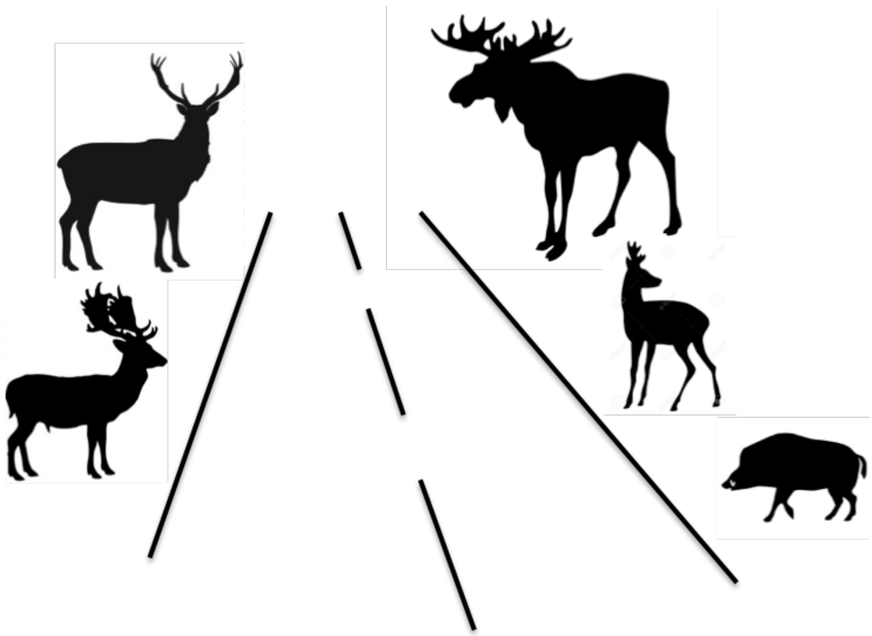
Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Ecology
Grimsö Wildlife Research Station

Road and landscape features affecting the aggregation of ungulate vehicle collisions in southern Sweden

Magnus Sjölund



Master´s thesis
Grimsö 2016

Independent project/Degree project / SLU, Department of Ecology 2016:13

Road and landscape features affecting the aggregation of ungulate vehicle collisions in southern Sweden

Magnus Sjölund

Supervisor: Andreas Seiler, SLU, Department of Ecology

Examiner: Johan Månsson, SLU, Department of Ecology

Credits: 30 HEC
Level: A2E
Course title: Independent Project/Degree Project in Biology- Master´s thesis
Course code: EX0565
Program/education: Master in ecology, Swedish University of Agriculture Sciences

Place of publication: Grimsö
Year of publication: 2016
Cover picture: Magnus Sjölund
Title of series: Independent project/Degree project / SLU, Department of Ecology
Part no: 2016:13
Online publication: http://stud.epsilon.slu.se

Keywords: Cluster, kernel density estimation, spatial pattern, traffic safety, ungulate, vehicle accidents, wildlife

Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Natural Resources and Agricultural Sciences
Department of Ecology
Grimsö Wildlife Research Station

Abstract

Ungulate-vehicle collisions (UVC) are increasing in Sweden and raises concern to traffic safety, socio-economics and wildlife management. Accident numbers are steadily growing but the trends are not well related to the changes in ungulate population sizes or hunting bag statistics. Authorities ask for more efficient mitigation strategies, but this require a good understanding of where and why UVC occur more frequently in some areas compared to others and which factors that affect these aggregated patterns. To find out which factors that are crucial to the emergence of UVC we studied a selection of roads stretches where UVC were frequent and compared road and landscape features with stretches with lower frequency of accidents. I used UVC records during 2010 - 2014 provided by hunters who have been called by the police to the accident site. In contrast to the official police records, these hunter reports contain exact location data as well as correct species identification.

A total of 189,733 UVCs has been reported during the 5-year period, of which most involved roe deer (77%), fewer involved moose (11%), wild boar (9%), fallow deer (3%) and red deer (1%). While roe deer and moose occur broadly across Sweden, the other ungulates have more restricted but expanding distributional ranges. For my study, I therefore selected southern and south-central Sweden where all five species occur and where road density, human population and UVC frequencies are highest. I further focused on primary and secondary roads, excluding the more comprehensive tertiary and private road network where about only 15% of reported UVC occur. I studied the summed UVC pattern in general and did not distinguish between the involved species.

To distinguish road stretches with high density of UVC (clusters) from stretches with low UVC density I used a modified kernel density estimation approach (KDE+; Bil et al. 2013) where a high density UVC road stretch have a minimum number of UVC (≥ 5 accidents within the cluster road section) I identified a total of 1596 UVC clusters. From these, we randomly selected 474 clusters, which we compared to 429 random and non-aggregated UVC sites outside the identified clusters. Due to the spatial error and uncertainty in UVC positioning, we considered each UVC location (in and outside cluster) to represent a 500 m road segment. At each site, we measured 15 road related factors (ocular evaluation of Google Street View™ imagery) and 17 landscape related factors (derived from topographic map data and GIS data bases within 1 km radius around the site). We used a generalized logistic regression approach to identify the most important factor combinations explaining the clustering of UVC. According to our results, the clustering of UVC tends to occur in areas where the road corridor is attractive, accessible and open for wildlife. Such areas are characterized by diverse landscapes with forest patches and with many leading structures such as watercourses, other roads, lakes etc. These features, in combination with traffic and road related data (speed, traffic volume, absence of wildlife fences) provide a powerful explanation of UVC clustering.

Keywords: *Ungulate-vehicle accidents, traffic safety, kernel density estimation, cluster, spatial pattern*

Populärvetenskaplig sammanfattning

Antalet viltolyckor som involverar klövdjuren ökar i Sverige, vilket bland annat har medfört högre samhällskostnader, trafiksäkerhetsproblem samt försvårat viltvård. Ökningen av viltolyckor med klövdjur tycks dock inte följa respektive arts avskjutningsstatistik. Myndigheter frågar efter nya och bättre strategier för att bryta trenden och minska antalet viltolyckor. En grundförutsättning för att åstadkomma detta är att förstå vilka faktorer som påverkar olycksrisken för att kunna förutsäga var och varför viltolyckor förekommer mer frekvent på vissa vägsträckor än på andra.

I studien använde jag av viltolycksstatistik mellan åren 2010 och 2014 med inriktning på de större klövdjuren i mellersta och södra Sverige. Statistiken bygger på rapporter från eftersöksjägare som kallats till olycksplatserna av polisen. Jägarnas rapporter innehåller exakta positionsuppgifter samt korrekt artbestämning, något som inte funnits tidigare i polisens olycksregister.

Under denna 5-årsperiod rapporterades totalt 189 733 viltolyckor med klövdjur, varav mest rådjur (77%), betydligt färre olyckor involverade älg (11%), vildsvin (9%), dovhjort (3%) och kronhjort (1%). Vi har valt södra och mellersta Sverige som studieområde där alla fem arter förekommer och där vägtäthet, befolkning och viltolycksfrekvenser är högst. Vi fokuserade på primära och sekundära vägar och exkluderade det privata vägnätet, där enbart ca. 10% av viltolyckorna är rapporterade. Vi särskilde inte olyckorna mellan de olika arterna, utan studerade viltolyckor som en generell händelse.

För att identifiera aggregationer (kluster) i olycksfördelningen längs det studerade vägnätet använde jag en ny, modifierad kernel density estimation metod (KDE+). Jag definierade ett olyckskluster som vägsträcka där minst fem olyckor registrerades under fem-års perioden 2010-2014. Jag identifierade totalt 1596 kluster. Av dessa valde jag slumpmässigt 474 olyckskluster och jämförde dem med 429 enskilda olycksplatser utanför klusterområdena (vägsträckor med mindre än tre viltolyckor under femårsperioden). Olyckor i och utanför kluster-sträckorna jämfördes med hänsyn till både väg- och landskapsrelaterade faktorer i en logistisk regression. För varje olyckssträcka uppmättes lokala vägrelaterade variabler med hjälp av okulär bedömning i Google Street View™ och i digitala väg- och trafikdatabaser. Landskapsrelaterade variabler kvantifierades från topografiska kartor och satellitbilder. Avskjutningsstatistik hämtades från jägarförbundet. Enligt våra resultat, tenderar olyckskluster att ske i områden där vägkorridoren är attraktiv, tillgänglig och öppen för vilda djur, samt ligger i ett småbrutet landskap med mindre skogsområden och många ledande fysiska strukturer som leder djurens vandringar mot vägen. Dessa egenskaper, i kombination med högre trafik och hastighet samt avsaknaden av viltstängsel förklarar till stor del var olyckskluster uppstår.

Nyckelord: *Kernel density estimation, kluster, klövdjur, olycka, spatiala mönster, trafiksäkerhet, vilt*

Table of contents

1. Introduction

Increasing human populations, urbanization, habitat transformation and extending infrastructures force wildlife to live in highly human dominated habitats. Conflicts between humans and wildlife are therefore very common (Zuberogoitia et al. 2014). These conflicts can lead to negative impacts on wildlife and ecosystems as well as on people (Forman et al. 2003, Seiler 2003). Collisions with wildlife, especially larger ungulates, are a problem to traffic safety (Danielson & Hubbard 1998, Nielsen et al. 2003) and produce substantial socio-economic costs (Putman 2004, Huijser 2009, Jägerbrand 2014, Häggmark-Svensson et al. 2014, Seiler 2015). They also can affect wildlife management, species conservation and animal welfare (Child & Stuart 1987, Lavsund & Sandgren 1991, Seiler & Helldin 2006, Helldin 2013).

In Europe, more than 1 million ungulates are involved in traffic accidents each year (Langbein et al. 2011). In Sweden more then 46000 ungulate-vehicle collisions (UVC) have been reported to the police in 2014, including roe deer (*Capreolus capreolus*), moose (*Alces alces*), wild boar (*Sus scrofa*), red deer (*Cervus elaphus*) and fallow deer (*Dama dama*). The true number of UVC that occurred on roads is likely more than 20% higher because not all accidents are reported and registered in the final database (Seiler & Jägerbrand 2016). We are facing an increasing number of accidents with ungulates in Europe, and the number is likely to increase in years to come (Apollonio et al. 2010) According to Seiler (2004a) and Seiler & Jägerbrand (2016), ungulate-vehicle collisions in Sweden have increased since the recordings started in the late 1960´s. The main reasons are presumably growing ungulate populations, expanding infrastructure and increasing traffic load (Seiler 2004b). There is strong correlation between the number of traffic accidents and population increase involving moose; during the 1980´s and roe deer during the 1990´s (Seiler 2004a), and therefore as a consequence, the number of reported traffic accidents involving ungulates has quickly increased. Moreover, wild boar populations have spread and grown exponentially during the past 15 years and are expected to continue to expand (Swedish Environmental Protection Agency 2010, Gren et al. 2015).

Today, several methods are used to prevent or reduce UVC. Most common are fences and warning signs, however not always with satisfying results (Putman 2004, Huijser 2008). Fencing can isolate wildlife population, but may be ineffective if the fence is too short and not terminated appropriately (Lavsund 1991, Huijser et al. 2015, Seiler 2015). Fencing can also just redistribute the problem towards the end of the fences (Clevenger et al. 2001). Road fencing in combination with safe wildlife passages that allow animals to cross the barrier appears to be the most efficient and secure way to mitigate UVC (Danielson & Hubbard 1998, Clevenger et al. 2001). Fences in combination with automated animal detection and alarm systems may also result in a substantial reduction of UVC (Rytwinski et al. 2016). However, due to the high costs of these systems they have not yet been commonly applied in Sweden before (Olsson & Norin 2010).

UVC results from the interplay of various environmental, behavioural and traffic related factors that create a complex spatial and temporal pattern of accident risk. Understanding these patterns is a necessary prerequisite for the development of effective countermeasures. Recent studies have shown that UVC are often aggregated in time and space (Seiler 2004b, Malo et al. 2004, Gunson & Teixeira 2015). Temporal factors may include the behaviour of individuals (e.g. daily activities (foraging periods), seasonal activities (mitigation periods); (Puglisi et al. 1974, Danks & Porter 2010, Morelle et al. 2013, Rodríguez-Morales et al. 2013). Spatial factors include space of use of animals, road characteristics, presence of wildlife fence, traffic volume, landscape topography and adjacent land use are examples of factors that have been studied (Knapp et al. 2004, Seiler 2005).

Knowledge about these patterns and their underlying factors are essential requisites to allow road managers to develop cost-effective mitigation strategies to prevent UVC (e.g., Bil et al.

2013, 2015). Previous studies in Sweden assessing the influences of landscape features on the distribution of UVC (Lavsund & Sandgren 1991, Seiler 2004b, 2005, Seiler et al. 2011) have shown the importance of large scale factors for UVC occurrences. However, the studies did not asses the influence of local variables describing the characters of the road and the roadsides.

The aim of this project is to study how well road related and landscape related features can explain spatial distribution to of UVC. In my study, I used reported accident statistics between 2010 and 2014, Google StreetView™ images combined with field visits, remotely sensed data (from satellite and topographic maps) and official road and traffic data to study local and regional factors that may contribute to local accumulations of UVC in South-central Sweden.

2. Materials and Methods

2.1 Study area and UVC data

The study was performed in south and central Sweden, including the counties of Värmland, Örebro, Västmanland, Uppsala, Stockholm, Västra Götaland, Östergötaland, Jönköping, Kalmar, Halland, Södermanland, Kronoberg, Blekinge and Skåne (see figure 1). Within this region, moose, roe deer and wild boar are widespread throughout the area. Fallow deer and red deer have still more restricted but expanding distributions. Hunting bag statistics indicate that their populations as well as the population of wild boar are increasing, while moose and roe deer harvests remain rather stable or are declining during the past decade (Swedish Hunting Association 2014). Traffic accidents including these species are very common and have increased during recent years, (Swedish National Wildlife Accident Council 2016). UVC occur over the entire study area, vehicle collisions with fallow deer and red deer are aggregated to regional parts (see figure 2). Geographically, the southern part of the study area consists mainly of flat lowland and further north the landscape shifts to a more hilly structure. The entire landscape consists of a gradient from agricultural land (especially in the south) to forest areas, particularly in the north. Forests are of broadleaved, coniferous and mixed types. The climate in south and central Sweden is relatively mild temperate. The study area is located between to different vegetation zones (temperate zone and boreal zone).

We used data on UVC reported by hunters who have been called to the accident site to track down injured or dead animal. About 80-90% of all police reported UVC are assumed to entail a visit by hunters and are thus represented in the hunter's reports (Lars-Erik Nilsson, Swedish National Police, pers.com. 2014-09-01). A total of 189,733 UVC were reported within the region during 2010 to 2014. Most of the accidents involved roe deer (77%), followed by moose (11%), wild boar (9%), fallow deer (3%) and red deer (1%) respectively. The primary and secondary road network length in the study area consists of 12,277 km. Road types vary in size and daily traffic load, ranging from motorways with more than 20,000 vehicles per day to common state-owned country roads with an average 1000 vehicles per day. More than 50 % of UVC in the study area occurred on these roads and with a mean accident frequency of 0.8 UVC per/year, this although already 35 % (5421 km) of the road network is fenced.

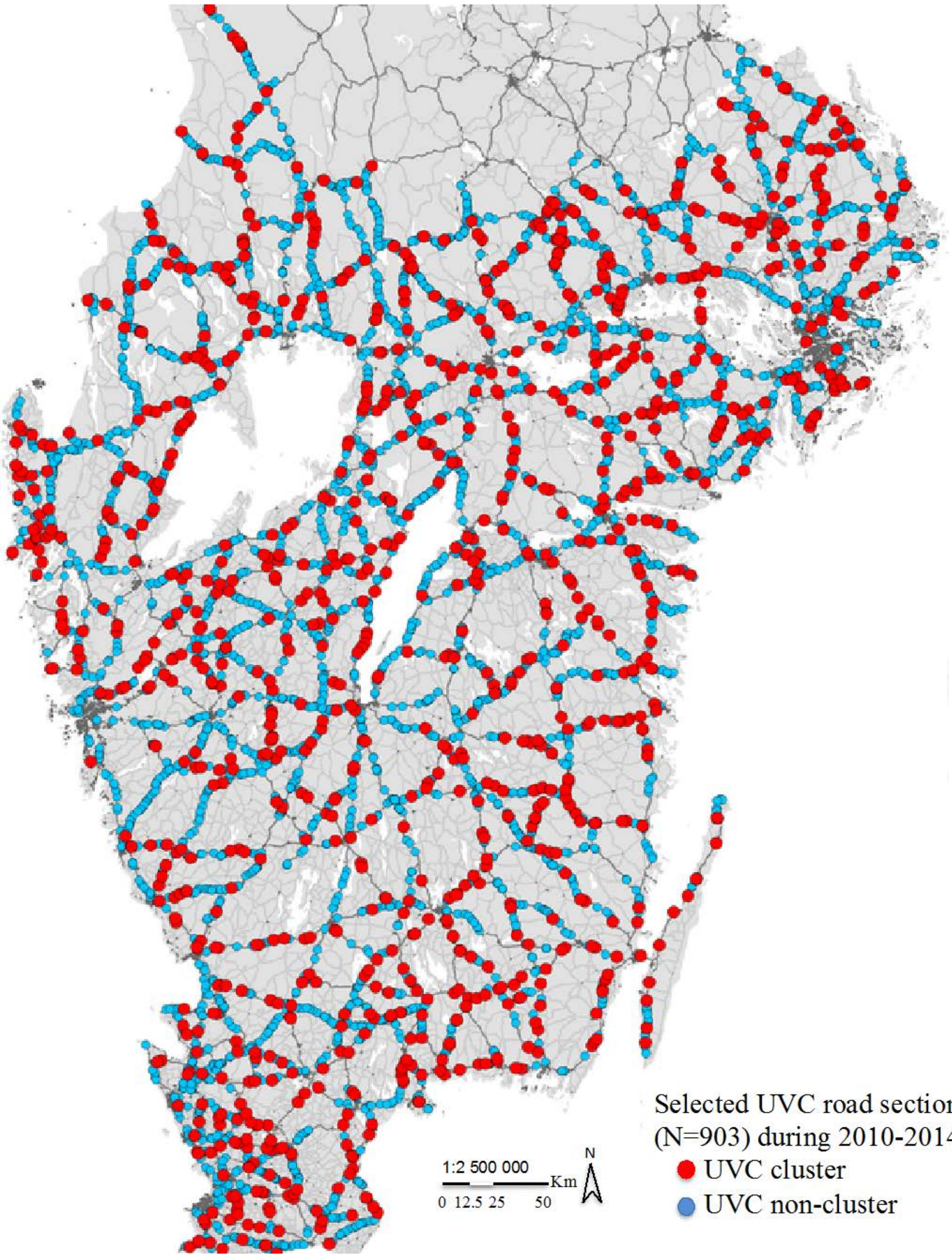


Figure 1. Overview of the study area containing all selected clusters (n=474) and non-clusters (N=429). Primary and secondary roads (dark lines) are the studied road network. Light grey lines indicate tertiary roads that have not been included in the analysis although they respond for about 40% of all ungulate-vehicle accidents.

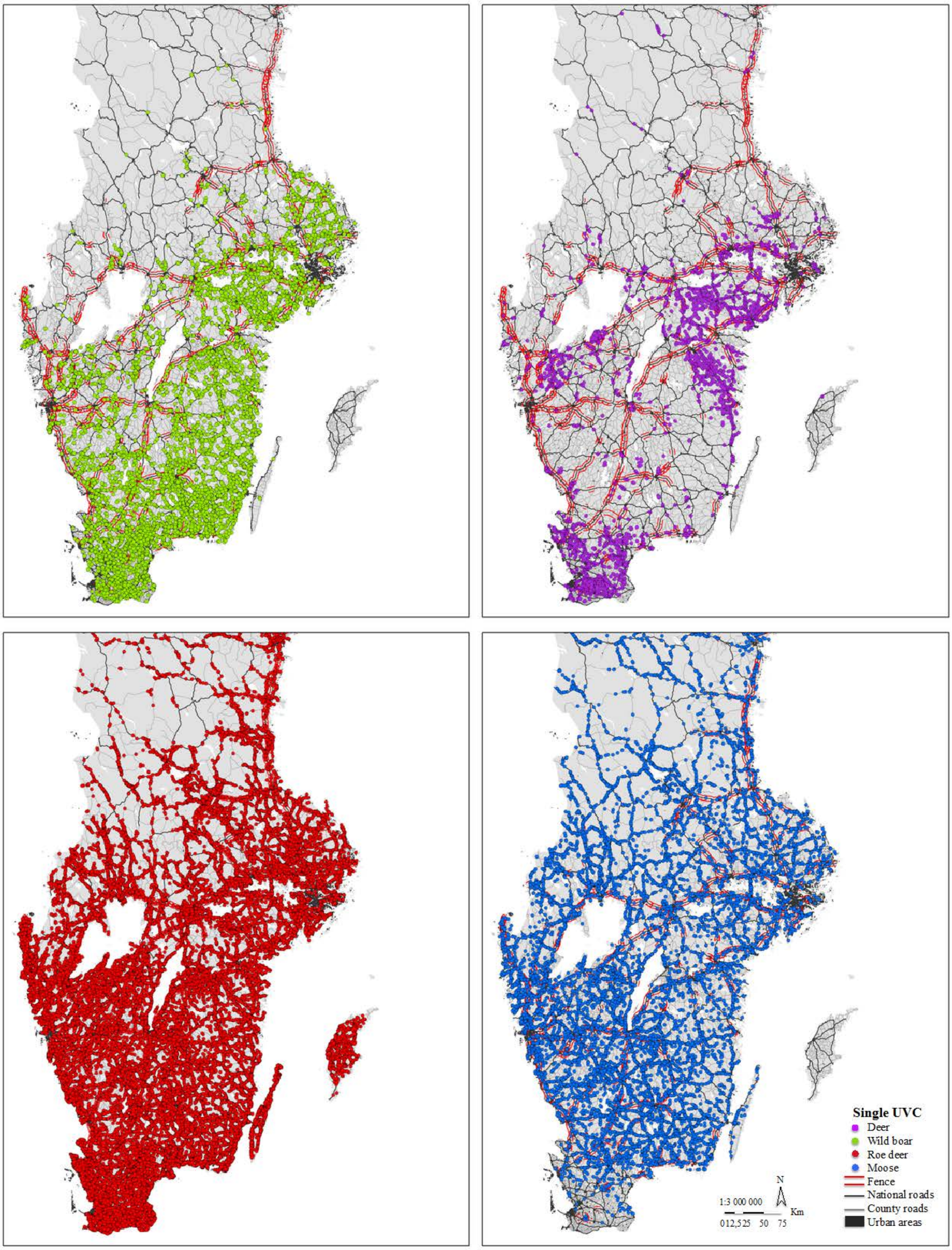


Figure 2. Distribution of all vehicle collisions involving four ungulates species in south-central Sweden. (Deer = red deer and fallow deer).

2.2 UVC clusters and controls

We applied the modified Kernel Density Estimation + (KDE+) method developed by Bil et al. (2013) to identify road sections where UVC occurred significantly more aggregated then elsewhere. The KDE+ method distinguishes significant aggregations of point events, i.e. UVC, from a random distribution of these events derived from Monte Carlo simulations of event locations along the respective road segment. KDE+ thus simulates clustering thresholds at road section level. KDE+ sorts the different clusters through its cluster strength. The strength of the cluster depends on the amount and the distance between the UVC. We identified in total 5875 clusters within the study area.

By adding a further criterion to characterize the most hazardous locations: a cluster road segment should contain > 5 accidents/km during the 5-year period, and have a cluster strength of more than 10%. With these criteria we identified 1793 clusters within the study area.

These clusters were then compared to accident locations that were > 1 km outside the previously identified clusters and on roads with ≤ 3 accidents/km during the 5-year period. Each selected UVC location (cluster and outside) was given a minimum length of 500 m, corresponding to the presumed overall error in the positioning of the accident events (± 250 m).

From the clusters and from the non-cluster UVC, we randomly selected 903 corresponding road segments (474 clusters and 429 non-clusters) for the in depth analysis in StreetView^{TM}. These corresponded for 237 km of clusters and 214 km of non-cluster roads, representing 1,9% and 1,7%, respectively, of primary and secondary road network in south-central Sweden. Species composition of UVC in the selected clusters: roe deer 65,6%, moose 15,9%, wild boar 10,7% and deer (fallow deer and red deer) 7,8%.

2.3 Road and landscape variables

The impact of local landscape- and road features on UVC is of interest since they, may contribute or discourage road crossings of ungulates (Clevenger et al. 2003, Seiler 2005, Gunson et al. 2009, Jägerbrand 2012). I selected (based on expert judgement and literature) 32 predictor variables (15 describing the road in detail and 17 general landscape features) that could affect road crossings by ungulates (Danielson and Hubbard 1998, Clevenger et al. 2003, Rea, 2003 Seiler 2005, Jägerbrand 2012).

The 15 categorical variables describing the road sections and the immediate surrounding of road sections was extracted by using Google earth satellite and Google Street View imagery. Each categorical variable contained 2 or 3 alternative levels (Table 1a). The data extraction was performed visually by surveying road segments (for each of the 903 UVCs) on computer screen. Each UVC road segment was 500 m in length, during the survey we added another 200 m from both ends of the road segment checking for any warning signs that foreworn drivers of collision risk with wildlife. This was done in order to ensure us that drivers were aware of a possible risk of collision with wildlife before entering the studied road section. When I characterized the different UVC road segments, I avoided bias by randomly select a UVC road segment without knowing if the road section was a cluster or non-cluster.

Table 1a. Description of predictor variables, collected in Street View inventorying and used in the UVC cluster analysis. LEAD STRUT and FOREST EDGE are used as landscape variables in the model analysis.

Categorical factors	Description
SPEED	Speed limit on current road segment: ≤70, 80 or 90, and 100 km/h .
ROAD_LEVEL	Dominant cross-section profile of road surface in relation to surrounding landscape: **Levelled**= at same level (no impediment or barrier), **Variable** = road lowered, raised (impediment), or barriers (vertical physical barriers on one side, or on both sides).
CURVATURE	Sinuosity/Curvature of the road. Dominant part (>60% of the road). **Straight** or **Curved**.
SAFETY RAIL	Combined safety rails (metal,wire, etc) coverage along both sides of the road: **Present**: >10% coverage, **Absent**: no safety rail present or < 10% coverage.
BARRIERS	Cliff, noise protection walls or tall fences or screen or other technical features (effective barriers). Combined coverage along both sides of the road: **Present**: >10% coverage, **Absent**: no barriers present or < 10% coverage.
IMPEDIMENT	Obstacles adjacent to the road corridor, such as electric fences, stonewalls, fences for livestock, etc. Combined coverage along both sides of the road: **Present**: >10% coverage, **Absent**: no impediment present or < 10% coverage.
MID SEPEERATION	Roads with multiple lanes separated by a central wire-railing (2+1 väg) or also a jersey barrier. Combined length of the separation relative to the road section: **Presen**t: >10% coverage, **Absent**: no mid separation present or < 10% coverage.
ROAD VERGE	Dominant type of vegetation cover in verge or adjacent to road verge: **Heather**: dry sparse vegetation; **Grassy**: open, grassy vegetation, **Woody**: low woody vegetation.
FOREST EDGE	Distance to the treeline from the road surface. Distance assessed in two categories: **Adjacent** = directly adjacent to road surface and or up 10 m), **Distant** = distant > 50m away from roads, or open spaces adjacent road surface.
LEAD STRUCT	Leading structures, other roads, railroads, trails, paths, forest edges, lakes, watercourses, etc. Number of leading structures, assessed in two categories: few **LS<3** features and many **LS≥3** features.
WARNINGSIGN	Presence of wildlife warning signs, Checked whether such signs are available up to <500m before/after or within the road section. (Two alternativ classes: **Present** or **Absent**).
PASSAGE	Presence of potential passages for wildlife = tunnels or bridges along or near to the road section. (Two alternativ classes: **Present** or **Absent**).
ACCESSIBILITY	Overall judgement of the road section. Open and free of obstacles for animals to cross (**Accessible**); Mainly shielded from animals by fences or other barriers or luring animals to cross while simultaneously imposing barriers or hindrances and thereby rising the risk for collisions (**Closed**).
ATTRACTIVITY	Overall judgement of the road section: Inviting animals to cross or to be near the road because of forage or landscape (**Attractive**); road area and the adjacent habitat is not attractive for animals (**Aversive**).
FENCE	**Presence** or **Absence** of wildlife fence alongside road segment.

Several of the variables that I used in the Street View survey have been investigated in earlier studies. I used these previous studies as a reference in selecting the variables. Previous studies have pointed out that the type of vegetation close to the road is of interest as it may attract ungulates (Rea 2003). Linear features leading animals towards roads have been proven to contribute to UVC (Seiler 2005). Road that have been built in deep cuttings or on embankments in relation to the surrounding landscape may also affect ungulate movements and contribute to UVC clustering (Clevenger et al. 2003). Different technical or natural structures close to road and forming barriers or smaller obstacles that may work as funnel for wildlife to the road corridor have also been studied (Clevenger et al. 2003 and Gunson et al. 2009).

We were also interested in several local landscape features and their composition surrounding the studied road section. Previous studies have identified various spatial structures in the landscape that are more prevalent along road sections where UVC occur, such as the land cover composition (proportions of urban land, forest, agriculture and other open habitats; Nielsen et al. 2003, Seiler 2005, Ng et al. 2008). In total we used 17 numerical variables (Table 1b) that were quantified from digital topographic maps (Sweden Land Survey, Terrain map) and satellite imagery (Kontinuerlig Naturtypskartering av skyddade områden (KNAS) describing the surrounding landscape and its composition within a radius of 1 km from the UVC location (figure 3). Moreover, data on traffic load, speed limits and hunting bag was obtained from the road data base of Swedish Transport Administration and Swedish Hunters Association (Jonas Kindberg, Jägarförbundet) respectively. Spatial analyses were done in ArcGIS 10.1.

Table 1b. Description of predictor variables measured in Arc GIS and used in the UVC cluster analyses. The numerical predictor variable traffic is used as a road variable in the model analysis.

Numerical factors	**Description**
rivers	Total watercourse length (m)
railway	Total railway length (m)
paths	Total patch length (m)
roads	Main roads and minor roads combined (road map)
houses	Number of houses
diversity	Shannon-Wiener index diversity, based on KNAS land cover porportion (%)
decidious	Porportion of decidious forest areas (%)
coniferous	Porportion of conifierous forest areas (%)
clearcut	Porportion of clearcut areas (%)
wetland	Porportion of wetland areas (%)
agricult	Porportion of acregultural areas (%)
pasture	Porportion of pasture areas (%)
open	Porportion of open areas (%)
water	Porportion of water areas (%)
traffic	Average traffic intensity on current road (number of vehicle per day)
urban	Porportion of urban areas (%)
hunting	Average game bag for ungulate per county during 2008-2012

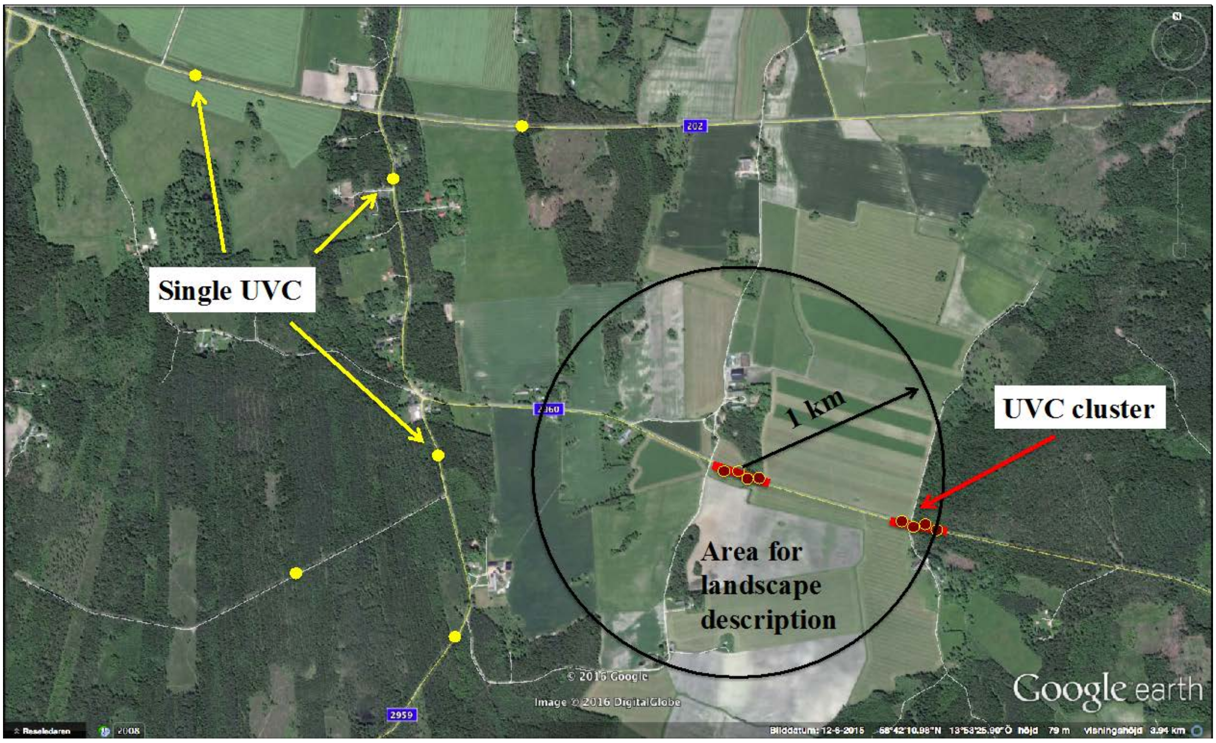


Figure 3. Map from Google earth with UVC cluster road sections (red mark). 1 km radius from the centre of the cluster is illustrated. All landscape predictor variables were measured within the circle.

2.4 Statistical analyses

I did a descriptive overview of the data by performing non-parametric univariate tests to identify important factors that differentiate between UVC in clusters and outside clusters, such as Pearson's chi-squared test for categorical variables (Table 2a) and Wilcoxon signed-rank (non-normally distributed data) test for numerical variables (Table 2b).

To avoid multicollinearity, I used spearman's rank correlation to identify numerical predictor variables that strongly correlate (rho >0,65) and to excluded correlated variables. Land cover type *Agriculture* was found to be highly correlated with *coniferous* (rho =-0,74), land cover *diversity* (rho =-0,59) and *clearcut* (rho = -0,58). *Urban land* was correlated with *open land* (rho = 0,66). I thus excluded *agriculture* and *urban land* from further analyses. The other variables showed low correlation (rho <50) and could be included in the following logistic regression models.

We also tested for the effect of interactions between independent variables *SPEED, traffic volume, ROAD VERGE* and *FENCE*, using Pearson's chi-squared test and Wilcoxon/Kruskal-Wallis test.

I developed three different logistic regression models built from different subsets of predictor variables using cluster and non-cluster as the binary response variable: 1) a road model (containing only road related variables); 2) a landscape model (containing landscape and large-scale environment factors); and a 3) mixed model (combining road and landscape factors). In addition, I used two summary variables obtaining from subjectively evaluating the overall attractiveness and accessibility of the road locations to ungulates in a forth mode, i.e. the "expert" model. Attractiveness and accessibility are to variables that describe the local area around the road section, if it is attractive and if the road is available for ungulates to cross. The two variables were assessed partly on our own subjective assessment and as a summary of all the other variables used in the street view inventory.

2.5 Model selection

The models were built using a stepwise approach. In the stepwise regression process, the probability for a variable to enter the model was set at $p < 0,25$ and probability to leave at $p > 0,1$ (Hosmer & Lemeshow 1989). This was done in order to select those variable combinations that most strongly distinguished between clusters and controls.

The second order AICc (Aikaike information criteria corrected) was used, (which is recommended for small sample size) and Aikaike weight *W* to compare the performance of the models and chose the most parsimonious model that still preformed equally well as the best model with the smallest AICc (Burnham & Andersson 2002).

This means that the various models AICc values are compared with the best model (the model with the lowest AICc value i.e. delta AICc). Using this approach, it's possible to evaluate whether the choice of the best model has weak or strong support. In general, if a model has a delta AICc value less than two the model is considered to be a competitor model (Burnham and Andersson 2002). In a similar way we used AICc weight although it's a relative measure and depends on the number of variables in the model. Models with Akaike weight values close to one is more likely to be considered as the best model (Burnham & Andersson 2002). To compare the relative importance of the variables that were included in different sets of the models, we summarized Akaike weight of each variable in the models were the variable was included.

This resulted in 14 variables in the Mixed model, 7 variables in the Road model and 7 variables in the landscape model. The “expert model” only contained two summary variables.

All the models were built from a random subsample containing 70% (N=633) of the total data. The remaining 30% (N= 270) of the data were used for model validation by evaluating the area under ROC curve (AUC). AUC is a measure of how well a models predicts the observed variation in data, with AUC > 0,7 being considered as fair and >0,8 is considered as good. After validation, the chosen parameter combination was applied to the entire data set to obtain the final parameters estimates and regression coefficient. The accuracy of the model was evaluated using the generalized R-square (Cox and Snell’s pseudo R-square) which is scaled to have a maximum value of 1. Model structure was considered adequately scaled if the Lack-of-Fit chi-square was > 0,05, that is, if a saturated model would not perform significantly better than the fitted model (Burnham and Andersson 2002). In addition, the misclassification rate specified what proportion of predicted (cluster or non-cluster) response did not match the observed response.

I compered the four whole model results (Mixed-, Road-, Landscape- and Expert models), by their respective accuracy in the identification of clusters and non-clusters, their AICc-, AUC, Lack of Fit statistics and their misclassification rate (Table 7). All statistics were preformed using JMP (version 12.1 2015)

3. Results

Several road- and landscape variables were able to distinguish between clusters and non-clustered UVC (Table 2a and 2b). The presence of *LEADING STRUCTURES*, the distance to *FOREST EDGES* and the presence of exclusion *FENCES*, *IMPEDIMENT* and *WARNINGSIGNS* were among the strongest predictors and contribute to UVC clustering. In general, UVC clusters were characterized by higher traffic, higher speed and lack of fences. Safety rail, barriers and other impediments to animal movements, but also grassy (open) vegetation in road verges were more often present on cluster-roads. Clusters were located in landscapes that were relatively more diverse and open and had a higher proportion of agriculture land use, broad-leaved forest, and more linear landscape elements that could direct animals towards the roads. Clusters were also more frequent in counties that reported higher game bags in ungulates. Non-cluster UVC was located in more homogenous landscapes dominated by coniferous forest, with less busy roads and lower speeds. I classified over 91% of the cluster-roads as "accessible and "attractive" to wildlife compared to 76% and 67%, respectively, of the non-clustered UVC locations.

The mixed model preformed best of all models and was able to correctly identify 79% of the UVC clusters and 72% of the non-clustered UVC, with a misclassification rate of 25%. Mixed model observed best variation of the data, with a good AUC value (AUC = 0,824). Mixed model had also lowest AICc (952,82) than all the other models. Road model was able to correctly identify 73% of the UVC clusters and 52% of the nun-clustered UVC. The landscape model preformed slightly better results than the road model and was able to correctly identify 77% of the UVC clusters and 65% of the nun-clustered UVC.

The road and landscape model, however, suffered a significant lack-of-fit and produced higher misclassification rates (37% and 29% respectively) than the mixed model. This suggests that UVC clustering in roads is clearly promoted by a combination of both landscape and road related features.

The expert model consists only of the two subjective assessed variables *ACCESSIBILITY* and *ATTRACTIVITY* (Table 6). For this model the identification of clusters was high (88%), but was much less effective in identifying non-clusters (46%).

Results of all four models and the model descriptive statistics are presented in Table (7).

Logistic regression analysis identified several alternative variable subsets that explain the aggregation of UVC. The most parsimonious (top model) road model included *traffic, WARNINGSIGN*, *FENCE*, *SPEED* and *SAFETY RAIL* (Table 3). The most parsimonious landscape and mixed model included *FOREST EDGE* and *LEADING STRUCTURE,* land cover *diversity* and proportion of *deciduous forest* (Table 4, 5).

Table 2a. Descriptive statistics and univariate test (Pearson's chi-squared test) for the categorical predictor variables. CURVATURE and BARRIER were later excluded in the logistic regression models.

Categorical factor	Level	N = 429 non-clusters	N = 474 clusters	Pearson chi^2	 p-value
LEAD STRUCT	many (>3) few (<3)	203 226	380 94	106.209	<0.0001*
ACCESSIBILITY	accessible closed	324 105	460 14	91.164	<0.0001*
ATTRACTIVITY	attractive aversive	288 141	431 43	78.589	<0.0001*
FORST EDGE	adjacent distant	231 198	143 331	52.031	<0.0001*
FENCE	present absent	108 321	43 431	41.932	<0.0001*
IMPEDIMENT	present absent	87 342	160 314	20.579	<0.0001*
WARNINGSIGN	present absent	8 421	36 438	15.952	<0.0001*
ROAD VERGE	heather woody grassy	68 124 237	50 103 321	15.129	0.0005*
SPEED	100kmh 70kmh 90kmh	82 92 255	62 74 338	14.139	0.0009*
MID SEPARATION	present absent	82 347	54 420	10.496	0.0012*
PASSAGE	present absent	39 390	24 450	5.629	0.0177*
BARRIER	present absent	56 373	84 390	3.746	0.0529
SAFETY_RAIL	present absent	131 298	172 302	3.34	0.0676
ROAD_LEVEL	variable levelled	70 359	68 406	0.676	0.4111
CURVATURE	curverd straight	184 245	207 267	0.056	0.8132

Table 2b. Descriptive statistics and univariate test (Wilcoxon signed-rank test) for the numerical predictor variables. Several of the numerical variables were later excluded in the regression models (Table 4 and 5).

	Non-clusters				Clusters				Wilcoxon	
Numerical factor	**Mean**	**Std.Dev.**	**Min**	**Max**	**Mean**	**Std.Dev.**	**Min**	**Max**	**Z**	**p-value**
open	0.10	0.09	0.00	0.56	0.13	0.08	0.01	0.59	-8.10	<0.0001*
houses	2.16	1.64	0.00	10.00	3.00	1.74	0.10	10.20	-8.08	<0.0001*
roads	10.11	3.17	2.95	21.14	11.58	3.08	3.23	24.19	-7.09	<0.0001*
decidous	0.09	0.06	0.00	0.44	0.12	0.08	0.00	0.62	-6.83	<0.0001*
agricult	0.24	0.30	0.00	1.33	0.30	0.25	0.00	1.33	-6.33	<0.0001*
traffic	3.73	4.29	0.07	25.03	3.81	2.50	0.22	17.68	-6.24	<0.0001*
diversity	1.31	0.32	0.14	1.97	1.42	0.29	0.15	1.96	-6.18	<0.0001*
hunting	14.85	7.96	4.39	30.54	16.76	7.65	4.39	30.54	-4.01	<0.0001*
coniferous	0.38	0.23	0.00	1.02	0.30	0.18	0.00	0.89	5.91	<0.0001*
pasture	0.01	0.04	0.00	0.47	0.01	0.04	0.00	0.76	-3.72	0.0002*
clearcut	0.11	0.09	0.00	0.54	0.09	0.07	0.00	0.38	3.20	0.0014*
water	0.06	0.10	0.00	0.50	0.04	0.07	0.00	0.47	3.09	0.0020*
wetland	0.04	0.06	0.00	0.39	0.03	0.06	0.00	0.64	2.84	0.0045*
railways	0.43	0.86	0.00	3.20	0.57	1.00	0.00	4.54	-2.18	0.0294*
urban	0.02	0.04	0.00	0.24	0.02	0.04	0.00	0.25	-1.24	0.2138
rivers	4.01	2.50	0.00	14.40	4.05	2.50	0.00	13.96	-0.36	0.7187
paths	0.84	1.27	0.00	7.18	0.86	1.30	0.00	6.50	-0.14	0.8916

Table 3. The best selected road model, with unstandardized estimates. For whole model results see Table 7.

Variable	**Estimate**	**Std Error**	**ChiSquare**	**p-value**
Intercept [cluster]	0.166	0.255	0.42	0.5146
FENCE [present]	- 0.646	0.113	32.6	<0.0001*
SPEED [100kmh and 70kmh]	- 0.288	0.079	13.41	0.0003*
WARNINGSIGN [present]	0.744	0.210	12.6	0.0004*
SAFETY_RAIL [present]	0.262	0.079	10.87	0.0010*
IMPEDIMENT [present]	0.262	0.082	10.19	0.0014*
ROAD VERGE [heath and wood]	- 0.222	0.074	8.9	0.0029*
traffic	0.066	0.023	8.01	0.0046*

Table 4. The Best selected landscape model, with unstandardized estimates. For the whole model results see Table 7.

Variable	**Estimate**	**Std Error**	**ChiSquare**	**p-value**
Intercept [cluster]	- 3.590	0.516	48.32	<0.0001*
FORST EDGE [adjacent]	- 0.461	0.079	34	<0.0001*
LEAD STRUCT [many]	0.633	0.083	58.41	<0.0001*
diversity	1.207	0.316	14.57	0.0001*
hunting	0.038	0.011	12.52	0.0004*
roads	0.083	0.026	9.89	0.0017*
decidous	3.798	1.292	8.64	0.0033*
water	- 2.876	0.998	8.3	0.0040*

Table 5. The best selected mixed model with unstandardized estimates. For whole model results see Table 7.

Variable	Estimate	Std Error	ChiSquare	p-value
Intercept [cluster]	- 4.556	0.663	47.15	<0.0001*
LEAD STRUCT [many]	0.598	0.090	44.12	<0.0001*
diversity	1.499	0.331	20.55	<0.0001*
roads	0.126	0.030	17.44	<0.0001*
traffic	0.119	0.030	15.93	<0.0001*
water	- 5.316	1.160	20.99	<0.0001*
FENCE [present]	- 0.842	0.137	37.85	<0.0001*
FORST EDGE [adjacent]	- 0.459	0.086	28.44	<0.0001*
PASSAGE [present]	- 0.598	0.173	11.97	0.0005*
decidous	4.351	1.369	10.1	0.0015*
SAFETY RAIL [present]	0.305	0.097	9.8	0.0017*
rivers	- 0.098	0.034	8.19	0.0042*
SPEED [70kmh]	- 0.516	0.181	8.12	0.0044*
WARNINGSIGN [present]	0.685	0.241	8.12	0.0044*
MID SEPARATION [present]	- 0.387	0.204	3.61	0.0576
SPEED [100kmh]	0.282	0.263	1.15	0.2834

Table 6. Expert model, containing the two summarizing categorical predictor variables, with unstandardized estimates. For whole model results see Table 7.

Variable	Estimate	Std Error	ChiSquare	p-value
Intercept[Cluster]	- 1.203	0.163	54.64	<0.0001*
ACCESSIBILITY [accessible]	1.089	0.150	52.89	<0.0001*
ATTRACTIVELY [attractive]	0.708	0.099	51.35	<0.0001*

Table 7. Descriptive statistics and comparison between all best selected models.

Model criteria	Road model	Landscape model	Mixed model	Expert model
-LogLikelihood	54.63	115.94	164.69	78.46
DF	7	7	15	2
ChiSquare	109.27	231.87	329.37	156.92
p-value	<0.0001*	<0.0001*	<0.0001*	<0.0001*
AUC for full model	0.70	0.77	0.82	0.68
Predictive power to correctly identify clusters	73%	77%	79%	88%
Predictive power to correctly identify control	52%	65%	72%	46%
Misclassification Rate	0.37	0.29	0.25	0.32
lack of fit -LogLikelihood	570.2	508.9	326.6	546.3
lack of fit DF	7	7	15	2
lack of fit p-value	<0.0001*	0.0023*	0.1384	0.237
AICc	1156.47	1033.87	952.822	1098.69

4. Discussion

4.1 Important results of the study

According to the results in this study, several of the studied features appear to be important factors increasing the risk for UVC clusters on primary and secondary roads in South-Central Sweden. These features include both landscape and local road variables. The models predict that vehicle accidents with ungulates are more likely to aggregate along road sections were the surrounding landscape is characterised by a higher proportion of deciduous forest, higher land cover diversity, more leading structures such as local roads, forest edges, rivers etc. (varied agricultural landscape). The present study thereby supports same patterns that were found in Seiler (2005). The species composition of the selected cluster UVCs consists of 65,6% roe deer, and are very likely the reason that this type of varied agricultural landscape has been referred, since roe deer prefer these type of areas. Moreover, if road and landscape features coincide with increased traffic volume, increased speed limit and absence of wildlife fences, the risk for clusters in UVC is substantially elevated (Seiler 2005, Ng et al. 2008).

All this is evidently summarized by the subjective evaluation in the Expert-model that predicts the risk of UVC clustering increases when road section is accessible and attractive. This include road sections that are; free of obstacles and when visibility across the road is possible, and when the area closes to the road provide shelter like tree- and shrub patches or when the area close to road consist of good options to forage like fields, meadows or lots of shrubs.
The expert model confidently identified clusters (88%), but weak in identifying non-clusters (46%) thus the model is not selective enough and would lead to an overestimation of clusters.

4.2 Factors and countermeasures

Wildlife fencing is most widely used countermeasure to collisions with ungulates and has been proven to be a cost-effective mitigation strategy to prevent UVC (Bashore et al. 1985, Danielson & Hubbard 1998, Clevenger et al. 2001a, Huisjer et al. 2015) The results in this study indicates that presence of fences reduces the risk for UVC clusters. But on the other hand, fencing most likely also consequently move the collision risk elsewhere where there is no fence present, since ungulates apparently want to cross the road a mitigation strategy that provide alternative passage would be more effectively.

My result alleviates the risk of clustering near possible passages, such as tunnels under the road or bridges that ungulates can use to cross the road. However, this variable (alternative passage) is not a major contributing factor, but this factor in combination with wildlife fence may be an important mitigation strategy to reduce UVC collisions more effectively, since ungulates will have a chance to cross the road with a limited risk of being hit by a vehicle. Fences are physical barriers and they increase the fragmentation of the landscape and thus reduce the movements between ungulate populations (Clevenger et al. 2001b, Seiler & Folkeson 2006, Olsson & Norin 2010). The infrastructure network is planned to expand in the near future, and so does consequently wildlife fencing (Swedish Road Administration 2015). Thus alternative passages may be important factor combining ungulate populations in an even more fragmented landscape.

The study clearly indicates that traffic volume and high speed limits are two important factors that contribute significantly to the UVC clustering. Seiler (2004b, 2005) and Ng et al. (2008) recommend speed reduction as a cost-effective mitigation measure. Today, Swedish Transport Administration employs fences and passages as standard measures but only when the average daily traffic exceeds 4000 vehicles (Swedish Road Administration 2016). Traffic volume, speed limitation and fencing are likely interrelated as roads with high traffic volume and high speed limits are more likely to be fenced than smaller roads. Indeed, our results show interactions between these factors, but these interactions did not improve our models and were dropped out in the stepwise selection process.

4.3 Barriers and impediments

We were interested in whether different types of physical structures acting as barriers like rock, noise protection walls, tall fence, screen or other technical features would increase the risk for UVC clusters. We also studied if high embankments or deep cuttings influence the clustering of UVC as suggested by (Clevenger et al. 2003). Furthermore, I tested whether smaller obstacles such as fences for domestic livestock or safety devices for vehicles adjacent or along the road may interfere the movement of ungulates (Clevenger & Kociolek 2013).

According to the results in the study UVC clustering are more likely to appear along those road sections where safety devices or fences for domestic livestock were present, while the physical barriers and relative road topography seemed to be of minor relevance for the clustering of UVC. Such pattern suggest that ungulates need to view the other side of the road before attempting to cross to avoid danger, and therefore avoid these places and try to cross the road elsewhere (Seiler & Olsson 2009). Livestock fences or safety rails may probably only comprise smaller obstacles but slow down wildlife while crossing and hence increase the risk for accidents (Gunson et al. 2009).

4.4 Road verge vegetation and foraging

Road verge vegetation can be attractive for ungulates if they provide shelter or forage. Road verge can be attractive especially during spring, because the road corridor provides sunlight and thereby earlier foraging possibility's compared to dense forests (Huijser et al. 2008, Krenz 2008). Generally, roadsides contain palatable plants like aspen and willow to a greater extent than what may be found in surrounding forests (Jägerbrand 2012). The results in my study does not support a shrubby vegetation as a factor that would increase the risk of UVC clustering; since road-side vegetation containing heath and scrubs (=cover), do not significantly contribute to UVC clustering, instead grassy vegetation appears to be more frequently present in UVC clusters. This may however be an effect of maintenance frequency, which is typically higher along larger roads with higher traffic volume and higher speed limit.

The analyses showed a significant relationship between traffic volume and presence of grassy road verges, but this relationship did not affect the model and was dropped out in the stepwise selection process. The results also stressed that UVC clustering was more likely to occur where the nearest forest edge was farther than 50m from the road. This may indicate that ungulates are not very interested in foraging in immediate vicinity of the road, which might be avoided because of disturbance, especially if traffic volume is high or can be a result of collinearity, were lager roads in general have wider and open roadsides. Open roadsides with grassy vegetation is probably more favourable habitat for roe deer, since the majority (77%) of the hunter reported UVC data I used in the study where roe deer vehicle collisions, it might explain why open areas where more prone to UVC clustering.

Various species use different habitats, have varying size of home ranges and have different migratory patterns (Cederlund 1989, Clevenger et al. 2003, Mysterud & Østbye 2004, Swedish Hunting Association, 2016), and therefore different species response differently when crossing roads (Clevenger et al. 2003). The results from the study can be expected to be more accurate if the clustering would be analysed in each respective species, rather than assembled together. However, the results describe the overall situation for UVC clustering for ungulates in south and central Sweden, and most of the mitigation actions of UVC applied today, such as wildlife fencing, reduced speed limit and warning signs do not distinguish between species.

4.5 Google Street View as a survey method

Using Google Street View as a method has some limitations. Several Google Street View images were taken during wintertime and snow cover can hamper the interpretation of some road features (e.g., the presence of safety devices and vegetation type). Wildlife fences are not always visible; they may be partially overgrown by vegetation or hidden by topography. At road intersections, it may be difficult to identify the type of wildlife fence applied (e.g., the presence of a gate along the intersection road or how far the wildlife fence is continuing at the intersecting road).

Google Street View has also advantages when it comes two identify smaller physical structures such as forest patches in agriculture landscape that are not always visible in topographic maps. Obviously, using Google Street View is an advantage compared to field studies since the number of variables that can be recorded are similar but are much more time- and cost efficient.

This study describes the importance of studying local road factors as the wider context of landscape features in future research on UVC. This study shows that it would be interesting study mitigation strategies on, for example, reducing forage and shelter alternatives close to road (attractiveness), an interesting tool worthy of more research. Overall, Google Street View is an effective and powerful tool identifying local factors of interest.

5. Conclusions

The models could be improved if species-specific clusters are analysed and if the long-term stability of clusters over time is considered. In this study, we decided that a cluster should include at least five accidents during a five-year period, but we did not pay concern to whether the accidents occurred during a short period only. It is possible that short-term clusters (instable clusters) are not significantly different from random UVC locations. If so, our results would be blurred and weaker than possible. Thus, in order to better identify explanatory variables that explain aggregated WVC patterns, one might want to include some measure of stability as a covariant in the analysis.

The results indicate that several local road and landscape variables together contribute to the aggregation of UVC and can help to predict where hazardous locations may exist. Such information is of importance to road planners as it provides guidance for road management and can give necessary support to the development of mitigation strategies.

Local factors such as appearance of road type, equipment's and local landscape structures are important to understand because they affect the behaviour of animal movements. Nevertheless, before conducting future strategies to prevent UVC, we need a better understanding of this underlying matrix of local and regional factors effecting animal behaviour including animal movements in a constantly changing landscape, if we can master this its possible to identify stable hazardous locations with sufficient reliability.

6. Acknowledgments

First, I would like to express my deepest gratitude to my supervisor Andreas Seiler who has been very patient with me. Thanks to his expertise, guidance within this subject, and for his constructive suggestions throughout the project, I have gained a lot of experience and knowledge in road ecology. I would also like to thank Linda Höglund, who has helped me with the Street View inventorying, there were some tuff days where we were sitting in front of the computer screen, scrolling along the road sections. And thanks to Richard Andrasik at the CDV in the Czech Republic for his guidance and assistance in the KDE+ analysis. I would also like to say thanks to Carme Rosell who together with Andreas Seiler gave me the opportunity to be involved in this study that was part of a more comprehensive project on wildlife and roads financed by CEDR (Conference of European Road Directors).

7. References

Apollonio, M., Andersen, R, Putman, R.J. 2010. Present status and future challenges for European ungulate management. In: Apollonio, M., Andersen, R and Putman, R.J. (eds.) European ungulate management in the 21st century. Cambridge University press, Cambridge, UK.

Bil, M., Andrasik, R., Janoska, Z. 2013. Identification of hazardous road locations of traffic accidents by means of kernel density estimation and cluster significance evaluation. -Accident Analysis and Prevention 55: 265-273.

Bil, M., Andrasik, R., Svoboda, T., Sedonik, J. 2015. The KDE+ software: a tool for effective identification and ranking of animal-vehicle collision hotspot along networks. -Landscape Ecology 31: 231-237.

Bashore., T. L., Tzilkowski, W, M., Bellis, E, D. 1985. Analysis of deer-vehicle collision sites in Pennsylvania. -Journal of Wildlife Management 49: 796-774.

Burnham, K.P., Andersson, D. R. 2002. Model selection and multimodel inference. A Practical Information-Theoretic Approach. Second edition. Springer -Verlag, New York, New York, USA.

Cederlund, G. 1989. Activity patterns in moose and roe deer in a north boreal forest. -Holarctic Ecology 12: 39-45.

Child, N.N., Stuart, K.M. 1987. Vehicle and train collision fatalities of moose, some management and socio-economic considerations. - Swedish Wildlife Research supplement 1 :1699- 703.

Clevenger, A. P., Chruszcz, B., Gunson, K. E. 2001a. Highway mitigation fencing reduces wildlife-vehicle collision. -Wildlife Society Bulletin 29: 646-653.

Clevenger, A. P., Chruszcz, B., Gunson, K. 2001b. Drainage culverts as habitat linkages and factors affecting passage by mammals. -Journal of Applied Ecology 38:1340-1349.

Clevenger, A. P., Chruszcz, B., Gunson, K. E. 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. -Biological Conservations 109: 15-26.

Clevenger, A. P., Kociolek, A, V. 2013. Potential impacts of highway median barriers on wildlife: State of practice and gap analysis. -Environmental Management 52: 1299-1312.

Danielson, B. J., Hubbard, M. W. 1998. A literature review for assessing the status of current methods for reducing deer-vehicle collisions. Task force on animal vehicle collisions, The Iowa Department of Transportation, and Iowa Department of natural resources, Iowa.

Danks, Z. D., Porter, W.F. 2010. Temporal, Spatial and landscape habitat characteristics of moose-vehicle collision in western main. -Journal of Wildlife Management 74: 1229-1242.

Forman, R.T., Sperling, D., Bissonette, J. A., Clevenger, A. P., Cutshall, C. D., Dale, V. H., Fahrig, L., France, R., Goldman, C. R., Heanue, K., Jones, J. A., Swanson, F. J., Turrentine, T., Winter, T. C. 2003. Road ecology. Science and solutions. Island Press, Washington, USA.

Gren, I.-M., Häggmark-Svensson, T., Andersson, H. Jansson, G., Jägerbrand, A. 2015. Using traffic data to estimate wildlife populations. -Journal of Bioeconomics 18: 17-31. Available: Bioecon (2016) 18:17–31 DOI 10.1007/s10818-015-9209-0.

Gunson, K. E., Clevenger, A. P., Ford, A. T., Bissonette, J. A., Hardy, A. 2009. A comparison of data sets varying in spatial accuracy used to predict the occurrence of wildlife vehicle collisions. -Environmental Management 44: 268-277.

Gunson, K. E., Teixeira, F. Z. 2015. Road-wildlife mitigation planning can be improved by identifying the patterns and processes associated with wildlife-vehicle collisions. In: Handbook of Road Ecology (eds van der Ree, R.,Smith, D.J.,Grilo, C), John Wiley & sons Ltd, Chichester, UK.

Helldin., J.O. 2013. Påkörda djur - ett växande naturvårdsproblem. TRIEKOL. CBM:s skriftelse 77. Centrum för biologisk mångfald.

Hosmer, D. W., Lemeshow, S. 1989. Applied Logistic regression. John Wiley, New York, New York, USA.

Huijser, M., Duffield, J. W., Clevenger, A. P., Ament, R.J., McGowen, P.T. 2009. Cost- benefit analyses of mitigation measures aimed at reducing collisions with large ungulates in the United States and Canada; a decision support tool. -Ecology and Society 14(2):15.

Huijser, M., Kociolek, A., Allan, T., McGowen, P., Cramer, P., Venner, M. 2015. Construction guidelines for wildlife fencing and associated escape and lateral access control measures. NCHRP Project 25-25, Task 84, National Cooperative Highway Research Program, Transportation Reasearch Board of the National Academies, Washington D. C.

Huijser, M., McGowen, P., Clevenger, A.P. and Ament, R. 2008. Wildlife vehicle collision reduction study: best management practice manual. Report to Congress. Best practices manual. U.S. Department of transportation. Federal Highway of Administration.

Häggmark- Svensson, T., Gren, I.-M., Andersson, H., Jansson, G., Jägerbrand, A. 2014. Costs of traffic accidents with wildboar in Sweden. Working Paper 2014:05. Department of Economcis, Swedish University of Agricultural Sciences, Uppsala, Sweden. Available at: https://ideas. repec.org/p/hhs/slueko/2014_005.html (2016-05-28, latest date of access)

Jägerbrand, A.K. 2012. Modification of the road environment as a measure against traffic fatalities involving wildlife. VTI, Swedish National Road Transport Research Institute. SE-581 95 Linköping, Sweden.

Jägerbrand, A.K. 2014, kollisioner och olyckor med rådjur i Sverige under 10 år (2003-2012). Variation i tid, geografi och kostnader. VTI rapport 818.

Krenz, J.,D, 2008. Best management practice no.8: managing roadside vegetation for wildlife and vehicle safety. In: Johnson, A. Best practices handbook for roadside vegetation management. Minnesota department of transportation, office of research Service, report MM/RC 2008-20.

Knapp, K., YI, X., Oakasa, T., Thimm, W., Hudson, E., Rathamann, C. 2004. Deer-vehicle crash countermeasures toolbox: a decision and choice resource. Final report. DVCIC-02. Midwest Regional University Transportation Center. Deer vehicle Crash Information Clearinghouse, University of Wisconsin-Madison, Madison, Wisconsin.

Langbein, J., Putman, R.J., Pokorny, B. 2011. Traffic collisions involving deer and other ungulates in Europe available measures for migration. In: Ungulate management in Europe Putman, R., Apollonio, M., Andersen, R (eds). Cambridge University press, Cambridge, UK.

Lavsund, S and Sandgren, F. 1991. Moose-vehicle relations in Sweden: a review. - Alces 27: 118-126.

Malo, J.E, Suárez, F., Díez, A. 2004. Can we mitigate animal-vehicle accidents using predictive models? -Journal of Applied Ecology 41: 701-710.

Morelle, K., Lehaire, F., Lejeune, P. 2013. Spatio-temporal patterns of wildlife-vehicle collisions in region with a high-density road network. -Nature Conservation 5: 53-73. Available at: 10.3897/natureconservation.5.4634 (2016-05-28, latest date of access).

Mysterud, A. and Østbye, E. 2004 Roe deer (Capreolus capreolus) browsing pleasure affect yew (Taxus baccata) recruitment within nature reserves in Norway. -Biological Conservation 120: 545-548.

Nielsen, C.K., Anderson, R.G, and Grund, M.D. 2003. Landscape influences on deer-vehicle accident areas in an urban environment. -Journal of Wildlife Management 67: 46-51.

Olsson, M., Norin, H. 2010. Faunapassager och gröna korridorer i Europa. Dokumentnummer: U:1001-20/10-udo/01-utr/rap001. Enviroplanning.

Puglisi, J., Lindzey, J. S. and Bellis, E.D. 1974. Factors associated with highway mortality of white-tailed deer. -Journal of Wildlife Management 38: 799-807.

Putman, R, J., Langbein, J. and Staines, B. W. 2004. Deer and Road Traffic Accidents: A Review of Mitigation Measures. Cost and Cost-Effectiveness. Report for deer commission for Scotland. Contract RP23A, UK Available: http://www.snh.org.uk/pdfs/publications/dcs/mitigation%20measures.pdf

Rea, R. V. 2003. Modified road vegetation management practices to reduce vehicular collisions with moose *Alces alces*. -Wildlife Biology 9: 81-91.

Rodriguez-Morales, B., Diaz-Varela, E. R. and Marey-Perez, M. F. 2013. Spatiotemporal analysis of vehicle collisions involving wild boar and roe deer in NW Spain. -Accident Analysis and Prevention 60: 121-133.

Rytwinski, T., Soanes K., van der Grift E. A., Jaeger J. AG, Findlay C. S., Fahrig L., Houlahan J. and van der Ree, R. in press 2016. How effective is road mitigation at reducing road-kill? A meta-analysis. PlosOne, in press.

Seiler, A. 2004a. Viltolyckor. In: Jansson, G., Andrén, H. and Seiler, C. (eds) Skogsvilt 3 - Vilt och Landskap i förändring. Lindesberg, Grimsö forskningsstation, SLU, pp. 262-268.

Seiler, A. 2004b. Trends and spatial patterns in ungulate-vehicle collision in Sweden. -Wildlife Biology 10: 301-313.

Seiler, A. 2005. Predicting locations of moose-vehicle collisions in Sweden. Journal of Applied Ecology. 42:371-382.

Seiler, A. and Folkeson, L. 2006. Habitat fragmentation due to transportation infrastructure. VTI Report 530A, Swedish National Road Transport Research Institute. Available at: http://www.vti.se/en/publications/pdf/habitat-fragmentation-due-to- transportation- infrastructure- cost- 341- national- state- of- the- art- report- sweden.pdf.

Seiler, A., Olsson, M. and Helldin, J.O. 2011. Klövdjursolyckor på järnväg – kunskapsläge, problemanalys och åtgärdsförslag. Trafikverket publikation 2011:058. Borlänge.

Seiler, A. (2015). "Cost-benefit evaluation of wildlife-mitigation fences." report to STA, in prep.

Seiler, A. and Olsson, M. 2009. Are non-wildlife passages effective passage for wildlife?. ICOET 2009. International Conference on Ecology and transportation. Duluth, Minnesota, Center for Transportation and the Environment, North Carolina State University 2009: 317-331.

Seiler, A. and Jägerbrand, A. 2016. Mörkertalet i Viltolycksstatistiken – Tolkning av förarenkät och databasanalyser. Trafikverket Rapport, in press 2016.

Swedish Environmental Protection Agency. 2010. Naturvårdsverket, Nationell förvaltningsplan för vildsvin (*Sus scrofa*). ISBN 91-620-ISSN 0282-7298.

Swedish Hunting Association. 2014. Jägareförbundet, Historisk avskjutning. Avskjutningsstatistik 1939/40 – 2012/13. Available: https://jagareforbundet.se/vilt/viltovervakning/historisk-avskjutning/ (2016-05-28, latest date of access).

Swedish Hunting Association. 2016. Jägareförbundet, Artpresentation Vildsvin. Jägarförbundet, Available at :https://jagareforbundet.se/vilt/vilt-vetande/artpresentation/daggdjur/vildsvin/. (2016-04-28, latest date of access).

Swedish National Wildlife Accident Council. 2016. Nationella viltolycksrådet, Statistik, Viltolyckor de senaste 5 åren (2011-2016). Available at: www.viltolycka.se (2016-05-28, latest date of access)

Swedish Road Administration. 2015. Trafikverket, Inriktningsunderlag inför transportinfrastrukturplanering för perioden 2018-2029. Trafikverket (Report, 2015:180). ISBN: 978-91-7467-842-0. Date: 2015-11-30.

Swedish Road Administration 2016. Trafikverket, Riktlinje landskap. Trafikverket (Document, TDOK 2015:0323). Date: 2016-02-02.

W. Ng, J., Nielsen, C. and St. Clair, C, C. 2008. Landscape and traffic factors infusing deer-vehicle collisions in an urban environment. -Human-wildlife conflicts 2(1): 34-47.

Zuberogoitia, I., del Real, J.,Torres, J.J., Rodriguez, L., Alonso, M. and Zabala, J. 2014. Ungulate vehicle collisions in a peri-urban environment: Consequences of transportation infrastructures planned assuming the absence of ungulates. Available at: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0107713 (2016-05-28, latest date of access).

Appendix 1

Step History	Model status	Parameter	L-R ChiSquare	Model p value	AICc	Delta AIC	Aikaike weights
1	included	LEAD STRUCT [few-many]	61.6	0.0000	818.79	134.3	0
2	included	decidous	27.82	0.0000	792.99	108.51	0
3	included	FORST EDGE [adjacent-distant]	23.47	0.0000	771.55	87.07	0
4	included	FENCE [present-absent]	18.13	0.0000	755.46	70.97	0
5	included	roads	27.05	0.0000	730.45	45.96	0
6	included	PASSAGE [present-absent]	7.58	0.0059	724.91	40.42	0
7	included	SPEED [100kmh-70kmh]	10.67	0.0011	718.35	33.86	0
8	included	SAFETY_RAIL [absent-present]	7.04	0.008	713.38	28.89	0
9	included	water	6.55	0.0105	708.9	24.41	0
10	included	rivers	6.68	0.0097	704.29	19.81	0
11	included	diversity	9.42	0.0021	696.95	12.47	0
12	included	traffic	6.82	0.009	692.22	7.74	0.005
13	included	WARNINGSIGN [absent-present]	6.14	0.0132	688.18	3.69	0.036
14	included	MID SEPARATION [present-absent]	4.16	0.0414	686.13	1.64	0.1
15	*excluded*	*hunting*	*2.64*	*0.104*	*685.6*	*1.11*	*0.13*
16	*excluded*	*railways*	*2.66*	*0.1029*	*685.06*	*0.57*	*0.171*
*17 **	*excluded*	*ROAD_LEVEL [variable-levelled]*	*2.69*	*0.1007*	*684.49*	-	*0.227*
18	*excluded*	*IMPEDIMENT [absent-present]*	*1.4*	*0.2375*	*685.22*	*0.74*	*0.157*
19	*excluded*	*clearcut*	*1.01*	*0.3161*	*686.36*	*1.87*	*0.089*
20	*excluded*	*BARRIER [absent-present]*	*1.00*	*0.3178*	*687.51*	*3.02*	*0.05*
21	*excluded*	*coniferous*	*0.44*	*0.5076*	*689.22*	*4.74*	*0.021*
22	*excluded*	*open*	*0.36*	*0.5474*	*691.02*	*6.53*	*0.009*
23	*excluded*	*ROAD VERGE [heath and wood-grass]*	*0.27*	*0.6041*	*692.92*	*8.43*	*0.003*
24	*excluded*	*houses*	*0.27*	*0.601*	*694.82*	*10.34*	*0.001*
25	*excluded*	*CURVATURE [straight-curved]*	*0.26*	*0.6128*	*696.75*	*12.26*	*0*
26	*excluded*	*ROAD VERGE [heath-wood]*	*0.13*	*0.7212*	*698.81*	*14.32*	*0*
27	*excluded*	*pasture*	*0.08*	*0.7817*	*700.93*	*16.44*	*0*

* model with lowest AIC, but the selected model contained only significant variables 1-14.

Appendix 2

Variables for UVC road inventory via Google Street View

Inventory of local factors associated with ungulate-vehicle collisions used in Saferoad Project 4.3 and master thesis of Magnus Sjölund. Project leader: Andreas.Seiler@slu.se

*Required

1. **ID-nummer (SL-ID of accident site) ***

   ....

2. **ROAD_LEVEL ***
   Describe the dominant road cross-section(> 60% of length or 300m) defined by the vertical location of the road in the landscape: LEVELLED= at same level, LOW= road lowered, RAISED= road raised, BARR 1 = vertical barriers on one side, BARR 2 vertical barriers on both sides. LEVEL implies no impediment or barrier for wildlife; LOW or RAISED are impediments but no barriers; BARR are physical barriers.
   Mark only one oval.

   ◯ Levelled
   ◯ Variable/Low
   ◯ Variable/Raised
   ◯ Variable/Barr_1
   ◯ Variable/Barr_2

3. **X DITCH ***
   Deep ditches (>3 m) may reduce the chance of discovering animals close to the road and may also act as impediment for animals trying to cross. Specify their combined coverage along both sides of the road: ABSENT= absent or < 10%, MINOR< 50%, MAJOR 50-90%, CONT= continuous or >90% and NotVisible, difficult to estimate depth of the ditch.
   Mark only one oval.

   ◯ Absent
   ◯ Present/Minor
   ◯ Present/Major
   ◯ Present/Cont
   ◯ NotVisible

4. **SAFETY_RAIL** *

Safety rails (metal,wire, etc) alongside roads may be an impediment as they slow down animals but they do not prevent crossings. Specify their combined coverage along both sides of the road: ABSENT= absent or < 10%, MINOR< 50%, MAJOR 50-90%, and CONT= continuous or >90%

Mark only one oval.

- Absent
- Present/Minor
- Present/Major
- Present/Cont

5. **BARRIERS** *

Noise protection walls or tall fences or screen or other technical features may impose effective barriers to wildlife and prevent them from entering or leaving the road. Also if there is cliff/ physical barrier. (Specify their combined coverage along both sides of the road: ABSENT= absent or < 10%, MINOR <50%, MAJOR 50-90%, and CONT = continuous or >90%.

Mark only one oval.

- Absent
- Present/Minor
- Present/Major
- Present/Cont

6. **IMPEDIMENTS** *

There may be other obstacles for wildlife alongside the road but outside the road corridor, such as electric fences, stonewalls, fences for livestock, etc. Specify their combined coverage along both sides of the road: ABSENT = absent or < 10%, MINOR <50%, MAJOR 50-90%, and CONT = continuous or >90%.

Mark only one oval.

- Absent
- Present/Minor
- Present/Major
- Present/Cont

7. **FENCE** *

Wildlife exclusion fences shall keep animals outside the road corridor. They are not entirely proof, but more effective than impediments. Fences are typically on both sides of the road, but exclude road intersections. Specify their combined coverage along both sides of the road (excluding intersections): ABSENT = absent or < 10%, MINOR <50%, MAJOR 50-90%, and CONT = continuous or >90%.

Mark only one oval.

- Absent
- Present/Minor
- Present/Major
- Present/Cont

8. **X FENCE_GATES ***

Fences have often gates to allow access to surrounding areas by vehicles. These gates are a major culprit for AVC occurring on fenced roads. Specify the quality of the majority of gates: G/absent = no gates present or no gate because no fence is present ; G/good = gates in good condition and closed; G/bad = gates in bad condition (i.e. not closed or tight enough to prevent wildlife from entering).
Mark only one oval.

- ◯ G/absent
- ◯ G/good
- ◯ G/bad

9. **X FENCEGATES_NR ***

If fence and gates are precent, enter total numbers of gates. If no wildlife fence is present enter "No fence" as an answer.

....

10. **X FENCE_OPENING ***

Intersections are typically not fenced and may often provide a free but rather hazardous passage for wildlife. Count the number of open intersections or other fence openings. (This may be categorized later.) Enter "No Fence" if no fence is present.

....

11. **X FENCE_CONDITION ***

Specify the quality and maintenance of the major part of the fence. F_standard = standard fence (not grounded but well maintained); F_ground = fence is grounded or anchored to prevent animals from crawling underneath (faunastängsel) and well maintained; F_bad = fence in bad condition (pressed down, lifeted up, broken, overgrown, etc..); F_other = specify condition … or enter "No fence" if no fence is present.
Mark only one oval.

- ◯ F_stand
- ◯ F_ground
- ◯ F_bad
- ◯ Other: ....

12. **MID_SEPARATION** *

Many larger roads have multiple lanes separated by a central wire-railing (2+1 väg) or rarely also a jersey barrier. These impede wildlife movements and may increase collision risks. Specify the length of the separation relative to the road section: ABSENT = absent or < 10%, MINOR <50%, MAJOR 50-90%, and CONT = continuous or >90%.
Mark only one oval.

- ( ) Absent
- ( ) Present/Minor
- ( ) Present/Major
- ( ) Present/Cont

13. **X MEDIAN_STRIP** *

Larger highways may have isolated driving lanes, separated by a median strip of vegetation (> ca. 15 m in width) that may offer a temporary refuge for wildlife. Specify its length along the road: ABSENT = absent or < 10%, MINOR <50%, MAJOR 50-90%, and CONT = continuous or >90%.
Mark only one oval.

- ( ) Absent
- ( ) Present/Minor
- ( ) Present/Major
- ( ) Present/Cont

14. **X MEDIAN_TYPE** *

Characterise the dominant part of the median strip: ABSENT (no median strip present); GRASS (open view, often combined with a ditch); SHRUB (vegetation blocking view and providing some cover); TREES (high vegetation, often in wider median areas); LAND (entire landscape lies between rather distant road lanes)
Mark only one oval.

- ( ) Absent
- ( ) Grass
- ( ) Shrub
- ( ) Trees
- ( ) Land

15. **ROAD_VERGE ***

The vegetation in road verges / roadsides can be attractive to wildlife, obscure animals from drivers and thus increase – or decrease the risk for collisions. Specify the dominant type of vegetation cover in verge or adjacent to road verge/ditch. HEATH=Heather, dry, open vascular plants; GRASS = open, Grassy, fresh,wet meadow vegetation, needs mowing; SHRUB = shrubs (salix, aspen etc; palatable as forage for moose), CLEAR = successional stage; young forest (providing attractive forage during the major part of the study period 2010 – 2014); OTHER = if available, please enter year of clearance or specify alternative type

Mark only one oval.

- ◯ Heath
- ◯ Grass
- ◯ Shrub
- ◯ Clear
- ◯ Other: ______________

16. **FOREST EDGE ***

Distance to the treeline from the road surface. Nearby trees reduce visibility of animals in time: Assess distance: IMMEDIATE = directly adjacent < 5m to road surface mainly in small roads; CLOSE = adjacent (after verge, up to ca 10 m), NEAR = some other vegetation may be in between, more then 10 m), DIST = distant > 50m away from roads.

Mark only one oval.

- ◯ Adjacent/Immediate
- ◯ Adjacent/Close
- ◯ Adjacent/Near
- ◯ Distent/Dist

17. **LEAD STRUCT ***

Other roads, railroads, trails, paths, forest edges, lakes, watercourses, etc may lead animals onto the road and increase the risk for accidents. Specify amount: NONE; FEW (< 3 features); SOME (3-6 features); MANY (> 6 features).

Mark only one oval.

- ◯ LS<3/None
- ◯ LS<3/Few
- ◯ LS≥3/Some
- ◯ LS≥3/Many

18. **WARNINGSIGN ***

Presence of wildlife warning signs may hopefully reduce collision risks; Check whether such signs are available up to <500m before/after the road section.

Mark only one oval.

- ◯ Absent
- ◯ Present

19. **CURVATURE** *

Sinuosity/Curvature of the road may affect visibility of wildlife. Specify the domninant part (>60% of the road). Straight or curved (where curved implies that the visibility is significantly reduced.
Mark only one oval.

- Straight
- Curved

20. **PASSAGE** *

Presence of potential passages for wildlife = tunnels or bridges along or near to the road section.
Mark only one oval.

- Present
- Absent

21. **ACCESSIBILITY** *

Give your overall judgement of the road section: Is it open and free of obstacles for animals to cross (OPEN); is it mainly shielded rom animals by fences or other barriers (CLOSED), or is it luring animals to cross while simultaneously imposing barriers or hindrances and thereby rising the risk for collisions (TRAP)?
Mark only one oval.

- Accessible/Open
- Closed
- Closed/Trap

22. **ATTRACTION** *

Give your overall judgement of the road section (whether the road is open, closed, or a trap), is it rather inviting animals to cross or to be near the road because of forage or landscape (ATTRACTIVE); Road, the road area and the adjacent habitat is not attractive for animals (AVERSIVE)
Mark only one oval.

- Attractive
- Aversive

23. **X DATA_IMAGE** *

Enter the year when the images were taken

....

24. **Comments**

Enter more information if needed!

....