5	37,16	37,17	0	195
	1 km	Wild Boar	26,08	14,43	0	205,19	23,53	13,67	0	111,9
	2 km	Moose	123,56	96,39	0	868,38	105,36	73,09	0,06	605,6
	2 km	ALL	125,74	95,01	0	897,24	121,97	91,68	0	866,1
	2 km	Fallow Deer	117,74	76,66	0	870,07	101,22	88,84	0	496,9
	2 km	Roe Deer	127,73	94,99	0	897,24	123,32	87,05	0	866,3
	2 km	Reindeer	143,27	134,37	0	695,36	115,52	131,03	0,72	618,7
	2 km	Wild Boar	115,55	77,82	0	866,59	112,01	88,01	0	543,7
	4 km	Moose	481,05	432,12	0,25	3331,7	491,51	444,69	1,68	2038
	4 km	ALL	497,56	416,18	0,13	3778,8	512,08	440,86	0,65	3620
	4 km	Fallow Deer	492,05	396	0,62	2763,2	482,44	520,63	4,52	2472
	4 km	Roe Deer	510,2	416,35	0,13	3778,8	525,48	437,86	0,72	3274
	4 km	Reindeer	460,99	497,02	12,59	2781,9	361,99	446,94	11,61	1802
	4 km	Wild Boar	493,59	393,18	0,04	3448	476,79	477,77	0,99	2135
WETLAND AREA	100 m	Moose	0,18	0,07	0	2,49	0,13	0,05	0	0,71
	100 m	ALL	0,19	0,07	0	2,49	0,15	0,05	0	1,79
	100 m	Fallow Deer	0,1	0,03	0	0,92	0,21	0,05	0	1,94
	100 m	Roe Deer	0,15	0,05	0	2,24	0,15	0,04	0	1,76
	100 m	Reindeer	0,32	0,16	0	2,06	0,24	0,08	0	1,71
	100 m	Wild Boar	0,12	0,04	0	1,37	0,18	0,07	0	1,29
	1 km	Moose	18,67	12,87	0	182,92	13,59	9,96	0	89,42
	1 km	ALL	21,05	14,67	0	198,51	12,94	8,62	0	148,6
	1 km	Fallow Deer	8,61	6,35	0	59,32	9,21	6,38	0,01	65,24
	1 km	Roe Deer	14,73	10,55	0	139,91	10,68	7,11	0	119,8
	1 km	Reindeer	31,99	31,22	0,17	198,51	25,25	24,8	1,37	148,7
	1 km	Wild Boar	10,6	7,81	0	117,9	11,32	8,41	0,02	62,92
	2 km	Moose	71,13	56,83	0	553,63	50,07	42,96	0,55	336,5
	2 km	ALL	80,87	64,78	0	711,19	50,53	39,14	0	507
	2 km	Fallow Deer	34,11	28,88	0,04	301,39	28,43	26,65	0,31	194,4
	2 km	Roe Deer	58,25	48,39	0	566,45	42,29	32,77	0,07	442,5
	2 km	Reindeer	120,83	138,93	0,33	711,19	107,66	133,91	12,71	502,9
	2 km	Wild Boar	38,84	34,74	0	502,86	38,8	34,35	1,22	333,5
	4 km	Moose	268,51	247,67	1,68	2210,2	185,15	191,97	14,02	1239
	4 km	ALL	305,87	276,4	0,8	2320	197,46	172,48	2	2150
	4 km	Fallow Deer	106,26	118,49	3,2	778,42	73,66	105,82	6,81	500,7
	4 km	Roe Deer	213,45	210,78	0,8	1992,8	147,87	141,56	2	1749
	4 km	Reindeer	426,42	581,27	14,53	2275,8	437,81	635,72	82,24	2149
	4 km	Wild Boar	147,56	153,33	1,84	1449,3	124,15	129,28	16,06	1248