Case studies on the effect of local road and verge features on ungulate-vehicle collisions

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Technical report 7

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Technical report No. 7
September, 2016

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Due date of deliverable: 04/31/2015
Actual submission date: 09/20/2016

Start date of project: 01/05/2014 End date of project: 31/10/2016

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Version: final, 09.2016

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Executive summary

Wildlife-vehicle collisions have become an increasingly acknowledged issue on European roads. As wildlife populations expand, especially ungulates, and roads and traffic continue to increase, people want more effective mitigation measures against accidents involving these species. Ungulate-vehicle collisions (UVC) occur widely across road networks, but their distribution is neither entirely random nor uniform; in fact, they tend to be concentrated at certain areas and on certain roads. A multitude of factors involving the ecology of ungulate species, the surrounding landscape and the road, its traffic and the drivers' behaviour influence the risk of UVC in general. Some of these factors are beyond the responsibility of road administrations, but others can be addressed locally through traffic adaptations, road design verge management or technical mitigation. However, these adaptations are usually very costly and therefore not applicable to the entire road network; but they are more cost-efficient if implemented at road sections where UVC occur frequently and often and are also likely to do so in the future. To successfully mitigate UVC, we need to know where UVC appear more frequently and which factors are responsible for the spatial aggregation.
The objective of this study is to reveal the influence of local factors related to road design and road verge management on the spatial aggregation pattern in UVC.

We analysed road sections with selected UVC clusters in Catalonia, Spain and south-central Sweden to study the effect of traffic, road, road verge and landscape features on UVC patterns. In addition, we analysed UVC statistics from central Norway to evaluate the effect of roadside vegetation clearance.

We used aerial photographs, Google-Street-View^{TM} imagery and field inventories to obtain high-resolution data on the characteristics of roads, road verges and landscape. We also used remotely sensed topographic data and satellite imagery to describe landscape composition and structure in surrounding areas within 1 km of the selected road sections. Data on vegetation clearing in Norway was obtained from county administrative boards. Road and traffic data were obtained from respective digital databases.

UVC data was obtained from 2010-2014 in south-central Sweden (98,007 UVC), 2007-2011 in Catalonia (2,320 UVC) and 2009-2015 in central Norway (3,253 UVC). In the Swedish data, 77% of all UVC involved roe deer, whereas wild boar collisions dominated the Catalonian UVC data (85%). Norwegian UVC consisted of 60% roe deer and 40% moose.

We used the modified Kernel Density Estimation (KDE+) to identify clusters in UVC distributions during the above 5-year periods. We compared features from accident locations in these clusters with features from individual accident sites outside the clusters by using logistic regression analyses with clusters versus non-clusters as the binary response variable. In Sweden, we identified 1,596 UVC clusters containing 13,985 UVC (14,3 % of all UVC). From these we randomly selected 475 clusters and 424 non-clusters for the further inventory in Google-Street-View. In Catalonia, we identified124 clusters including 433 UVC (18.7 % of all UVC). From these, we selected 300 UVC in clusters and equally as many locations outside the clusters.

We found that a clustering of UVC is more likely to occur on roads that lack any impediments or hindrances such as fences, barriers, safety rails or high embankments. UVC were also clustered where road verges provided either shelter or attractive forage and where traffic volume and vehicle speed were high.
Road verge characteristics were significant parameters in the models from both Sweden and Catalonia, but were generally less able to distinguish clusters from non-clusters than

mitigation measures such as exclusion fences. When combined with landscape features such as land cover type, distance to water or forest, occurrence of garbage containers (Catalonia) or linear landscape elements (Sweden) that attract or lead animals towards the roads, the resulting mixed road-landscape models were able to correctly identify 79% and 68% of the UVC clusters in Sweden and Catalonia, respectively. The identification of non-clusters, however, was less successful, suggesting that it is easier to predict the occurrence of clusters than to predict their absence.

The Norwegian study revealed no relative decline in the number of deer and moose collisions following vegetation clearing. It is possible that the clearing zone was either too narrow to deter animals from crossing or to increase visibility or that the animals were partly attracted to the clearing zone to feed on logging waste.

Overall, our study shows that factors prevalent in UVC clusters are typically associated with the occurrence of UVC in other studies. The combination of local factors creating attractiveness and accessibility for wildlife results in UVC clusters on certain road sections. Whether these factors also contribute to the stability of UVC clusters over longer time periods remains to be studied.

We conclude that road verge characteristics and hence verge management are indeed of significance, especially in reducing the attractiveness of road corridors for wildlife. However, different effects can outweigh each other and confuse the overall result. Verge management alone does not appear to be effective in reducing UVC; instead, management should be seen as part of a mitigation package that also contains measures that prevent animals from accessing roads and, preferably, leads them towards safe crossing locations.

1 Introduction

Many countries in the world struggle with increasing numbers of traffic accidents with wildlife such as wild boar (*Sus scrofa*), roe deer (*Capreolus capreolus*), moose (*Alces alces*) and other deer species (*Cervus, Dama, Rangifer*) (Putman et al., 2004; Langbein et al., 2010). These increases are typically attributed to the recovery and growth of ungulate populations, to the continued expansion of vehicular traffic and road networks or to changes in agriculture, forestry and land use patterns at large (Skölving et al., 1987; Bruinderink and Hazebroek, 1996; Seiler, 2004; Apollonio et al., 2010; Sullivan, 2011; Elmeros et al., 2014; Massei et al., 2015). While these factors may indeed explain the overall upward trend in ungulate-vehicle collisions (UVC), they can hardly explain the spatio-temporal patterns in UVC frequencies, nor can these factors be addressed by those counteractive measures implemented by road administrations.

UVC are a complex product of environmental, behavioural and technical factors (Seiler, 2003; Litvaitis and Tash, 2008) that create a non-uniform and non-random pattern in space and time (Gunson et al., 2011; Bíl et al., 2013; Rodríguez-Morales et al., 2013; Barthelmess, 2014; Gunson and Teixeira, 2015). In principle, these factors converge in three overarching domains: i. the animal (its presence, movement and behaviour), ii. the vehicle and its driver (traffic volume, speed, reaction time) and iii. the place where the accident occurs as characterized by road and landscape features (Table 1).

Clearly, UVC can only occur where and if animals and vehicles meet. Thus, on large spatial scales, UVC will reflect the geographic distribution of both ungulate populations and trafficked roads. On smaller spatial scales, variations in the number of UVC may instead reflect regional variations in population densities and traffic flows (Seiler, 2004). Locally, however, the spatial pattern in which UVC occur are more likely influenced by the individual behaviour of animals and drivers that, in turn, respond to prevailing environmental conditions. To effectively reduce UVC numbers and increase traffic safety, we need both a better understanding of the local factors that cause accidents to occur more frequently in certain areas and on certain roads than on others (Gunson and Teixeira, 2015) and a cooperative strategy involving transport administrations, landowners, hunters and other stakeholders such as the police, municipalities, etc. to effectively address large-scale factors (Rosell et al., 2013).

In general, UVC are more likely to occur on high-speed roads with intermediate to high traffic volumes, low visibility and a lack of mitigation measures to keep wildlife off the roadway (Clevenger et al., 2003; Seiler, 2005; Van Langevelde et al., 2008). Vehicle speed is often considered the single most important reason for traffic accidents in general since an increase in speed reduces the drivers' relative reaction time and extends the vehicles' braking distance (Elvik et al., 2009). The effect of traffic volume on the occurrence of UVC appears to be more complex because very high densities of vehicles may repel animals from entering the roadway, leading to fewer UVC. This non-linear relationship between traffic volume and UVC is likely related to the anti-predator behaviour and cognitive abilities of the species in question (Seiler and Helldin, 2006; Jacobson et al., 2016).

Research on UVC has also shown that accidents occur more frequently where roads pass through areas of high animal abundances, where attractive resources for wildlife are close to the road or where structural elements in the landscape funnel animals towards traversing roads (Finder et al., 1999; Hubbard et al., 2000; Malo et al., 2004; Seiler, 2005; Gunson et al., 2011). If roadsides provide attractive forage (herbaceous and young shrubs and trees) and/or cover and concealment from the view of motorists, UVC frequencies may also increase (Jaren et al., 1991; Rea, 2003; Rea et al., 2010; Sivertsen et al., 2010; Rolandsen et al., 2015b; Tanner and Leroux, 2015).

Many but not all of these factors can be targeted by physical, i.e., technical measures. Exclusion fences combined with fauna passages, animal detection and driver warning systems can be effective measures to either prevent animals from entering roadways or alert drivers (Clevenger et al., 2001; Beckmann et al., 2010; Huijser et al., 2015). Adaptations in road design and in the management of vegetation within and adjacent to road corridors determine the accessibility and attractiveness of roads for wildlife (Jaren et al., 1991; Lavsund and Sandegren, 1991; Putman, 1997; Rea et al., 2010; Sivertsen et al., 2010). Local speed reduction, temporary road closure and traffic calming are further options that deserve more thorough evaluation (Jaarsma et al., 2007; van Langevelde and Jaarsma, 2009). More extreme are the large-scale culling of wildlife populations or road removal as the final, and rather desperate, but nevertheless proposed solutions to reduce UVC in Sweden (Ingemarson et al., 2007).

For road administrations, mitigation options are mainly confined to technical installations along roads or to adaptations in road verge management. These, however, are often expensive to install and therefore need to prevent a high number of UVC in order to be cost-effective. Hence, they may only be appropriate in places where clusters of UVC occur and future UVC frequencies are expected to be high.

In section 2 of this report, we discuss UVC in Sweden and Spain and the factors related to the spatial aggregation of accidents with ungulates. We emphasize local factors related to the road and its immediate surroundings. This study was based on two Master's theses, one conducted at the Autonomous University of Barcelona (Torrellas, 2015) and one at the Swedish University of Agricultural Sciences (Sjölund, 2016).

In section 3 we discuss UVC statistics in Norway and evaluate the effect of vegetation clearance in road verges less than 20 m from the road. This study was based on a Master's thesis being conducted at the Norwegian University of Science and Technology (Lindstrøm, 2016, in preparation).

Table 1. Major factors that may influence the occurrence and the pattern of animal-vehicle collisions.

Animal factors	Traffic factors	Environmental factors
Individual behaviour	***Vehicle/Driver***	***Road corridor***
sex, age, status	vehicle speed	corridor width
dispersal, migration	road surface	road-side habitat
foraging behaviour	visibility	fences, gullies
anti-predatory behaviour	detection time	bridges, tunnels
…	reaction time	road lighting
	…	…
Species ecology	***Traffic***	***Landscape***
abundance	density	topography
solitary / group-living	continuous / clumped	linear features
habitat preferences	velocity	adjacent habitat
migratory movements	diurnal / seasonal pattern	landscape composition
nocturnal / diurnal	…	microclimate

2 UVC cluster analyses in Spain and Sweden

2.1 Methods

2.1.1 Study area

The cluster analysis of ungulate-vehicle collisions was conducted in two study areas: Catalonia and south-central Sweden.

2.1.1.1 Catalonia

Catalonia, an autonomous community of Spain, with a surface area of 32,108 km^2, is located in the northeast section of the Iberian Peninsula. Geographically, this territory is diverse with a combination of mountain ranges and flatlands. There is a high variety of land cover, with coniferous and broadleaved forests alternating with croplands, scrublands and grasslands. Climate is also very varied, ranging from dry Mediterranean to Atlantic and high-mountain climates. These characteristics create prime habitats for ungulates such as wild boar (*Sus scrofa*) and roe deer (*Capreolus capreolus*) (Rosell et al., 2001; Acevedo et al., 2006; Mateos-Quesada, 2011), which are the most problematic species mostly involved in UVC in Spain (Camps et al., 2012; Rosell et al., 2013; Sáenz-de-Santa-María and Tellería, 2015). The Catalonian road network is 12,094 km long, 12% of which is multi-lane motorways (usually fenced), 87% is single causeway secondary roads and 1% is double-causeway secondary roads. On the majority of roads (66%) traffic density is less than 5,000 vehicles a day; on 20% of the roads, this exceeds 10,000 vehicles per day.

2.1.1.2 South-central Sweden

South-central Sweden encompasses the four southern administrative regions of the Swedish Transport Administration, with the counties of Värmland, Örebro, Västmanland, Uppsala, Stockholm, Västra Götaland, Östra Götaland, Jönköping, Kalmar, Halland, Södermanland, Kronoberg, Blekinge and Skåne. This region covers about 157,000 km^2, includes the southern-boreal and nemoral vegetation zones and covers a gradient of land use forms ranging from large-scale forestry in the northwest to extensive agriculture in the south and east. Its topography is mostly relatively flat or with soft hills and valleys and plenty of lakes and waterways. It includes most of the larger cities in Sweden and, consequently, most of the road network. Within this region, moose (*Alces alces*), roe deer and, more recently, wild boar are commonly found. Fallow deer (*Dama dama*) and red deer (*Cervus elaphus*) have more restricted distributions in the western and southern parts of the region, but their ranges are expanding. All ungulate species are intensively managed and game-bag statistics for both deer and wild boar are quickly increasing, while moose and roe deer harvests are slightly decreasing (Source: Swedish Association for Hunting and Wildlife Management, http://jagareforbundet.se/vilt/viltet/).

The public road network in this region includes a total of 66,417 km of state-administered roads. Primary and secondary roads comprise about 23% of the public road network; we selected 12,277 km of this for our analysis. Primary and secondary roads carry about 90% of the traffic flow and consist of a wide range of road types ranging from multi-lane motorways with traffic volumes of over 30,000 vehicles a day to single-lane highways with less than 1,000 vehicles per average day. About 35% (5,421 km) of these roads are already fenced to avoid UVC, yet over 53% of all UVC in the region occur on these major roads. Mean accident frequencies are 0.8 UVC per km and year. We did not include tertiary roads in our study; they extend to three times the length of major roads, but with UVC frequencies of < 0.2 UVC per km and year.

2.1.2 UVC data

2.1.2.1 Catalonia

We used UVC data from the period 2007-2011. In this period a total of 2,320 UVCs were reported on the Catalonian road network (Figure 1) (Camps et al., 2012). Over these five years, the number of UVC increased by 44%; more than 85% of these collisions involved wild boar, while a minor percentage involved species of deer (5%), mostly roe deer (Rosell et al., 2013). Data were registered by traffic police (CME, Cos Mossos d'Esquadra) and completed with data provided by road management teams (DG Roads), the traffic management agency (DG Traffic) and the wildlife management department of the Catalan government (Departament d'Agricultura, Ramaderia, Pesca, Alimentació i Medi Natural). UVC locations were registered with reference to 100 m road markers. The error in the positioning of UVC was estimated to be about 150 m, producing a 300 m length for each individual UVC stretch of road.

2.1.2.2 South-central Sweden

UVC data was obtained for the period 2010-2014. Since 2010, car drivers in Sweden have been legally obliged to report any road incident with ungulates and large carnivores to the police. In most (80-90%) of the cases, the police then call a contracted hunter to visit the accident site and take care of the injured or dead animal. These hunters provide information about place (GPS location), time and species involved in the accidents. Hunter reports and police records are managed by the Swedish National Council for Wildlife Accidents (www.viltolycka.se). A total of 98,007 UVC during 2010 to 2014 from primary and secondary roads could be used for further GIS analysis. This approximates 75% of all UVC reported to the police during these years in this region. The UVC involved roe deer (77%), moose (11%), wild boar (9%), fallow deer (3%) and red deer (1%).

We estimated a linear error of ± 250 m in the given GPS position of a UVC, partly due to discrepancies in the GPS positioning, errors in the reporting of coordinates and uncertainties in the exact location of the accident, and partly due to the adjustment of a UVC position in GIS to match with the digital road map. Thus, each UVC location is represented by a 500m stretch of the respective road.

2.1.3 UVC cluster analysis

To identify UVC clusters, we applied the traditional two-dimensional Kernel Density Estimation (KDE) technique combined with the modified one-dimensional version (KDE+) developed by (Bíl et al., 2013; Bíl et al., 2016). KDE+ distinguishes significant aggregations of point events from an expected random distribution derived through Monte Carlo simulations of event distributions along each individual road segment. KDE+ thus simulates clustering thresholds at road-section level, making it possible to statistically distinguish clustered from random UVC.

Due to differences in sample sizes between the study areas, we selected those KDE+ clusters that contained ≥ 5 UVC/km in Sweden and ≥ 3 UVC/km in Catalonia over the respective 5-year periods. UVC in clusters were opposed to non-clustered UVC on road sections with < 3 UVC/km and > 1 km distant from the nearest UVC cluster. On average, clusters contained more than 10 times as many UVC per km than the rest of the road network.

In Catalonia, we distinguished 124 clusters containing 433 UVC (18.7% of all UVC) and covering 0.2% of the road network. From these, we selected a stratified sample of 300 UVC in clusters and selected equally as many UVC outside of clusters (Figure 1). In Sweden, we identified 1,596 UVC clusters containing 13,985 UVC (14,3 % of all UVC) and covering 3.35% of the major road network or 0.78% of all public roads in the region. From these, we randomly selected 474 clusters represented by one UVC each and used 429 non-clustered UVC for further analysis (Figure 2). As both data sources contained a spatial error in the positioning of the accidents, we defined the minimum length of road sections with UVC clusters by their respective errors, i.e., 300 m in Catalonia and 500 m in Sweden.

2.1.4 Independent variables

At each of the 300 m, respectively 500 m-long road sections (for UVC in clusters as well as for non-clustered UVC), we measured a set of features that related to either the road or the landscape and that we believed could potentially influence the clustering of UVC. As far as possible, we applied the same measurements and categorizations in both study areas (Table 2).

Data on the local road features and its immediate environment were obtained from aerial photographs, Google Street View TM imagery and, in a few cases, through field visits. Data on traffic, wildlife harvests and the composition and structure of the surrounding landscape (within 1 km radius from the selected road sections, Figure 3) were obtained from official databases, digital topographic maps and satellite imagery. Spatial operations were done in Esri ArcGIS 10.1.

Table 2. Description of the potential predictor variables used in both the Spanish and the Swedish analysis of UVC clusters. How these variables are measured differs slightly between the countries.

Model	Variables	Type	Description
road	BARRIERS	cat	Any natural or technical feature that may effectively prevent wildlife from entering the roadway (fences, noise protection walls, road on bridge, etc).
	CURVATURE	cat num	Sinuosity/Curvature of the road. In Sweden: straight or curved. In Catalonia: measured as the ratio of shortest length to actual length
	FENCE	cat	Presence or absence of wildlife fences along the road.
	FENCE_2	cat	In Sweden: gaps, gates and other openings, as well as low quality and bad conditions of fences that may reduce efficacy. In Catalonia: type of fence
	IMPEDIMENT	cat	Any natural or technical obstacle adjacent to the road corridor that may reduce wildlife movements but not prevent them (electric fences, stonewalls, fences for livestock, etc.)
	ROAD_XING	cat	Occurrence of intersections or connections with other infrastructure
	MEDIAN	cat	Roads with multiple lanes separated by any technical feature that prevents animals from crossing both lanes (central wire-railing, jersey barrier, etc.)
	PASSAGE	cat	Presence of potential passages for wildlife = tunnels or bridges along or near the road section. (Two alternative classes: Present or Absent).
	ROAD_LEVEL	cat	Shape of the cross-section profile of the road embankment in relation to the surrounding landscape. The road surface may be level with its surroundings and impose no impediment or barrier or it may be raised or lowered and provide a physical hindrance on one or both sides.
	VERGE	cat	Presence and type of vegetation cover for ungulates in road verge (absent = grass, open; present = shrubs or trees)
	SAFETY_RAIL	cat	Coverage of safety rails (metal, wire, stone, etc) along both sides of the road section.
	SPEED	cat	Speed limit on current road segment (2 classes in Catalonia: ≤ 90 and >90 km/h; in Sweden <90, ≥90 km/h)
	TRAFFIC	num	Average traffic intensity on current road, vehicles/day
	WARNINGSIGN	cat	Presence of wildlife warning signs near and within the selected road section.
landscape	GARBAGE	cat	Presence of garbage containers next to the road (only in Catalonia)
	HUNTING	num	Average game bag for ungulates (per county or district)
	INFRASTRUCTURE	num	Density of other infrastructure within 1 km radius from the road
	BROADLEAVED	num	Proportion of broadleaved forest cover within 1 km radius
	CONIFEROUS	num	Proportion of coniferous forest cover within 1 km radius
	CLEARCUT	num	Proportion of clear-cut forest cover within 1 km radius
	WETLAND	num	Proportion of wetland cover within 1 km radius
	AGRICULTURE	num	Proportion of cropland cover within 1 km radius
	PASTURE	num	Proportion of grassland cover within 1 km radius
	OTHER OPEN	num	Proportion of other non-forested land cover within 1 km radius
	URBAN / BUILTUP	num	Proportion of built-up land cover within 1 km radius
	WATER	num	Proportion of open water surface within 1 km radius
	LAND DIVERSITY	num	Shannon-Wiener index of land cover diversity
	LEAD_STRUCT	cat	Count of linear leading structures or ecotones that intersect with the road and may lead animals onto the road (small roads, railroads, trails, paths, forest edges, shore lines, watercourses, etc.)
	DIST_FOREST	num cat	In Catalonia: distance to the nearest forest edge from the road surface In Sweden: distance to nearest forest edge (adjacent, near, distant)
	DIST_SHRUB	num	In Catalonia: distance to the nearest shrub vegetation from the road surface
	DIST_BUILT	num	In Catalonia: distance to nearest human settlement
	DIST_WATER	num	in Catalonia: distance to nearest body of water
expert	ACCESSIBILITY	cat	In Sweden: Individual evaluation (subjective) of whether the road section appears to be open and accessible to wildlife or closed and protected.
	ATTRACTIVITY	cat	In Sweden: Individual evaluation (subjective) of whether animals may be attracted to enter or cross the road section or whether they may instead be averted and repelled.

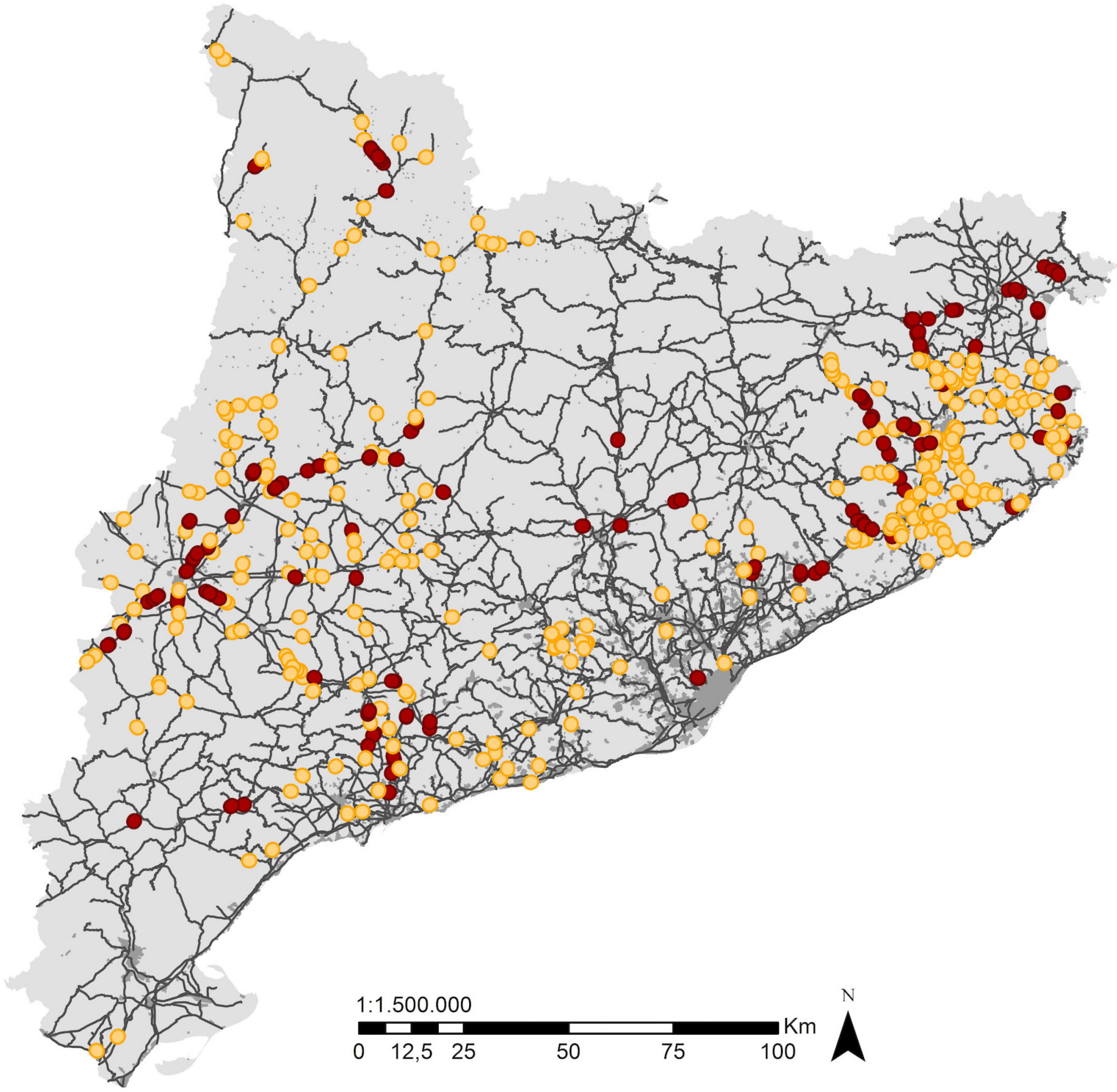

Figure 1. Catalonian study: Distribution of the selected 600 UVC in clusters (dark dots) and outside of clusters (light dots) on the major road network (grey lines).

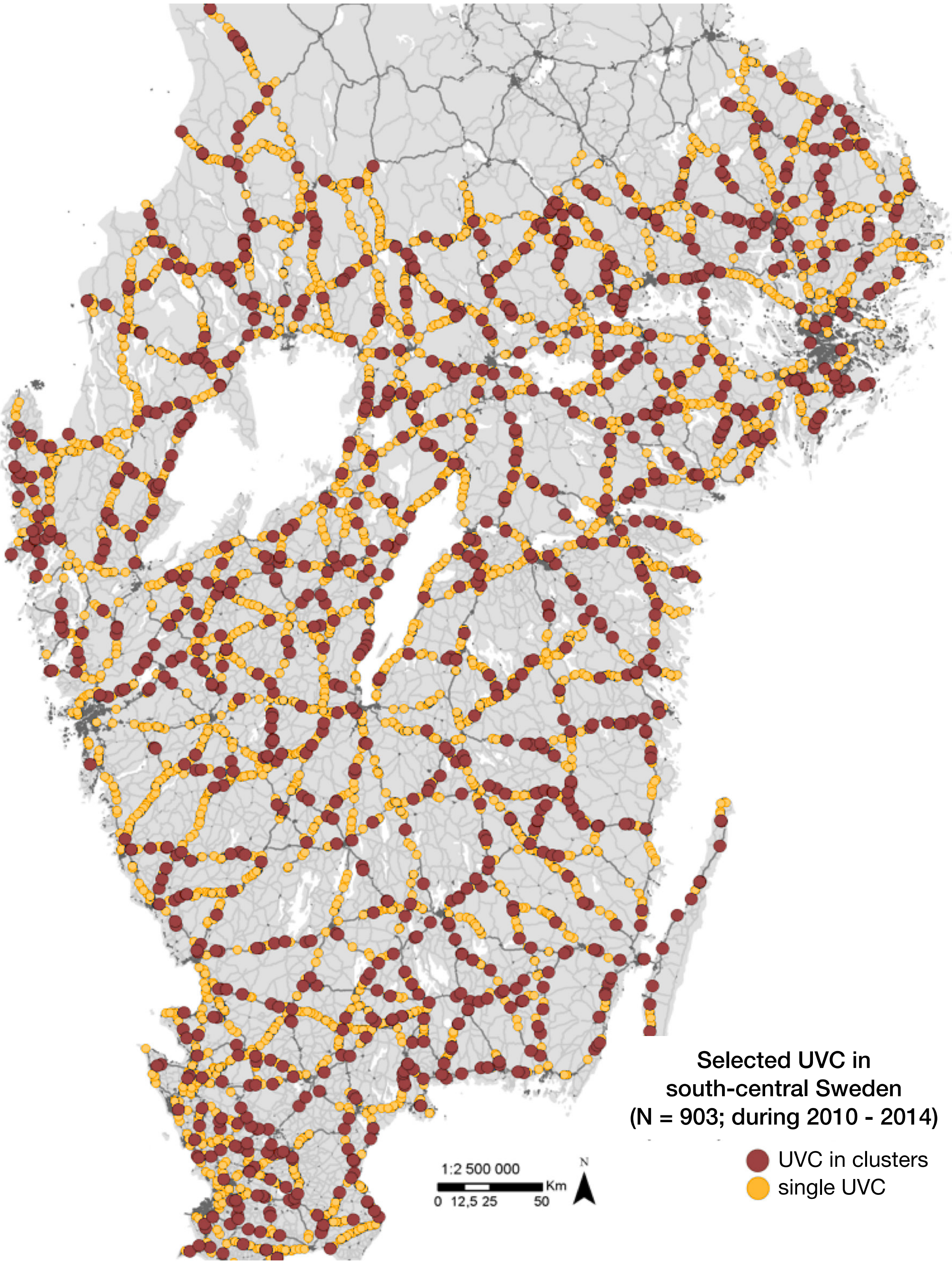

Figure 2. Swedish study: Distribution of selected 474 UVC clusters (dark dots) and 429 single UVC (light dots) in south-central Sweden. Dark-grey lines indicate primary & secondary roads, light-grey lines represent tertiary roads (not included in analysis).

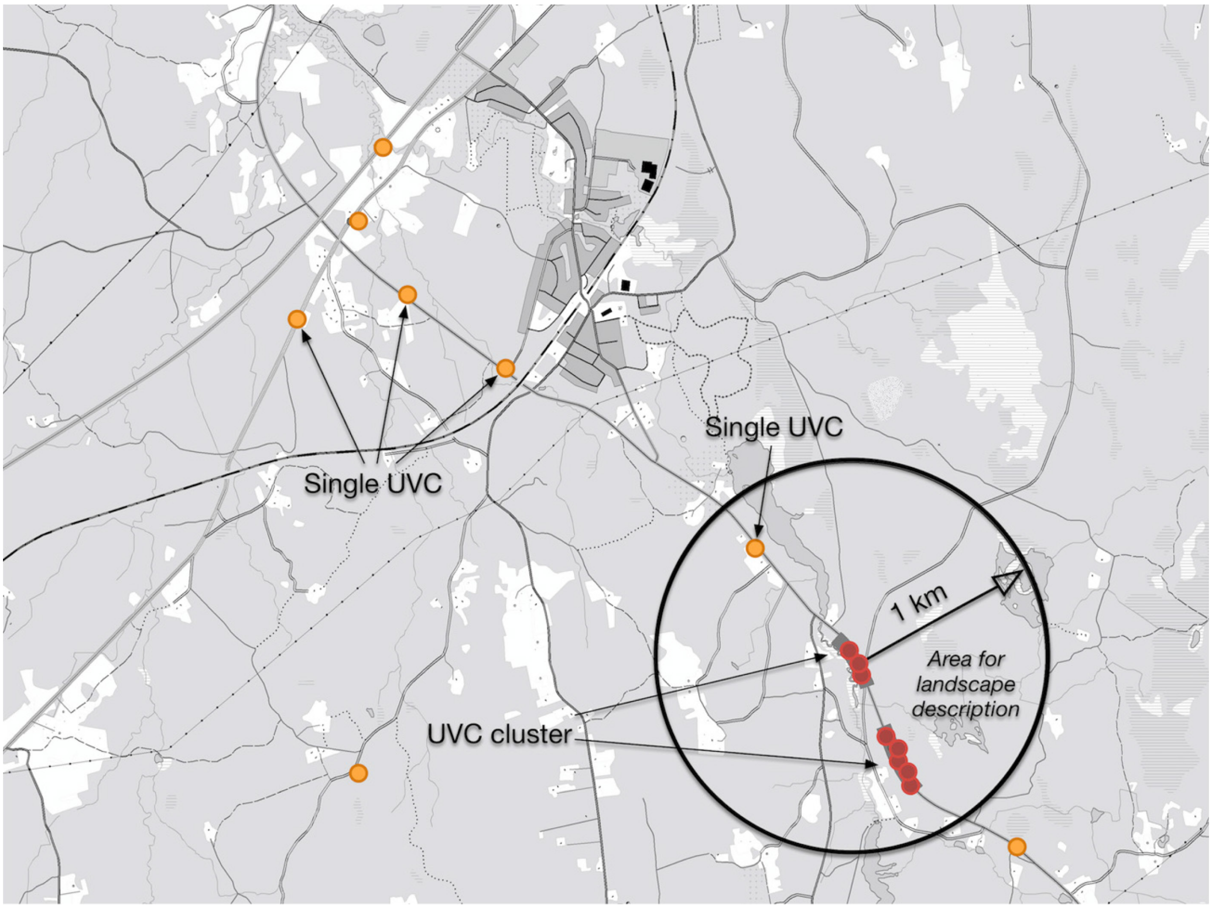

Figure 3. Example of topographic map with single and clustered UVC locations illustrating cluster-road sections and the 1 km radius around UVC locations within which landscape features were measured.

2.2 Statistical analysis

We used univariate tests to explore how well the individual predictor variables were able to distinguish between clusters and controls. Continuous variables were studied with the non-parametric Wilcoxon signed-rank test; categorical variables with the Pearson chi-square test. We measured the cross-correlation of independent numerical variables to reduce multicollinearity among the predictors. Agricultural land, urban land and cropland were strongly negatively related to forest cover, but as they performed less well in distinguishing between clusters and controls than did forest cover measurements, they were excluded from further analyses.

We then developed 3 logistic regression models for different subsets of independent variables and 1 common binary dependent variable (clusters = 1 and non-clusters = 0):

1. mixed model
   (mixed road and landscape effects)
2. road model
   (only road and traffic data from the selected road section)
3. landscape model
   (only landscape and environmental data within 1 km around the road)

In the Swedish study, we also tested the subjective overall impression of the persons conducting the image evaluation on whether the particular road section was attractive and accessible to wildlife. These two properties were originally planned as control variables against which the other qualitative and quantitative variables could be tested. The persons conducting the Street View inventory were largely unaware of whether a particular road section was a cluster or a non-cluster, and road sections were studied in random order. This “expert model” thus contained only these two factors.

The models (except for the expert model) were built using stepwise regression procedures, where the probability for a variable to enter the model was set at $p < 0.25$ and probability to leave at $p > 0.1$ (Hosmer and Lemeshow, 1989). Among the alternative variable combinations that significantly distinguished between clusters and controls, we preferred the most parsimonious model (using the fewest number of predictor variables) that still performed equally well as the best model with the smallest AICc (delta AICc < 2). We referred to the second order AICc (Aikaike Information criteria) to compare model performance (Burnham and Anderson, 2002).

The models were built from a random subsample containing 70% of the total data. The remaining 30% was used for model validation. Model accuracy was evaluated from the generalized RSquare (also called Cox & Snell’s pseudo RSquare) that is scaled to have a maximum value of 1. Model structure was considered adequately scaled if the Lack of Fit Chi-square in the Hosmer-Lemeshow test was > 0,05, i.e. if a saturated model would not perform significantly better than the fitted model (Burnham and Anderson, 2002). Model discrimination was evaluated by the area under the ROC curve (AUC, with AUC > 70 performs fairly well, AUC > 80 good). After validation, the chosen variable combination was applied to the entire data set to obtain the final parameter estimates and regression coefficients.

Details in the statistical procedures differed slightly between the two case studies; further information is given in the respective Master’s theses (Torrellas, 2015; Sjölund, 2016). The statistics were performed using R software (version 3.1.3; R Core Team 2015) and JMP Pro 12 (SAS Inc. 2015).

2.3 Results

2.3.1 Univariate analyses

Most of the measured road and landscape variables differed significantly between UVC clusters and non-cluster UVC; however, the relative significance of the factors differed between the countries (Table 3 and 4). In both case studies, roads with UVC clusters were characterized by a higher traffic volume and a lack of exclusion fences.

In Catalonia, potential barriers and safety rails that could impede the movement of wildlife were less likely to be found on cluster roads, while developed verge vegetation, garbage containers and open water were more likely to be present at or near cluster roads than on roads without UVC clusters.

In Sweden, impediments to animal movements, barriers and safety rails, but also grassy (open) vegetation in road verges were slightly more often present on cluster roads. In contrast to non-cluster UVC, clusters were located in landscapes that were more diverse and open and had a higher proportion of agricultural land use, broadleaved forests and more linear landscape elements that could direct animals towards the road. Clusters were also more frequent in counties that reported higher game bags in ungulates. Non-cluster UVC, on the other hand, were characterized by more homogenous landscapes dominated by coniferous forest and with less busy roads. Over 91% of the cluster roads in Sweden were assessed to be “accessible” and “attractive” to wildlife, compared to 76% and 67%, respectively, on non-clustered UVC locations.

In both Catalonia and Sweden, some of the identified UVC clusters were already known because they had been marked with warning signs, whereas signs were largely missing at non-cluster locations.

Table 3. Descriptive statistics and univariate tests of numerical predictor variables measured in the Catalonian and the Swedish study. Not all variables and categories initially included in the analysis (Table 2) provided sufficient data.

CATALONIA										
	Clusters (N=300)				**Non-clusters (N=300)**				**Wilcoxon**	
Numerical variables	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Z**	**p-value**
DIST_WATER	565.4	526.7	4.13	1500	750.8	564.8	0.00	1500	4.12	<.0001*
TRAFFIC	9902	7792	592	36723	9175	9560	35	55212	-3.29	0.0010*
CURVATURE	0.99	0.02	0.77	1.00	0.98	0.04	0.65	1.00	-3.02	0.0025*
URBAN	0.096	0.090	0.007	0.549	0.126	0.116	0.006	0.701	2.73	0.0064*
PASTURE	0.046	0.029	0.003	0.182	0.042	0.028	0.001	0.240	-1.72	0.0859
DIST_BUILD	148.0	232.2	0.72	1500	150.78	262.14	0.00	1500	-1.63	0.1031
CONIFEROUS	0.132	0.168	0.000	0.728	0.141	0.152	0.000	0.904	1.60	0.1096
DECIDUOUS	0.216	0.261	0.000	1.122	0.185	0.224	0.000	1.060	-1.57	0.1174
AGRICULTURE	0.477	0.311	0.000	1.137	0.463	0.317	0.001	1.305	-0.79	0.4275
DIST_FOREST	107.5	236.9	0.00	1500	99.50	225.01	0.00	1500	-0.79	0.4323
DIST_SHRUB	61.68	94.11	0.00	428.3	65.43	97.54	0.39	523.4	0.70	0.4809
DIVERSITY	0.900	0.260	0.110	1.420	0.910	0.250	0.130	1.370	0.13	0.8949

SWEDEN										
	Clusters (N=429)				**Non-clusters (N=474)**				**Wilcoxon**	
Numerical variables	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Z**	**p-value**
OPEN	0.130	0.083	0.010	0.590	0.098	0.090	0.000	0.560	-8.10	<.0001*
HOUSES	3.000	1.741	0.100	10.200	2.157	1.644	0.000	10.000	-8.08	<.0001*
ROADS	11.58	3.08	3.23	24.19	10.11	3.17	2.95	21.14	-7.09	<.0001*
DECIDUOUS	0.122	0.080	0.000	0.620	0.090	0.064	0.000	0.440	-6.83	<.0001*
AGRICULTURE	0.298	0.252	0.000	1.330	0.245	0.301	0.000	1.330	-6.33	<.0001*
TRAFFIC	3814	2496	215	17675	3732	4290	67	25028	-6.24	<.0001*
DIVERSITY	1.423	0.286	0.154	1.964	1.305	0.325	0.135	1.974	-6.14	<.0001*
HUNTING	16.76	7.65	4.39	30.54	14.85	7.96	4.39	30.54	-4.01	<.0001*
CONIFEROUS	0.302	0.181	0.000	0.890	0.382	0.226	0.000	1.020	5.91	<.0001*
PASTURE	0.012	0.041	0.000	0.760	0.010	0.040	0.000	0.470	-3.72	0.0002*
CLEARCUT	0.088	0.072	0.000	0.380	0.109	0.089	0.000	0.540	3.20	0.0014*
WATER	0.039	0.074	0.000	0.470	0.062	0.104	0.000	0.500	3.09	0.0020*
WETLAND	0.031	0.059	0.000	0.640	0.040	0.060	0.000	0.390	2.84	0.0045*
RAILWAYS	0.567	0.997	0.000	4.543	0.425	0.857	0.000	3.203	-2.18	0.0295*
URBAN	0.018	0.040	0.000	0.250	0.018	0.044	0.000	0.240	-1.24	0.2138
RIVERS	4.050	2.500	0.000	13.96	4.007	2.503	0.000	14.40	-0.36	0.7187
PATHS	0.861	1.296	0.000	6.504	0.835	1.271	0.000	7.178	-0.14	0.8916

Table 4. Descriptive statistics and univariate tests of the categorical variables measured in the Catalonian and the Swedish case study. Not all variables and categories initially included in the analysis (Table 2) provided sufficient data.

CATALONIA Categorical variables	**Classes**		**Clusters (N=300)**		**Non-clusters (N=300)**		**Pearson chi^2**	**p-value**
WARNINGSIGN	*absent*	*present*	275	25	296	4	15.979	<.0001*
VERGE	*absent*	*present*	120	180	166	134	14.137	0.0002*
SPEED	*≤90 km/h*	*>90 km/h*	149	151	191	109	11.973	0.0005*
BARRIER	*absent*	*present*	256	44	226	74	9.494	0.0021*
FENCE	*absent*	*present*	248	52	218	82	8.648	0.0033*
SAFETYRAIL	*absent*	*present*	132	168	100	200	7.196	0.0073*
ROADLEVEL	*flat*	*variable*	249	51	223	77	6.713	0.0096*
GARBAGE	*absent*	*present*	197	103	225	75	6.262	0.0123*
MEDIAN	*absent*	*present*	271	29	254	46	4.404	0.0359*

SWEDEN Categorical variables	**Classes**		**Clusters (N=474)**		**Non-clusters (N=429)**		**Pearson chi^2**	**p-value**
LEAD STRUCT	*few (<3)*	*many (>3)*	94	380	226	203	106.209	<.0001*
DIST_FOREST	*distant*	*adjacent*	331	143	198	231	52.031	<.0001*
FENCE	*absent*	*present*	431	43	321	108	41.932	<.0001*
IMPEDIMENT	*absent*	*present*	314	160	342	87	20.579	<.0001*
VERGE	*absent*	*present*	321	153	237	192	15.953	0.0005*
WARNINGSIGN	*absent*	*present*	438	36	421	8	15.952	<.0001*
MEDIAN	*absent*	*present*	420	54	347	82	10.496	0.0012*
PASSAGE	*absent*	*present*	450	24	390	39	5.629	0.0177*
SPEED	*<90 km/h*	*≥90 km/h*	74	400	92	337	5.107	0.0238*
BARRIER	*absent*	*present*	390	84	373	56	3.746	0.0529
SAFETY RAIL	*absent*	*present*	302	172	298	131	3.34	0.0676
ROAD LEVEL	*flat*	*variable*	406	68	359	70	0.676	0.4111
CURVATURE	*straight*	*curved*	267	207	245	184	0.056	0.8132
ACCESSIBILITY	*closed*	*accessible*	14	460	105	324	91.164	<.0001*
ATTRACTIVITY	*aversive*	*attractive*	43	431	141	288	78.589	<.0001*

2.3.2 *Multiple generalized regression models*

All three alternative factor combinations (only road features, only landscape features or a mixture of both) were able to significantly distinguish between clustered and non-clustered UVC (Tables 5 and 6). The mixed model performed best and identified 79% of the UVC clusters in Sweden and 68% of the clusters in Catalonia (Table 7). The identification of non-clusters, however, was less effective. The models correctly identified only 33%-40% of non-clusters in Catalonia and 52%-70% in Sweden, suggesting that it is easier to predict the occurrence of clusters than to predict their absence.

In both case studies, the road and the landscape models suffered a significant lack of fit in the Goodness of fit analysis and produced higher misclassification rates (34%-40% in Catalonia and 29%-37% in Sweden) than the mixed models (32% and 25, respectively). This suggests that UVC clustering in roads is clearly prompted by a combination of both landscape and road-related features.

Both the Swedish and the Catalonian road models contain similar variable combinations: vehicle speed, the occurrence of fences, safety rails and the vegetation cover in the road verge were selected in both road models. Traffic volume did not significantly improve the Catalonian road model, but it did contribute to the Swedish road model, whereas the relative level of the road to its surrounding was not included in the Swedish road model. Differences between the case studies in the inclusion of movement barriers (IMPEDIMENT and BARRIER) may be due to differences in interpreting these parameters in the Google Street View analyses.

The landscape models, on the other hand, not only performed very differently in the two study areas (Table 7), but they also included different variable combinations. The presence of garbage containers next to the road was the strongest factor in the Catalonian landscape model, followed by the proximity to water (Table 6). In Sweden, water was of lesser significance, whereas the presence of natural or human-made landscape structures that could lead animals towards the road was highly influential. Also, the proximity to forest cover with a high proportion of broadleaved trees in a preferably diverse landscape was a significant factor in Sweden.

Although the mixed models contained most of the factors already included in the road and landscape models, there were nevertheless a few differences. In Catalonia, traffic volume and the proportion of grassland land cover were introduced in the mixed model; in Sweden, the presence of bridges providing a potential passage to wildlife, the width of the median strip of the road and the presence of larger waterways were added in the mixed models, while they excluded the county game bag, verge characteristics and features impeding the movement of animals onto and from the road.

The expert model in the Swedish case study consisted only of the two subjectively assessed variables ACCESSIBILITY and ATTRACTIVITY. Interestingly, the expert model performed even better than the mixed model in the identifying clusters (88%, Table 7), but was much less effective in identifying non-clusters (46%).

Table 5. The selected best model variants in the Swedish case study with unstandardized estimates. For whole model results, see Table 7.

Swedish Case Study				
Road Model				
Variables	**Estimate**	**Std Error**	**Chi^2**	**p-value**
INTERCEPT	0.005	0.261	-	0.9858
FENCE [absent]	0.743	0.114	42.710	<.0001*
SPEED [<90]	-0.330	0.092	12.850	0.0003*
WARNINGSIGN [absent]	-0.708	0.208	11.550	0.0007*
IMPEDIMENT [absent]	-0.273	0.082	11.060	0.0009*
VERGE [absent]	0.227	0.075	9.230	0.0024*
SAFETYRAIL [absent]	-0.224	0.079	8.070	0.0045*
TRAFFIC	0.050	0.023	4.590	0.0321*
Landscape model				
Variables	**Estimate**	**Std Error**	**Chi^2**	**p-value**
INTERCEPT	-3.590	0.516	48.320	<.0001*
LEAD STRUCT [few]	-0.633	0.083	58.410	<.0001*
DIST_FOREST [near]	0.461	0.079	34.000	<.0001*
DIVERSITY	1.207	0.316	14.570	0.0001*
HUNTING	0.038	0.011	12.520	0.0004*
ROADS	0.083	0.026	9.890	0.0017*
DECIDUOUS	3.798	1.292	8.640	0.0033*
WATER	-2.876	0.998	8.300	0.0040*
Mixed model				
Variables	**Estimate**	**Std Error**	**Chi^2**	**p-value**
INTERCEPT	-4.675	0.665	49.410	<.0001*
LEAD STRUCT [few]	-0.598	0.090	44.120	<.0001*
FENCE [absent]	0.839	0.134	39.220	<.0001*
DIST_FOREST [near]	-0.459	0.086	28.440	<.0001*
WATER	-5.322	1.160	21.070	<.0001*
DIVERSITY	1.498	0.330	20.540	<.0001*
ROADS	0.126	0.030	17.570	<.0001*
TRAFFIC (1000 vehicles)	0.119	0.030	15.970	<.0001*
PASSAGE [absent]	0.597	0.173	11.950	0.0005*
DECIDUOUS	4.346	1.368	10.090	0.0015*
SAFETYRAIL [absent]	-0.305	0.097	9.840	0.0017*
RIVERS	-0.098	0.034	8.180	0.0042*
SPEED [<90]	-0.376	0.105	12.790	0.0003*
WARNINGSIGN [absent]	-0.687	0.240	8.160	0.0043*
MEDIAN [absent]	0.371	0.151	6.050	0.0139*

Table 6. The selected best model variants in the Catalonian case study with unstandardized estimates. For whole model results, see Table 7.

Catalonian Case Study ***Road Model*** **Variables**	**Estimate**	**Std Error**	**Chi^2**	**p-value**
INTERCEPT	0.375	0.298	1.580	0.2087
SAFETYRAIL [absent]	0.239	0.097	6.030	0.0141*
LEVEL [flat]	0.281	0.113	6.160	0.0131*
FENCE [absent]	0.309	0.110	7.850	0.0051*
BARRIER [absent]	0.364	0.118	9.490	0.0021*
WARNINGSIGN [absent]	-0.902	0.281	10.290	0.0013*
VERGE [absent]	-0.376	0.090	17.450	<.0001*
SPEED [≤ 90]	-0.471	0.098	23.280	<.0001*

Landscape model **Variables**	**Estimate**	**Std Error**	**Chi^2**	**p-value**
INTERCEPT	0.787	0.164	23.020	<.0001*
GARBAGE [absent]	-0.031	0.009	12.640	0.0004*
DIST_WATER	-0.001	0.000	12.200	0.0005*
URBAN	-0.225	0.095	5.690	0.0171*

Mixed model **Variables**	**Estimate**	**Std Error**	**Chi^2**	**p-value**
INTERCEPT	0.772	0.392	3.870	0.0491*
URBAN	-0.055	0.012	22.000	<.0001*
VERGE [absent]	-0.440	0.096	21.130	<.0001*
SPEED [≤ 90]	-0.425	0.109	15.240	<.0001*
WARNINGSIGN	-0.951	0.284	11.210	0.0008*
BARRIER [absent]	0.424	0.127	11.110	0.0009*
DIST_WATER	-0.001	0.000	10.790	0.0010*
FENCE [absent]	0.336	0.117	8.270	0.0040*
SAFETYRAIL [absent]	0.266	0.104	6.520	0.0106*
TRAFFIC (1000 vehicles)	0.032	0.014	6.280	0.0122*
PASTURE	0.081	0.035	5.430	0.0198*
GARBAGE [absent]	-0.209	0.104	4.080	0.0435*

Table 7. Whole model results and variable combinations of the selected models for the Catalonian and Swedish case study. All included variables are significant and ranked in decreasing order of their chi-square.

Case study: Catalonia **Model criteria**	**Road**	**Landscape**	**Mixed**
-LogLikelihood	41.63	17.09	63.88
DF	7	3	11
ChiSquare	83.27	34.18	127.77
Prob>ChiSq	<0.0001*	<0.0001*	<0.0001*
AUC for full model	0.707	0.635	0.751
lack of fit -LogLikelihood	374.25	398.80	352.00
lack of fit p-value	0.0032*	<0.0001*	<0.0001*
AICc	764.75	805.66	728.54
Misclassification Rate	0.342	0.403	0.323
Predictive power to correctly identify clusters	66%	59%	68%
Predictive power to correctly identify controls	34%	40%	33%
Included significant variables in the most parsimonious models, ranked in regressing order of their explanatory power.	SAFETYRAIL *LEVEL* FENCE BARRIER WARNINGSIGN VERGE SPEED	GARBAGE DIST_WATER URBAN	URBAN VERGE SPEED WARNINGSIGN BARRIER DIST_WATER FENCE SAFETYRAIL TRAFFIC *PASTURE* GARBAGE LEVEL

Case study: Sweden **Model criteria**	**Road**	**Landscape**	**Mixed**	**Expert**
-LogLikelihood	54.63	115.94	164.69	78.46
DF	7	7	15	1
ChiSquare	109.27	231.87	329.37	156.92
Prob>ChiSq	<0.0001*	<0.0001*	<0.0001*	<0.0001*
AUC for full model	0.702	0.774	0.824	0.679
lack of fit -LogLikelihood	570.16	508.86	460.11	546.33
lack of fit p-value	<0.0001*	0.0023*	0.2065	0.237
AICc	1156.47	1033.87	950.76	1098.69
Misclassification Rate	0.371	0.287	0.251	0.32
Predictive power to correctly identify clusters	73%	77%	79%	88%
Predictive power to correctly identify controls	52%	65%	70%	46%
Included significant variables in the most parsimonious models, ranked in regressing order of their explanatory power.	TRAFFIC SPEED WARNINGSIGN FENCE *VERGE* IMPEDIMENT SAFETYRAIL	LEADSTRUCT DIST_FOREST DIVERSITY HUNTING ROADS DECIDUOUS WATER	LEAD STRUCT FENCE DIST_FOREST WATER DIVERSITY ROADS TRAFFIC PASSAGE DECIDUOUS SAFETYRAIL RIVERS SPEED WARNINGSIGN MEDIAN	ACCESSIBILITY ATTRACTIVITY

3 Case study on mitigating effects of roadside vegetation clearing on ungulate-vehicle collisions

3.1 Introduction

The number of ungulate-vehicle collisions has increased substantially in Norway over the last four decades. For example, the number of moose killed in traffic (cars and trains) increased from about 200 to 2100 between 1970 and 2007, while the number of traffic kills of roe deer increased from 200 to 4000 (Solberg et al., 2009). This is a serious animal welfare issue and is also a concern with regard to human injuries, fatalities and economic losses: In Norway, 2-5 humans are killed annually as a result of UVC and the societal costs are estimated to be about 900 million kroner per year (Vegdirektoratet et al., 2014).

To decrease the socioeconomic costs related to UVC, several mitigation actions have been implemented, one of which is vegetation control along roads (Andreassen et al., 2005; Huijser et al., 2009; Sivertsen, 2010). Vegetation control usually involves removing trees, shrubs and other vegetation in a distance of 6-25 meters from the roadside (Iuell, 2005), assuming that this will prevent ungulates from residing in cleared areas and crossing the road. Clearing the roadside may help motorists to detect crossing ungulates and thus may provide them with more time to react and avoid collisions. Emerging new vegetation (after vegetation clearing) can, however, also attract ungulates to roadsides (Child et al., 1991; Waring et al., 1991) so cleared areas should be regularly maintained to have a preventive effect (Iuell, 2005).

By analysing moose and roe deer collision data from central Norway in 2009 – 2015, we evaluated the accident-preventive effects of roadside vegetation clearing conducted in 2011 and 2012. We expected the probability of UVC to be substantially higher on cleared than on uncleared road stretches since vegetation clearing was most likely to be conducted where the collision rate was initially high. Moreover, we expected a decrease in collision probability in the year after vegetation clearing, possibly followed by a slow increase in the subsequent years as the vegetation re-emerged.

3.2 Methods

The study was conducted in the county of Nord-Trøndelag (Figure 4), with a total area of 22,412 km^2 and a public road network of about 5,700 km. During the last ten years, about 150-300 moose were killed in traffic each year in this county, about 50 % of which were killed on roads (Rolandsen, 2010; Statisitics Norway, 2015). For roe deer, the corresponding numbers were about 200-400 annually, and almost all such collisions happened on roads (Statisitics Norway, 2015).

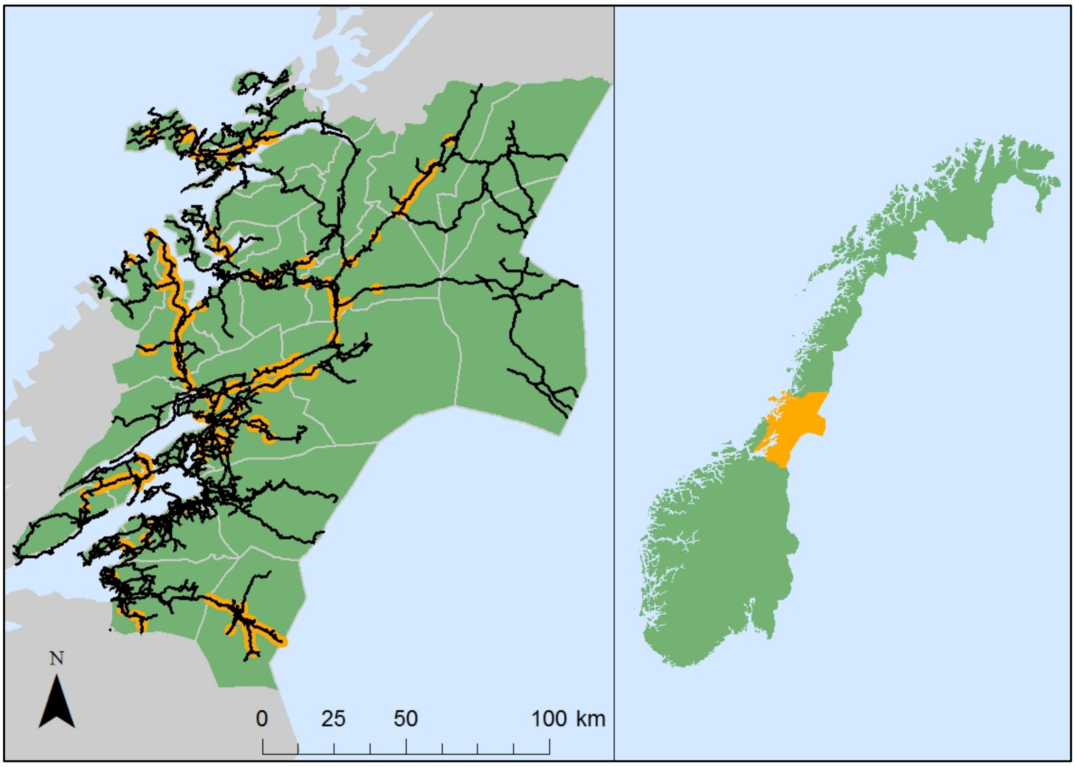

Figure 4. The study area, Nord-Trøndelag County. The black lines show the public road network, and the orange markings on the map to the left show road stretches where roadside vegetation clearing was conducted in 2011 and 2012.

In the study period 2009-2015 (to September only), we used data from 3,253 UVCs (1,267 moose and 1,986 roe deer) that were reported by wildlife officials from the study area to the National Cervid Register (www.hjorteviltregisteret.no). Vegetation clearing data were obtained from the County Council of Nord-Trøndelag (www.gint.no), the organization to which the municipalities receiving mitigation funding report such information. The municipalities report where and when vegetation clearing has been conducted but are not obliged to report the width of the clearing zone. During the study period (2009-2015), all vegetation clearings were conducted in 2011 and 2012, but to avoid including previously cleared stretches in the sample, we also collected data on stretches cleared in the period 2003-2009. We used the AR5 land cover map in vector format (http://www.skogoglandskap.no) to calculate the distance to forested areas.

To be able to link UVC data to road and land cover data, we first associated collision points with the nearest road. We then created a set of 100,000 random points along the road network and calculated the distance from collision points and random points to the nearest forest. Similarly, we calculated the distance to nearest cleared stretch for both collision and random points. As we were primarily interested in the effects of vegetation clearing in forested areas, we only used points that were located in a forest, defined as within 5 m from a forest map polygon.

We used generalized linear mixed-effects models (GLMM) with collision (0 = random point, 1 = collision point) as the binary response variable to model the probability of UVC on cleared and uncleared road stretches. Years since last clearing and collision year were included as main effects, while municipality ID was included as a random factor to account for the inter-correlations among observations within municipalities.

3.3 Results

For both species, the probability of collision was substantially higher in cleared than in uncleared areas, indicating that the management had targeted high-risk areas for vegetation clearing – as expected. However, we found no relative decline in the number of deer and moose collisions following vegetation clearing. Potential explanations are that the clearing zone is too narrow to deter moose and deer from crossing or that that they were partly attracted to the clearing zone to feed on logging waste. This may happen along stretches where clearing involved removing regrowth of deciduous tree species such as birch and willow. We find this explanation less likely in areas where more mature forest is logged because forests in Nord-Trøndelag consist mainly of Norway spruce, which are not among the preferred browsing species for moose and deer. More likely, we believe the clearing zone is too narrow (6-20 meters), particularly as most crossings occur in darkness during winter.

Extending the clearing zone could therefore increase the preventive effect because this may discourage more moose and deer from crossing the road as well as improve the probability of detecting and avoiding them if they cross. Indeed, several studies where the clearing zone is wide (20-30 meters) record a positive effect of vegetation clearing (e.g., Jaren et al., 1991; Lavsund and Sandegren, 1991), and as most UVCs seem to happen close to forests (Meisingset et al., 2014; Rolandsen et al., 2015a), it is likely that vegetation clearing will eventually work as long as the clearing zone is wide enough. Accordingly, Seiler (2005) found that the probability of UVC decreased by 15 % at 100 meters from a forest. However, clearing zones of 100 meters would not be an acceptable option in most forest areas due to high maintenance costs and the loss of large areas for forestry and wildlife. We did not have information about the width of each clearing zone, but in in Norway in general, the clearing zones are seldom wider than 6-20 meters. It is questionable whether this is sufficient to deter moose from crossing the road, although a recent study of red deer found a 53 % reduction in collisions after clearing all vegetation up to 8 m from the road shoulder (Meisingset et al., 2014).

In this study, we found no accident-reducing effect of vegetation clearing despite the relatively high number of UVCs recorded and large stretches of roadsides being cleared. Part of the reason for a lack of effect could be inappropriate vegetation clearing or too narrow a clearing zone to deter moose and deer from crossing. To improve our ability to validate the effectiveness of future measures, we suggest that these measures be implemented as experiments in which most of the confounding variables can be controlled as part of the design. To facilitate such a process, researchers should also be included in the planning, implementation and data collection phases, not only during the final phase of effect assessment.

4 Discussion

Our results suggest that UVC clustering on roads is clearly prompted by a combination of both landscape and road-related features. Road features can be directly addressed and adjusted through mitigation efforts made by road administrations. Landscape features are, of course, less easily adjusted, and any change requires cooperating with landowners, municipalities and other stakeholders. Nevertheless, to effectively address UVC at large, this collaboration is needed (Putman, 1997; Apollonio et al., 2010; Niemi, 2016).

We found that UVC clusters were more likely to occur on busier roads with higher vehicle speed but without fences, barriers, safety rails or large embankments that might hinder wildlife from entering the road. UVC clustered where road verges provided either high vegetation for shelter (Catalonia) or attractive forage (grassy verges in Sweden) and where landscape structures directed animal movements towards the roads. These results concur well with earlier studies in UVC (Clevenger et al., 2003; Malo et al., 2004; Seiler, 2005; Langbein et al., 2010; Ascensão et al., 2013; Barthelmess, 2014), suggesting that a generally open and attractive road corridor is more prone to UVC than a road environment that is closed (fenced) and/or unattractive or even repulsive to ungulates. This was also supported by the “expert model” that was based on only two subjective assessments of the attractiveness and accessibility of the road for ungulates (Table 7). While these findings provide no ground-breaking news, they still convey important information.

The road models from both study areas were rather similar in their composition, but not only did the landscape models perform very differently but they also included different variable combinations. This may be linked to differences in topography, land use, vegetation cover and climate between Sweden and Catalonia and it may reflect differences in UVC species’ composition. In Sweden, UVC were dominated by roe deer, followed by moose and wild boar, while UVC in Catalonia consisted mainly of wild boar with fewer roe deer collisions.

In the Catalonian mixed model, the amount of urban habitat in the surroundings of the road section and the proximity to water were the strongest landscape predictors for UVC clusters, followed by the amount of grassland and pastures and the presence of garbage containers placed next to the road. Urban and peri-urban habitats and garbage containers may provide an attractive food source for wild boar (Cahill et al., 2012; Colino-Rabanal et al., 2012) and may thus either increase wild boar abundance in the surrounding landscape or attract animals to the road corridor itself. Roe deer or fallow deer may not be attracted to garbage containers, but instead forage on grass, shrubs and other herbaceous vegetation (Virgos and Telleria, 1998; Mysterud et al., 1999; Madsen et al., 2002; Nyenhuis, 2002). Small-scaled landscapes containing a mixture of cropland, grassland and forests provide a suitable habitat for roe deer and wild boar, whereas moose is more abundant in landscapes dominated by coniferous forests (Cederlund, 1989). Thus, the significance of landscape diversity on UVC clusters in the Swedish model (Table 7) also reflects habitat preferences in the predominant species, i.e., roe deer.

One of the most influential factors in the Swedish study, however, was the presence of linear landscape elements that may direct animal movements towards the road. Clearly, where waterways, topographic features, hedgerows, paths, railways and minor local roads intersect with a major road, wildlife following these structures may be led onto the road and exposed to traffic. In diverse and open landscapes, these linear structures may be prominent features funnelling animal movements and shaping the occurrence of UVC (Finder et al., 1999; Hubbard et al., 2000; Seiler, 2005; Seiler et al., 2011), whereas these structure may be much less visible and potent in a homogeneous, forest-dominated landscape where animal movements may be more diffuse and UVC thus more random. Therefore, one may expect stronger and more stable UVC cluster in landscapes with a clear structure in topography and vegetation / land cover.

Verge management, i.e., structure and vegetation cover in road verges, was of significance to the clustering of UVC, especially in the Catalonian case study. Verges that attract ungulates by providing forage or that reduce motorists' ability to detect hidden animals have demonstrated the effects of vegetation on UVC on both roads and railroads (Jaren et al., 1991; Rea, 2003; Found and Boyce, 2011). Lavsund and Sandegren (1989) observed that vegetation control in forests adjacent to roads (20-30m) resulted in a 20 % decrease in moose-vehicle accidents in Sweden, while Jaren et al. (1991) reported a 50 % reduction in moose-train collisions on railways where vegetation was cleared up to about 30 m from the railway. Similarly, Rolandsen et al. (2015a) found some support for a decrease in moose-train accidents in the years following vegetation clearing, but the results were associated with a high level of uncertainty. In contrast, Eriksson (2014) found no effect of tree removal along railways in Sweden, and Sivertsen (2010) reported both a decrease and an increase in UVC after roadside clearing in different parts of Norway. In our Norwegian case study, we found that vegetation clearing in road verges (6-20m from the road surface) had no effect on UVC.

These mixed results suggest the interplay of several opposing factors:

A) Habitat: the likelihood of UVC is generally higher where forest cover is adjacent to roads (or railroads) because ungulates may use forests for shelter and forage (Seiler, 2005; Meisingset et al., 2014; Rolandsen et al., 2015a).
B) Food: if vegetation control is not done frequently and intensively enough to prevent the regrowth of highly palatable, early successional species, this forage will attract ungulates and consequently increase the risk of accidents (Jaren et al., 1991; Putman, 1997; Rea et al., 2010).
C) Visibility: it is argued that the removal of undergrowth and low branches of trees in the immediate proximity to roads may provide better visibility and allow drivers to detect animals in time (Johansson, 1987; Lavsund and Sandegren, 1991). However, since most UVC occur during dusk/dawn and at night, when light conditions limit the drivers' ability to detect wildlife near roads, there may be little to gain from vegetation removal anyway.
D) Shelter: Higher vegetation (shrubs, trees) may not only provide forage but also shelter to ungulates and allow them to get closer to the road than if they were entirely exposed. Cleared roadsides and adjacent areas may appear unattractive to these animals and thus have a certain repellent effect. However, if the cleared corridor is narrow (only road verges), this effect may not suffice to reduce accident risks (Sivertsen, 2010).

Whether road clearance and verge management have some effect even along fenced roads is uncertain. Most likely, verges and roadsides can be allowed to contain higher vegetation if effectively fenced against larger wildlife, but observations from northern Sweden (Seiler et al., 2003) suggest that at least moose may eventually breach fences in order to gain access to attractive forage growing within the road corridor.

Surprisingly, verge vegetation appeared to have opposite effects on UVC in Catalonia and in Sweden. While UVC clusters were, as expected, correlated with dense and high vegetation providing cover in the Catalonian study, the Swedish data indicated that clusters occurred more often where road verges were open and grassy. This may be confounded by a dependency between road verge characteristics and type of road since busier and larger roads usually have wider and open road verges. Along motorways, verges are especially wide and open to prevent fatal accidents when drivers lose control of the vehicle and leave the roadway. In Catalonia, road verges are typically smaller and less open than in Sweden.

Clustering of UVC is clearly not due to one individual factor or reason but to a complex interplay of local and larger-scaled factors. Our models successfully distinguished UVC clusters from random UVC locations. However, with an overall misclassification rate of 25% in the Swedish case and 32% in the Catalonian study, it is evident that we were not able to include all relevant factors in the models and that other confounding factors may not have been sufficiently considered. One source of error may derive from differences in the stability of UVC clusters over time. Clusters that recur year after year may differ in their environmental and road-related characteristics from clusters that only appear once during a short time. As longer time series in UVC become available, this question will likely receive further attention.

Also, the UVC data we used was comprised of different proportions of multiple species in the two study areas. The Catalonian data mainly contained wild boar accidents with only a few roe deer incidents, while the dominant species in the Swedish UVC was roe deer.
As the different species behave differently, have different life histories and show different habitat preferences, it is very likely that model performances could be improved if the analyses were made species-specific. Thus, clusters in e.g., moose accidents are likely to differ from clusters in roe deer accidents simply because moose and roe deer prefer different habitats (Cederlund and Okarma, 1988; Cederlund, 1989; Guillet et al., 1996). However, even if the inclusion of species in our models reduces the remaining error in the prediction models, the overall pattern is likely to remain unaltered. Moreover, from a road management perspective, it may make little difference which deer species is involved in UVC since the options for mitigation measures (mostly fencing) are not species-dependent.

In general, the factors that are typically associated with UVC locations (Finder et al., 1999; Hubbard et al., 2000; Malo et al., 2004; Seiler, 2005; Gunson et al., 2011; Rodríguez-Morales et al., 2013) are also prevalent in UVC clusters; however their combinations create particular conditions that make UVC especially frequent.

Local, road-related factors appear as important as the wider context of the landscape for the clustering of UVC. We conclude that verge management is indeed significant in reducing the attractiveness of road corridors to wildlife, but the overall effect on traffic safety is not yet entirely conclusive. Vegetation control in verges and adjacent habitats should be considered as one part of a mitigation package that also contains measures to minimize the animals' access to roads or to funnel animals towards safer crossing locations. Here, the function of verge vegetation as leading structures (and not forage) deserves further research.

5 Conclusions

- A significant number of UVC occur in clusters at specific road sections. The remaining UVC are rather randomly distributed across the road network.
- Up to 75% of the studied UVC clusters can be predicted from a combination of landscape and local road features.
- Local, road-related factors may be as important for the clustering of UVC as surrounding landscape factors.
- Overall, factors related to the attractiveness and the accessibility of the road to wildlife play a major role in the clustering of UVC.
- Verge management can be of significance but is only one of many significant factors and appears not to be the most important factor.
- Exclusion fences (including crossing structures), safety barriers and local speed reductions are the most relevant traffic and road-related factors that can be directly addressed by road administrations.
- Another mitigation approach that deserves further evaluation is the presence and direction of landscape features that may funnel animal movements. If such linear landscape elements can be oriented parallel to the road rather than perpendicular to it, animals might be diverted from the road in the first place.
- To improve our ability to validate the effectiveness of (new) mitigation options, we recommend conducting controlled experiments as part of the standard implementation of mitigation measures.
- Predicting the risk of UVC clusters is essential for mitigation planning. Model improvements may be possible if cluster calculations are made species-specific and stable clusters are distinguished from short-term, potentially unstable clusters.

6 Acknowledgements

The research presented in this report was carried out as part of the CEDR Transnational Road Research Programme Call 2013. The funding for the research was provided by the national road administrations of Austria, Denmark, Germany, Ireland, Norway, Sweden, Netherlands and UK.

We are grateful to the assistance and support from Michael Bil, Richard Andrasik and Jiri Sedonik in identifying UVC clusters with the KDE+ method they developed.

We also thank the Swedish National Council for Wildlife Accidents and the Directorate General of Land Transport Infrastructure of the Catalan Government for data on ungulate-vehicle collisions.

The studies were carried out in relation to three Master's theses in Ecology: Marina Torellas at the Autonomous University of Barcelona (Torrellas, 2015), Magnus Sjölund at the Swedish University of Agricultural Sciences (Sjölund, 2016) and Ingrid Lindstrøm at the Norwegian University of Science and Technology in Trondheim (Lindstrøm, 2016). We are grateful to Ferran Rodà, Marc Fernàndez and Roberto Molowny for their supervision of and assistance with Marina Torrellas' thesis and to Johan Månsson and Linda Höglund for their contribution to and help with Magnus Sjölund's thesis.

7 References

Acevedo, P., Escudero, M.A., Munoz, R. & Gortazar, C., 2006. Factors affecting wild boar abundance across an environmental gradient in Spain. *Acta Theriologica,* 51**,** 327-336.

Andreassen, H.P., Gundersen, H. & Storaas, T., 2005. The effect of scent-marking, forest clearing, and supplemental feeding on moose-train collisions. *Journal of Wildlife Management,* 69**,** 1125-1132.

Apollonio, M., Andersen, R. & Putmam, R.J., 2010. Present status and future challenges for European ungulate management. *In:* Apollonio, M., Andersen, R. & Putmam, R. J. (eds.) *European ungulates and their management in the 21st century.*: Cambridge University Press.

Ascensão, F., Clevenger, A., Santos-Reis, M., Urbano, P. & Jackson, N., 2013. Wildlife-vehicle collision mitigation: Is partial fencing the answer? An agent-based model approach. *Ecological Modelling,* 257**,** 36-43.

Barthelmess, E.L., 2014. Spatial distribution of road-kills and factors influencing road mortality for mammals in Northern New York State. *Biodiversity and Conservation,* 23**,** 2491-2514.

Beckmann, J.P., Clevenger, A.P., Huijser, M.P. & Hilty, J.a.E., 2010. *Safe Passages: Highways, Wildlife, and Habitat Connectivity,* Washington, US, Island Press.

Bíl, M., Andrášik, 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.

Bíl, M., Andrášik, R., Svoboda, T. & Sedoník, J., 2016. The KDE+ software: a tool for effective identification and ranking of animal-vehicle collision hotspots along networks. *Landscape Ecology,* 31**,** 231-237.

Bruinderink, G.G. & Hazebroek, E., 1996. Ungulate traffic collisions in Europe. *Conservation Biology,* 10**,** 1059-1067.

Burnham, K.P. & Anderson, D.R., 2002. *Model selection and multimodal inference: a practical information-theoretic approach,* New York, Springer Verlag.

Cahill, S., Llimona, F., Cabañeros, L. & Calomardo, F., 2012. Characteristics of wild boar (Sus scrofa) habituation to urban areas in the collserola natural park (Barcelona) and comparison with other locations. *Animal Biodiversity and Conservation,* 35**,** 221-233.

Camps, F., Rosell, C., Boronat, C., Fernández-Bou, M., Martínez, M., Navàs, F. & Serra, V., 2012. Estudi d'accidentalitat provocada per animals en llibertat a la xarca de carreteres de la Generalitat de Catalunya. - Unpublished report. Departament de Territori i Sostenibilitat. DG Roads, Catalan Government, Barcelona.

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

Cederlund, G. & Okarma, H., 1988. Home range and habitat use of adult female moose. *Journal of Wildlife Management,* 52**,** 336-343.

Child, K.N., Barry, S.P. & Aitken, D.A., 1991. Moose mortality on highways and railways in British Columbia. *Alces,* 27**,** 41-49.

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

Clevenger, A.P., Chruszczc, B. & Gunson, K.E., 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. *Biological Conservation,* 109**,** 15-26.

Colino-Rabanal, V.J., Bosch, J., Munoz, M.J. & Peris, S.J., 2012. Infuence of new irrigated croplands on wild boar (Sus scrofa) road kills in NW Spain. *Animal Biodiversity and Conservation,* 35**,** 247-252.

Elmeros, M., Andersen, P.N., Sunde, P., Haugaard, L., Skov, F. & Madsen, A.B., 2014. *Påkørte større vilde dyr i Danmark 2003-2012,* Aarhus, DK, Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi. Videnskabelig rapport nr. 91. http://dce2.au.dk/pub/SR91.pdf

Elvik, R., Høye, A., Vaa, T. & Sørensen, M., 2009. *Handbook of Road Safety Measures,* Bingley, UK, Emerald Group Publishing Limited.

Eriksson, C., 2014. *Does tree removal along railroads in Sweden influence the risk of train accidents with moose and roe deer?* Master thesis, Swedish University of Agricultural Sciences, SLU.

Finder, R.A., Roseberry, J.L. & Woolf, A., 1999. Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois. *Landscape and Urban Planning,* 44**,** 77-85.

Found, R. & Boyce, M.S., 2011. Predicting deer-vehicle collisions in an urban area. *Journal of Environmental Management,* 92**,** 2486-2493.

Guillet, C., Bergström, R. & Cederlund, G., 1996. Size of winter home range of roe deer Capreolus capreolus in two forest areas with artificial feeding in Sweden. *Wildlife Biology,* 2**,** 107-111.

Gunson, K. & Teixeira, F.Z., 2015. Road–Wildlife Mitigation Planning can be Improved by Identifying the Patterns and Processes Associated with Wildlife-Vehicle Collisions. *Handbook of Road Ecology.* John Wiley & Sons, Ltd.

Gunson, K.E., Mountrakis, G. & Quackenbush, L.J., 2011. Spatial wildlife-vehicle collision models: A review of current work and its application to transportation mitigation projects. *Journal of Environmental Management,* 92**,** 1074-1082.

Hosmer, D.W. & Lemeshow, S., 1989. *Applied logistic regression,* New York, John Wiley & Sons.

Hubbard, M.W., Danielson, B.J. & Schmitz, R.A., 2000. Factors influencing the location of deer-vehicle accidents in Iowa. *Journal of Wildlife Management,* 64**,** 707-713.

Huijser, M.P., 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**,** 15.

Huijser, M.P., Mosler-Berger, C., Olsson, M. & Strein, M., 2015. Wildlife Warning Signs and Animal Detection Systems Aimed at Reducing Wildlife-Vehicle Collisions. *Handbook of Road Ecology.* John Wiley & Sons, Ltd.

Ingemarson, F., Claesson, S. & Thuresson, T., 2007. *Costs and values of moose and roe deer populations in Sweden. (In Swedish: Älg- och rådjursstammarnas kostnader och värden)*, National Board of Forestry (Skogsstyrelsen), Rapport 3 - 2007.

Iuell, B., 2005. Veger og dyreliv. Statens vegvesen. Håndbok V134.

Jaarsma, C., Van Langevelde, F., Baveco, J., Van Eupen, M. & Arisz, J., 2007. Model for rural transportation planning considering simulating mobility and traffic kills in the badger Meles meles. *Ecological Informatics,* 2**,** 73-82.

Jacobson, S., Bliss-Ketchum, L., De Rivera, C. & Smith, W.P., 2016. A behavior based framework for assessing barrier effects to wildlife from vehicle traffic volume. *Ecosphere,* 7**,** article e01345.

Jaren, V., Andersen, R., Ulleberg, M., Pedersen, P.H. & Wiseth, B., 1991. Moose-train collisions: the effects of vegetation removal with a cost-benefit analysis. *Alces,* 27**,** 93-99.

Johansson, Ö., 1987. *Vegetation clearence as mitigation againast wildlife-vehicle accidents. (In Swedish: Sikttröjning som viltolycksminskande åtgärd),* Borlänge, Swedish Road Administration, Vägverket Rapport 1987:14.

Langbein, J., Putman, R. & Pokorny, B., 2010. Traffic collisions involving deer and other ungulates in Europe and available measures for mitigation. *In:* Putman, R., Apollonio, M. & Andersen, R. (eds.) *Ungulate management in Europe: problems and practices 2010.*

Lavsund, S. & Sandegren, F., 1989. Swedish Moose management and harvest during the period 1964-1989. *Alces,* 25**,** 58-62.

Lavsund, S. & Sandegren, F., 1991. Moose-vehicle relations in Sweden. *Alces,* 27**,** 118-126.

Lindstrøm, I.M., 2016. No mitigating effects of roadside vegetation clearing on ungulate-vehicle collisions in Nord-Trøndelag. MSc-thesis at the Norwegian University of Science and Technology, NTNU, Dept. of biology, supervised by Thor H. Ringsby, with E.Solberg, C. Rolandsen and B. van Moorter (NINA)

Litvaitis, J.A. & Tash, J.P., 2008. An approach toward understanding wildlife-vehicle collisions. *Environ Manage,* 42**,** 688-97. http://www.ncbi.nlm.nih.gov/pubmed/18427884

Madsen, A.B., Strandgaard, H. & Prang, A., 2002. Factors causing traffic killings of roe deer Capreolus capreolus in Denmark. *Wildlife Biology,* 8**,** 55-61.

Malo, J.E., Suarez, F. & Diez, A., 2004. Can we mitigate animal-vehicle accidents using predictive models? *Journal of Applied Ecology,* 41**,** 701-710.

Massei, G., Kindberg, J., Licoppe, A., Gacic, D., Sprem, N., Kamler, J., Baubet, E., Hohmann, U., Monaco, A., Ozolins, J., Cellina, S., Podgorski, T., Fonseca, C., Markov, N., Pokorny, B., Rosell, C. & Nahlik, A., 2015. Wild boar populations up, numbers of hunters down? A review of trends and implications for Europe. *Pest Manag Sci,* 71**,** 492-500. http://www.ncbi.nlm.nih.gov/pubmed/25512181

Mateos-Quesada, P., 2011. Corzo – Capreolus capreolus. *In: Enciclopedia Virtual de los Vertebrados Españoles. Salvador, A., Cassinello, J. (Eds.). Museo Nacional de Ciencias Naturales, Madrid.* http://www.vertebradosibericos.org/.

Meisingset, E.L., Loe, L.E., Brekkum, O. & Mysterud, A., 2014. Targeting Mitigation Efforts: The Role of Speed Limit and Road Edge Clearance for Deer-Vehicle Collisions. *Journal of Wildlife Management,* 78**,** 679-688.

Mysterud, A., Larsen, P.K., Ims, R.A. & Ostbye, E., 1999. Habitat selection by roe deer and sheep: does habitat ranking reflect resource availability? *Canadian Journal of Zoology,* 77**,** 776-783.

Niemi, M., 2016. *Animal-vehicle collisions - from knowledge to mitigation.* PhD, University of Helsinki, Faculty of Agriculture and Forestry, Department of Forest Sciences. http://hdl.handle.net/10138/160439

Nyenhuis, H., 2002. Road traffic mortality of roe deer (Capreolus capreolus L.) associated with landscpae, weather and behaviour. *Tierarztliche Umschau,* 57**,** 683-687.

Putman, R.J., 1997. Deer and road traffic accidents: Options for management. *Journal of Environmental Management,* 51**,** 43-57.

Putman, R.J., Langbein, J. & Staines, B.W., 2004. *Deer and road traffic accidents: A review of mitigation measures: costs and cost-effectiveness*. http://www.snh.org.uk/pdfs/publications/dcs/mitigation measures.pdf

Rea, R., Child, K., Spata, D. & Macdonald, D., 2010. Road and Rail Side Vegetation Management Implications of Habitat Use by Moose Relative to Brush Cutting Season. 46**,** 101-109. http://www.springerlink.com/index/P1732T3826572623.pdf

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

Rodríguez-Morales, B., Díaz-Varela, E.R. & Marey-Pérez, M.F., 2013. Spatiotemporal analysis of vehicle collisions involving wild boar and roe deer in NW Spain. *Accident Analysis & Prevention,* 60**,** 121-133. http://www.sciencedirect.com/science/article/pii/S000145751300300X

Rolandsen, C.M., Solberg, E.J., Van Moorter, B. & Strand, O., 2015a. Dyrepåkjørsler på jernbanen i Norge 1991–2014. *NINA Rapport 1145***,** 111.

Rolandsen, C.M., Solberg, E.J., Vanmoorter, B. & Strand, O., 2015b. *Dyrepåkjørsler på jernbanen i Norge 1991– 2014,* Trondheim, NINA Rapport 1145.

Rolandsen, C.M., Solberg, E.J., Bjørneraas, K., Heim, M., Van Moorter, B., Herfindal, I., Garel, M., Pedersen, P.H., Sæther. B.-E., Lykkja, O.N., Os, Ø., 2010. Elgundersøkelse i Nord-Trøndelag, Bindal og Rissa 2005-2010 - NINA Rapport 588. 142.

Rosell, C., Fernández-Bou, M., Camps, F., Boronat, C., Navàs, F., Martínez, M. & Sorolla, A., 2013. Animal Vehicle Collisions: A new cooperative strategy is needed to reduce the conflict. *Proceedings ICOET 2013 International Conference on Ecology and Transportation. Scottsdale, Arizona, USA.*

Rosell, C., Fernandez- Llario, P. & Herrero, J., 2001. El Jabalí - Sus scrofa. *Galemys,* 13**,** 1-25.

Sáenz-De-Santa-María, A. & Tellería, J.L., 2015. Wildlife-vehicle collisions in Spain. *European Journal of Wildlife Research,* 61**,** 399-406.

Seiler, A., 2003. *The toll of the automobile - Wildlife and roads in Sweden.* PhD, SLU.

Seiler, A., 2004. Trends and spatial patterns in ungulate-vehicle collisions 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., Cederlund, G., Jernelid, H., Grängstedt, P. & Ringaby, E., 2003. The barrier effect of highway E4 on migratory moose (Alces alces) in the High Coast area, Sweden. *In:* Turcott, E. (ed.) *IENE 2003 International Conference on "Habitat fragmentation due to transport infrastructure".* Brussels: Infra Eco Network Europe (IENE).

Seiler, A. & Helldin, J.O., 2006. Mortality in wildlife due to transportation. *In:* Davenport, J. & Davenport, J. L. (eds.) *The ecology of transportation: managing mobility for the environment.* Amsterdam: Kluwer.

Seiler, A., Olsson, M. & Helldin, J.O., 2011. *Klövviltolyckor på järnväg - kunskapsläge, problemanalys och åtgärdsförslag.,* Borlänge, Trafikverket Publikation 2011:058.

Sivertsen, T.R., Gundersen, H., Rolandsen, C.M., Andreassen, H.P., Hanssen, F., Hanssen, H.G. & Lykkja, O., 2010. *Evaluering av tiltak for å reducere elgpåkjörsler på veg*, Høgskolen i Hedmark, Oppdragsrapport nr.1 - 2010.

Sivertsen, T.R., Gundersen, H., Rolandsen, C.M., Andreassen, H.P., Hanssen, F., Hanssen, M.G., Lykkja, O., 2010. Evaluering av tiltak for å redusere elgpåkjørsler på veg.

Sjölund, M., 2016. *Landscape and road variables describing clusters of ungulate vehicle collisions in south-central Sweden.* MSC-thesis, supervised by Andreas Seiler, Swedish University of Agricultural Sciences, SLU.

Skölving, H., Bernard, J.M., Lansiart, M., Kempf, C. & Tille, M., 1987. Traffic accidents with moose and roe-deer in Sweden. Report of research, development and measures. *Actes du colloques "Route et fauna sauvage". Strasbourg, 1985.* Colmar, France: Ministère de l'Équipement, du Longement, de l'Aménagement du Territoire et des Transports.

Solberg, E.J., Rolandsen, C.M., Herfindal, I. & Heim, M., 2009. Hjortevilt og trafikk i Norge. *NINA Rapport 463. Norsk institutt for naturforskning (NINA), Trondheim.*, 84 pp.

Statisitics Norway. 2015. *Avgang av hjortevilt utenom ordinær jakt, 2014/2014* [Online]. ssb.no. Available: http://ssb.no/jord-skog-jakt-og-fiskeri/statistikker/hjortavg [Accessed 09.05 2016].

Sullivan, J.M., 2011. Trends and characteristics of animal-vehicle collisions in the United States. *Journal of Safety Research,* 42, 9-16. http://www.sciencedirect.com/science/article/pii/S0022437510001234

Tanner, A.L. & Leroux, S.J., 2015. Effect of Roadside Vegetation Cutting on Moose Browsing. *PLoS One,* 10, e0133155. http://www.ncbi.nlm.nih.gov/pubmed/26244576

Torellas, M., 2015. *Ungulate-vehicle collisions in Catalonia: Identifying the main landscape and road-related variables describing the most hazardous road locations.* MSc-thesis, supervised by Carme Rosell (Minuartia) & Ferran Rodà (CREAF). Univeristat Autònoma de Barcelona.

Van Langevelde, F. & Jaarsma, C.F., 2009. Modeling the Effect of Traffic Calming on Local Animal Population Persistence. 14, 39. http://www.ecologyandsociety.org/vol14/iss2/art39/

Van Langevelde, F., Van Dooremalen, C. & Jaarsma, C., 2008. Traffic mortality and the role of minor roads. *Journal of Environmental Management,* 90, 660-667.

Vegdirektoratet, Helsedirektoratet, Politidirektoratet, Utdanningsdirektoratet & Tryggtrafikk 2014. Nasjonal tiltaksplan for trafikksikkerhet på veg, 2014-2017.

Virgos, E. & Telleria, J.L., 1998. Roe deer habitat selection in Spain: constraints on the distribution of a species. *Canadian Journal of Zoology,* 76, 1294-1299. ISI:000078084600011

Waring, G.H., Griffis, J.L. & Vaughn, M.E., 1991. White-Tailed Deer Roadside Behavior, Wildlife Warning Reflectors, and Highway Mortality. *Applied Animal Behaviour Science,* 29, 215-223. ISI:A1991FE75500016

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