Title

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What Features of the Landscape and Highway Influence Ungulate Vehicle Collisions in the Watersheds of the Central Canadian Rocky Mountains: A Fine-Scale Perspective?

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Abstract: Wildlife-vehicle collisions represent an additive source of mortality to wildlife populations, in addition to other mortality, such as predation and disease. The trends of increasing traffic volumes and road densities will only magnify the mortality impacts of roads on large mammals and other vertebrates. In this study, we examined the descriptive and spatial aspects of ungulate-vehicle collisions (UVCs) in the Central Canadian Rocky Mountains (CCRMs). We then specifically addressed the landscape and highway characteristics associated with the UVCs in four major watersheds: the Bow Valley, Kananaskis Valley, Kicking Horse Valley, and Kootenay Valley, each with differing road-types, topography, and habitat. We grouped the factors associated with vehicle collisions into three groups: combined, landscape-animal, and highway-vehicular-animal. The combined model included all variables, the landscape-animal model included factors that influence whether an animal makes it to the roadway, and the road-vehicular model included factors that influence the probability of an interaction between the animal and the vehicle. Between 1999 and 2003 all kill sites were initially measured with a Global Positioning System (GPS) (accuracy <3 m) and later revisited to measure all field measurements. Many other studies have looked at the factors associated with wildlife vehicle collisions; however, our study is unique in that we were able to revisit exact collision sites (accuracy <10 m). There were a total of 546 ungulate mortalities on all highways in the watershed with the majority occurring in the Bow Valley followed by the Kicking Horse Valley, and Kananaskis Valley, and the least occurring in Kootenay Valley. The distribution of kills was correlated with the traffic volumes on each road-type. Further, UVC distributions differed significantly from random distributions along all road types in each watershed. Type of habitat was the most important variable in explaining UVCs in the combined, landscape and Bow watershed models. UVCs were less likely to occur in open water, rock, and closed coniferous forest relative to open habitat. The proportion of open vegetation in the Bow Valley positively influenced wildlife mortality, while in the Kicking Horse watershed it negatively influenced mortality. Width and traffic volume were significantly positively correlated with the occurrence of UVCs in the combined model and Bow model, respectively. Elevation was a significant factor in the combined, landscape, Bow, and Kootenay watersheds, having a negative correlation on ungulate mortality. The proportion of open habitat positively contributed to kills in the Bow; whereas, it negatively influenced kills in the Kicking Horse. The three grouped models were ranked differently in their ability to predict the observed likelihood for UVCs. The combined model was the most important model in predicting the occurrence of UVCs, followed by the landscape model, and lastly the road-vehicular-animal model. Our findings show that kills do not occur randomly in the landscape. Different scales of analysis, i.e., ecoregion or watershed perspective, can influence which variables are important in contributing to the spatial distribution of UVCs. Further, different groups of variables, i.e., roads and motorist related factors, or landscape and animal behavior factors, may contribute differently to the spatial occurrence of UVCs. The factors contributing to UVCs along each landscape and highway are critical for developing knowledge-based mitigation for reducing effects of vehicle collisions on large animal populations and increasing public safety on highways.

Introduction

Roads are a formidable linear feature within the landscape directly impacting wildlife populations through vehicle collisions. These collisions represent an additive source of mortality to wildlife populations, in addition to other mortality, such as predation and disease. Further, these collisions are a considerable threat to traffic safety, socio-economics, animal welfare, and wildlife management and conservation (Child and Stuart 1987, Lavsund and Sandegren 1991, Romin and Bissonette 1996, Groot-Bruinderink and Hazebroek 1996, Schwabe et al. 2002).

Wildlife biologists can begin to assess the degree to which road mortality may impact wildlife populations by recording the number and location of wildlife-vehicle collisions on different road-types. Kill locations are often reported to local departments of transportation and natural resource agencies by way of police reports completed for insurance purposes or by maintenance workers directly recording the location of animal kills when removing carcasses. Spatial error can vary depending on protocol developed by the collecting agency. Most published studies focus on the features of road sections with high collision rates (Bashore, Tzilkowski, and Bellis 1985; Finder, Roseberry, and Woolf 1999; Hubbard, Danielson, and Schmitz 2000; Joyce and Mahoney 2001; Nielsen, Anderson, and Grund 2003; Seiler 2003). This study is unique because our analyses are based on each UVC location as measured by research personnel using a Geographic Positioning System (GPS).

For years wildlife-vehicle collisions have been a problem in the CCRM national parks and a cause for concern among park managers and transportation planners (Damas and Smith 1982, Woods 1990, Banff-Bow Valley Study 1996, Woods et al. 1996). The long-term trend and prospects are for increasing traffic volumes on the Trans-Canada Highway and other primary roads in the parks (Parks Canada Highway Service Center, unpublished data).

In order to effectively mitigate highways for wildlife and motorist safety, managers need to determine the causes of wildlife-vehicle collisions and whether they are best explained by parameters relating to roads and motorists, or landscape and animal behavior. We described the spatial distribution of UVCs in the CCRMs and more specifically in the four major watersheds, the Bow Valley, Kananaskis Valley, Kicking Horse Valley, and Kootenay Valley, each with differing road-types, topography, and habitat. We then examined numerous habitat and landscape variables that are thought to influence the occurrence of vehicle collisions.

Methods

Study area

This study was carried out in the CCRMs, approximately 150 km west of Calgary, in southwestern Alberta and southeastern British Columbia (fig.1). The study area encompassed 11 400 km^2 of mountain landscapes in Banff, Kootenay, and Yoho national parks and adjacent Alberta provincial lands. We divided the landscape into four major watersheds: the Bow Valley, Kananaskis Valley, Kicking Horse Valley, and the Kootenay Valley.

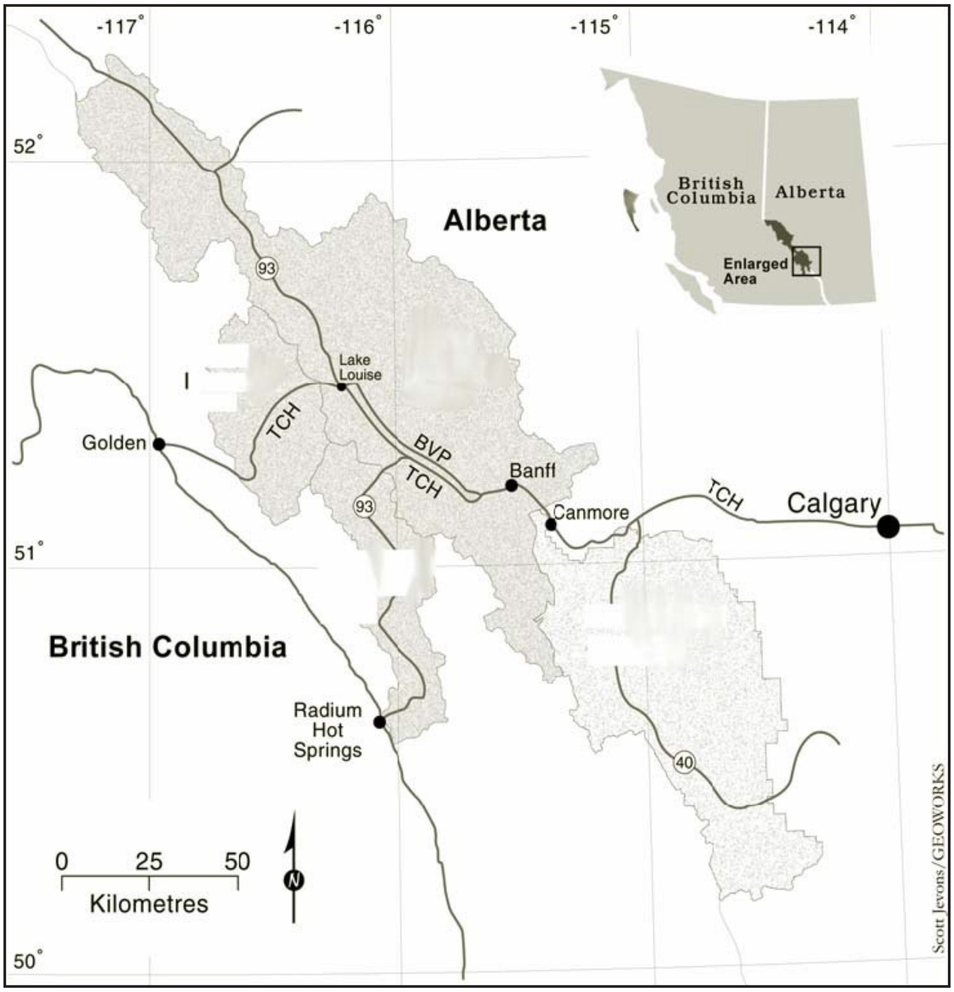

Figure 1. Location of study area and highways within the four major watersheds used to examine factors contributing to ungulate vehicle collision in the Central Canadian Rocky Mountains.

The Trans Canada Highway (TCH), extends west to east within the study area, running along the floors of two watersheds, the Kicking Horse in Yoho National Park (YNP) and the Bow in Banff National Park (BNP) and neighboring provincial lands. The TCH shares the Kicking Horse Valley with the township of Field (population <500), the Kicking Horse river, and the Canadian Pacific Railway. Annual average daily traffic volume (AADTV) on this 44.6-km stretch of two-lane highway in 1998 was 4,600 vehicles. The TCH continues eastward along the floor of the Bow, sharing the valley bottom with the Bow river, several small towns (population <10,000), numerous secondary roads, and the railway. The western segment of highway (32.7 km) still remains two lanes and has an AADTV of 7,000 vehicles, while the portion of highway east of BNP in neighboring provincial lands (37.4 km) is four lanes with an AADTV of 14,000 vehicles in 1998 (Parks Canada Highway Service Center, unpublished data). The Kananaskis and Kootenay watersheds have no major town sites, or railways, and both share their valley bottom with a two-lane highway, 50.2 and 101.0 km, respectively, with traffic volumes of approximately 2,000 vehicles per day in 1998 (Parks Canada Highway Service Center and Alberta Infrastructure, unpublished data). All highways in this study were two (90 km/hr) to four lanes (110 km/hr) and unmitigated (no fence or wildlife crossing structures).

The geography of the central and eastern portions of the study area is dictated by the geology of the Front ranges of the Rocky Mountains. The parallel and shale valleys create a landscape much more conducive to north-south than east-west movements. The few large valleys, the Bow Valley being the most prominent, that dissect the Front and Central ranges are recognized as critical, not only in maintaining regional-scale, east-west movements of animals, but also in providing a vital link between the valleys nested through out our study area, i.e., the Kootenay and Kananaskis valleys. For the same reasons the Bow Valley is also one of the most important transportation corridors in the region. This geography along with the transportation corridors associated with each watershed influences the distribution and movement of wildlife in the region.

Situated within the Front and main ranges of the Canadian Rocky Mountains, the study area has a continental climate characterized by long winters and short summers (Holland and Coen 1983). The roads in our study area traverse montane and subalpine ecoregions. Vegetation consisted of open forests dominated by Lodgepole pine (*Pinus contorta*), Douglas-fir (*Pseudotsuga menziesii*), white spruce (*Picea glauca*) Englemann spruce (*Picea englemannii*), trembling aspen (*Populus tremuloides*), and natural grasslands.

Data collection

Since January 1999 we maximized wildlife-vehicle collision (WVC) reporting and its accuracy. We contacted all parties responsible for collecting and reporting WVCs within our study area: Banff-Kootenay-Yoho national parks and the province of Alberta (Bow Valley and Kananaskis Country). Cooperators included national park wardens, provincial park rangers, and the private highway maintenance contractor (Volker-Stevin).

We provided cooperators with colored pin-flags to be carried with them in their vehicles. After collecting road-killed wildlife they were advised to mark the site by placing a pin-flag in the right of way and report back to us via telephone, fax, or email. Most accidents were pinflagged and reported to us within 48 hours.

The reported location of WVCs was recorded by the collaborators by describing the location with reference to a nearby landmark (e.g., 0.3 km west of BNP east gate). The true location of a WVC was acquired by visiting the accident site, recovering the pin-flag, and obtaining the actual location by measuring the odometer distance from the same reported landmark to the pinflag. The Universal Transverse Mercator (UTM) grid co-ordinates of the site were obtained using a differentially correctable Global Positioning System (GPS) unit (Trimble Navigation Ltd., Sunnyvale, California, USA) with high spatial accuracy (=<3m). The UTM co-ordinates were recorded in a database, along with date of kill and information regarding the number, species, sex, and age of the wildlife involved.

Factors contributing to wildlife collisions

We only used ungulate road mortality data for this study because these species were involved in 76 percent of the total mortalities (carnivores and ungulates). These included white-tailed deer *Odocoileus virginianus*, elk *Cevus elaphus*, mule deer *Odocoileus hemionus*, deer *Odocoileus* sp., moose *Alces alces*, and bighorn sheep *Ovis Canadensis*. A total of 546 ungulate-vehicle collisions were GPSed between August 1997 and November 2003. We compared the site-specific attributes of 499 observed locations to attributes of 729 random locations along the sampled roads. We only used 499 observed sites because 47 kills in Kootenay were not used as they had occurred prior to roadside vegetation clearance along a 23.9-km stretch of road. Random points were distributed along each roadway in proportion to the number of observed kills in each watershed. At least an additional 20 percent of observed locations were included as random points in each watershed.

At each sampling point we measured 24 variables to be used as probable factors explaining road-kill occurrence (for definition, see table 1). Fourteen of the variables were grouped as landscape-animal interaction variables, and 10 were grouped as road-vehicular interaction variables. Landscape-animal variables included factors that influence whether an animal makes it to the roadway. The road-vehicular variables include factors that influence the probability of an interaction between the animal and the vehicle.

Depending on accuracy and efficiency each variable was either measured in the field or in ArcView 3.3 GIS (Environmental Systems Research Institute, 1999). Field measurements were derived at each site by revisiting each UTM location with a GPS unit (Trimble Naviagation Ltd., Sunnyvale, California, USA) between April 2003 and February 2004. The spatial accuracy of the location of the measured site-related variables with the actual location was (<9m). A laser range finder (Yardage Pro® 1000, Bushnell® Denver, CO) was used to measure distance to cover and the inline and angular visibility. Vegetative cover, habitat, topography, and slope were all estimated visually.

Field visibility variables measured the extent to which a motorist could see ungulates on the right of way or, conversely, how far away an oncoming vehicle could be seen from the side of the highway. Field visibility was defined as the shortest distance along the highway at which an observer, standing at a distance perpendicular to the pavement edge, could no longer see an oncoming vehicle. Since, in most cases, it could not be determined from what side or which direction a vehicle struck an animal, four visibility measurements were taken at the pavement edge at each site, two facing each direction, on both sides of the highway. The average of the four visibility measurements were taken to calculate an in-line and two angular measurements (5-m and 10-m transect from pavement edge) (table 1).

Distance from data points to each landscape feature was calculated in ArcView 3.3 GIS using various physiographic layers. Highway spatial and elevation data were collected along each road approximately every 25 m, by driving at 50 km/hr and recording a GPS location every one second. Elevation data were obtained from a GPS unit for the observed points; whereas, elevation was extracted from the GPSed highway layer for the random points.

Change in elevation (table 1) was measured as the distance from each point where there was an inflection in the highway elevation profile which exceeded more that 3 m. The change in curvature (table 1) was measured as the distance from each point where the absolute difference between the straight line length and the curved line length exceeded 0.2 m over a stretch of at least 50 m. A distance of 1000 m was assigned as the distance measurement if the required change in elevation or curvature was not reached. This cut-off distance was chosen since in the field the range finder did not operate beyond that distance. Means were calculated from distance measurements taken from both directions at each point. A second mean in-line visibility (table 1) was calculated by taking the average of the shortest distance between curvature and elevation from each direction of the point. A Spearmans rank correlation was used to see if mean in-line visibility measurements taken in the field were similar to mean in-line visibility generated with the computer.

Table 1. Definition and description of variables used in the analysis of factors explaining

Variable Name	Definition	Continuous/Categorical
Landscape-animal		
Habitat Class[a]	Dominant habitat within a 100-m radius on both sides of the highway measured as open (O)-meadows, barren ground; water (W)-wetland, lake, stream; rock (R); deciduous forest (DF); coniferous forest (CF); open forest mix (OFM)	Categorical
Topography[ac]	Landscape-scale terrain measured as flat (1), raised (2), buried-raised (3), buried (4), part buried (5), part raised (6)	Categorical
Forest cover[a]	Mean percentage (%) of continuous forest cover (trees > 1 m height) in a 100-m transect line perpendicular to the highway, taken from both sides of the road	Continuous
Shrub cover[a]	Mean percentage (%) of shrub cover (trees and shrubs < 1 m high) in a 100-m transect line perpendicular to the highway, taken from both sides of the road	Continuous
Openess[a]	Mean percentage (%) of area devoid of vegetation (rock, gravel, water, pavement, etc.) in a 100-m transect line perpendicular to the highway, taken from both sides of the road	Continuous
Cover[a]	Mean distance (m) to vegetative cover (trees and shrubs > 1 m high) taken from both sides of the road	Continuous
Roadside slope[a]	Mean slope (°) of the land 0-5 m perpendicular to the pavement edge taken from both sides of the road	Continuous
Verge slope[a]	Mean slope (°) of the land 5-10 m perpendicular to the pavement edge taken from both sides of the road	Continuous
Adjacent land slope[a]	Mean slope (°) of the land 10-30 m perpendicular to the pavement edge taken from both sides of the road	Continuous
Waterways[b]	Distance (m) to the nearest waterway (river, stream, or creek) that crossed the road	Continuous
Human use[b]	Distance (m) to the nearest human use feature along the highway	Continuous
Railway[b]	Distance (m) to the nearest railway	Continuous
Powerline[b]	Distance (m) to the nearest powerline	

Table 1 (continued).

Elevation[b]	GPS height (m)	Continuous
Road-Vehicular-Animal		
Traffic Volume[b]	Annual Average Daily Traffic Volumes from 1980 to 2000 for each road type in the BOW watershed, measured as high (1) and low (2)	Categorical
Barrier 1[a]	Number of jersey and guard rails at the site measured as 0, >1	Categorical
Barrier 2[b]	Distance (m) to the nearest jersey or guardrail barrier	Continuous
Width[a]	Distance (m) from one side of the highway pavement to the other	Continuous
In-line visibility field[a]	Mean distance at which an observer standing at the pavement edge could no longer see passing vehicles taken from each direction on both sides of the highway	Continuous
Angular visibility 1[a]	Mean distance at which an observer standing 5 m from the pavement edge could no longer see passing vehicles taken from each direction on both sides of the highway	Continuous
Angular visibility 2[a]	Mean distance at which an observer standing 10 m from the pavement edge could no longer see passing vehicles taken from each direction on both sides of the highway	Continuous
Change in curvature[b]	Mean distance at which the absolute difference of the curved line length minus the straight line length changed by a magnitude of 0.2 m along a segment of at least 50 m, taken from each direction	Continuous
Change in elevation[b]	Mean distance where there was an inflection point in the road elevation profile, of at least 3 m, taken from each direction	Continuous
In line visibility-GIS[b]	The mean shortest distance between the change in curvature and the change in elevation from each direction, indicating a loss in the line of sight	

[a]Variable measure obtained from field measurement
[b]Variable measure obtained from a geographic positioning system and geographic information system or other source
[c] (1)flat  (2)raised  (3)buried-raised 

(4)buried  (5)part-buried  (6)part-raised 

Data analysis

Spatial distribution
We tested whether ungulate collisions were distributed randomly by comparing the spatial pattern of collisions with that expected by chance, in which case the likelihood of collisions for each road section would show a Poisson distribution (Boots and Getis 1988). We divided each road type in each watershed into 100-m segments and recorded presence (1) or absence (0) of the observed points in each highway segment. We used a Kolmogorov-Smirnoff one-sample test to determine whether the empirical distribution differed from a Poisson distribution. We also used a X^2 test to determine if obvious UVC aggregations were significant based on road length.

Univariate Analyses
We used univariate analyses to identify which of the continuous variables (unpaired t-tests) and categorical variables (X^2 contingency tests) significantly ($p<0.05$) differed between accident and control sites with all the data. Because some of the selected variables only pertain to specific watersheds these analyses were repeated within each of the four main watersheds: Bow, Kootenay, Kicking Horse, and Kananaskis. The significance of each differentiated class within the categorical variables was evaluated using Bailey's confidence intervals (Cherry 1996).

Model Building
We grouped the significant variables for the combined dataset and each watershed subset into reduced models and used multiple logistic regression analyses (Hosmer and Lemeshow 1989) to identify which of the above selected parameters best predict the likelihood of UVC occurrence. Further, we ran the logistic regressions on the two *a priori* model variable sets (table 1) representing parameter combinations as a function of landscape and road variables. We used stepwise (backward) regression procedures to allow variables to be removed from the equation until the ensuing new model was not significantly more informative than the previous one. We compared the landscape and road models with the combined model with Akaike's Information Criterion (AIC) and Akaike weights (w_i) to determine which variable grouping was most important in determining the occurrence of UVCs (Burnham and Anderson 2002). We used the log-likelihood ratio test (Hosmer and Lemeshow 1989) to determine significance of models to discriminate between UVC and random locations based on location attributes.

Significance of explanatory variable coefficients was based on chi-square tests of Wald statistics (Hosmer and Lemeshow 1989). Standardized estimate coefficients were calculated by multiplying logistic regression coefficients (*B*) by the standard deviation of the respective variables to assess the relative importance of the explanatory variables within the model. Odds ratios were examined to assess the contribution that a unit increase in the predictor variable made to the probability of a collision occurring (Tabachnick and Fidell 1996). Hosmer-Lemeshow goodness-of-fit test statistics were included to see how well the model predicts the dependent variable. We also included the cross-validation classification accuracies for the combined observed and random points for each model. The Combined, Bow, Kootenay, and the two grouped models were validated with 20 percent of the data not included in their development, and these cross validation classification accuracies are included. The Kicking Horse model was not validated due to low sample size.

Prior to performing the regression analysis we tested potential explanatory variables for multicollinearity (Menard 1995). Where variables were correlated ($r>0.7$) we removed one of the two variables from the analysis. Final models and variable coefficients with a p-value <0.10 were considered significant. Distance between the road and landscape elements or linear features was log(e) transformed to correct for non normality. We used the SPSS statistical package version 13.0 for all statistical analyses (SPSS 2004), and we used Microsoft Excel and ArcView GIS 3.3 (Environmental Systems Research Institute 1998) for all other analyses.

Results

Ungulate-vehicle collision composition
There were a total of 546 ungulate mortalities on all highways in the watersheds with the majority occurring in the Bow watershed (56%), followed by Kootenay (21%), and the least occurring in Kananaskis (12%) and the Kicking Horse (10%). When taking into account roadway length, the majority of kills occurred in the Bow Valley (4.82 kills/km), followed by the Kicking Horse and Kananaskis with 1.30 kills/km, and the least occurring in Kootenay with 1.13 kills/km. This did follow traffic volume trends, which were highest in the Bow watershed, followed by the Kicking Horse, Kananaskis, and Kootenay. Deer (consisting of mule deer, white-tailed deer, and unidentified deer) were most frequently involved in collisions comprising 58 percent of the kills, followed by elk (27%), moose (7%), bighorn sheep (3%), and others (mountain goats and unknown ungulates) (5%). Fifty percent of the moose and big-horn sheep kills occurred within the Kootenay watershed.

Spatial distribution
UVC distributions differed significantly from random distributions along all road types in each watershed (Kolmogorov-Smirnov one-sample test, Bow; d=0.715, Kootenay; d=0.940, Kicking Horse; d=0.892, Kananaskis; d=0.874, all $P<0.01$). Kills in Kootenay showed a significant aggregated distribution on the cleared section of highway with 60.0 percent of the kills occurring along a 23.9-km (22.9%) stretch of road (X^2=63.9, $P<0.0001$). The road in this section bisects key ungulate ranges in the valley bottoms of the montane region, with elevation less than 1,240 m (Poll et al.

1984). Due to this aggregation of UVCs, we addressed specific questions as to what landscape and road-vehicular factors contribute to this non-random distribution of collisions in our study area.

Factors contributing to ungulate-vehicle collisions

Univariate Analysis

Table 3 shows the results of the univariate comparison of each environmental variable thought to be contributing to the probability of UVCs. Seventy-one percent of the landscape variables and 30 percent of the road-related variables were significant in detecting differences between UVC sites and non-accident control sites within all the datasets (table 3).

Within the combined and the Bow datasets the significant landscape variables between observed and random sites were habitat class, topography, amount of cover, slope, and elevation. The Bow was the only watershed that had mortality sites within open habitat. In the Bow, collisions occurred more frequently in open, open forested, and deciduous forest areas, and less frequently in coniferous forest and with rock cliffs or open water present. The positive relationship between openness and distance to cover with collision occurrence further illustrates the higher probability of kills occurring in cleared habitat. The opposite relationship occurred in the Kicking Horse where there was less open space where kills occurred. In the Kicking Horse, kills occurred less frequently than expected at open water sites, and the opposite occurred in the Kananaskis watershed. In the Bow, kills occurred in terrain that was flat, and fewer than expected occurred in steeper topography when it was found on both sides or one side of the highway. Topography was significant in the Kootenay and Kananaskis watersheds; however, none of the differentiated categories was significant. Roadside, verge, and adjacent slopes were significant in the Bow, with more kills than random occurring at smaller grades in all three cases. Where the railway was present (Kicking Horse and Bow) kills occurred farther away than the random points, and this was significant in the Bow. Road-kills significantly increased at lower elevations in the combined, Bow, and Kootenay watersheds.

The road-vehicular-animal variables that significantly influenced UVC occurrences in the combined and Bow watersheds were the distance to a barrier (guardrail and jersey) and the width and traffic volume along the highway. More kills occurred at higher traffic volumes and increased road width within the Bow. Traffic volume was not compared in the other watersheds due to the absence of variability within each study area. Kills occurred closer to barriers in the Bow and Combined datasets. None of the in-line and angular field visibility measurements was significant between kills and control locations. Further, the change in elevation and curvature generated in a GIS were not significant in all the watersheds. The mean field line of sight was significantly correlated with the mean GIS line of sight ($r=0.69$, $P<0.01$).

Model Building

To reduce inter-correlation between the variables (Zar 1988), we omitted the percentage forest cover from further analyses as they were highly correlated ($R>0.70$) with percentage openness. The logistic regression results were not reported for Kananaskis, as the model was insignificant.

Table 3. Results from the univariate comparison of the factors contributing to UVCs at the 499 observed and 729 random locations for the entire study area and each watershed. Mean values are shown for quantitative variables, and frequencies for each differentiated type are shown for categorical variables, along with their associated P-values. Only those values that were significant (P<0.05) are displayed.

Variable	Combined (n=499)			Bow (n=310)			Kootenay (n=67)			Kicking Horse (n=57)			Kananaskis(n=65)		
	Obs	Ran	P-value	Obs	Ran	P-value	Obs	Ran	P-value	Obs	Ran	P-value	Obs	Ran	P-value
Landscape-Animal															
Habitat			<0.0001			<0.0001						0.009			0.003
Open	46	21		46	23										
Water	70	115		42	77					9	19		8	2	
Rock				2	7										
Decid forest	58	31		50	26								4	7	
Conif forest	193	237		67	104										
Open forest mix	127	84		102	72										
Topography			<0.0001			<0.0001			0.013						0.043
Flat	289	237		223	177										
Buried-raised	52	77		13	26										
Part-buried	93	121		42	66										
Forest cover	48	53	0.002	37	45	<0.0001									
Openess	46	41	0.003	55	47	<0.0001				29	39	0.020			
Cover	39	33	0.006	47	37	<0.0001									
Roadside slope	10	13	<0.0001	7	10	<0.0001									
Verge slope	10	11	0.033	7	9	0.026									
Adjacent land slope	12	15	0.004	9	11	0.035									
Railway				861	680	0.0001									
Elevation	1344	1389	<0.001	1350	1406	<0.0001	1276	1340	0.009						
Road-Vehicular-Animal															
Traffic Volume						<0.0001									
High				255	151										
Low				55	159										
Barrier 2	686	1142	<0.0001	588	1361	<0.0001									
Width	32	23	<0.0001	43	30	<0.0001									

Table 4. Results from the logistic regression analyses for the Combined, Landscape, Road-animal vehicular and watershed models with their ranking of significant (*P*<0.10) standardized estimate coefficients and their sign. Numbers indicate rank of importance of variable. Sign indicates influence variable or variable level has on the probability of a road kill occurring, (-) negative correlation or (+) positive correlation. Hosmer and Lemeshow goodness of fit test, validation results, Akaike Information Criterion (AIC) and Akaike weights (w_i) are also included.

Variable	Combined	Landscape	Road-vehicular-animal	Bow	Kootenay	Kicking Horse
Habitat						
Water	1-	2-				
Coniferous forest	2-	3-				
Rock	4-	1-		1-		
Openness						1-
Roadside slope		5-		3-		
Width	5+		2+			
Barrier 2			1-			
Elevation	3-	4-		4-	1-	
Traffic Volume						
High				2+		
Hosmer and Lemeshow test	0.444	0.601	0.192	0.857	1.000	0.410
AIC	1244	1248	1260			
? AIC	0	4	16			
w_i	0.88	0.12	<0.0002			
Model development & validation accuracies (%)	64.9 61.8	65.5 59.9	61.9 62.2	66.2 65.3	71.2 64.7	63.6

The three grouped models ranked differently in their ability to predict the observed likelihood for UVCs (table 3). The combined model ranked highest according to AIC weights (w_i=88%), followed by the landscape model (w_i =0.12%), and lastly the road-vehicular-animal model (w_i < 0.0002%). The addition of extra variables in the combined model did not have a negative effect on its relative AIC weight. For the three grouped models, the Hosmer and Lemeshow statistic was highest for the landscape model, followed by the combined model, then the road model. The predictive capabilities of all three models were similar, correctly classifying 61.9-65.5 percent of the selected points. Model validation accuracies ranged from 59.9-62.2 percent. Validation accuracies were low because all three models had difficulty correctly predicting the observed points (< 45%) but scored high when classifying the random points (> 75%).

The two watershed models (Bow and Kootenay) and the three grouped models were statistically significant (all *P*<0.0001). The Kicking Horse Model was also significant (*P*<0.05). For all watersheds the Hosmer and Lemeshow goodness of fit was highest for the Kootenay (test statistic=1.000), followed by the Bow (test statistic=0.857), and then Kicking Horse (test statistic 0.410). The overall cross-validation accuracies were highest for the Kootenay model (71.2%-model development and 64.7%-validation). The combined and Kicking Horse models scored the lowest goodness of fit test statistics and overall cross validation accuracies below 65 percent in model development and validation.

Type of habitat was the most important variable in explaining UVCs in the combined, landscape and Bow models. UVCs were less likely to occur in open water, rock, and closed coniferous forest relative to open habitat. In the combined model water was ranked as the most important variable, and kills were 63 percent less likely to occur at wet areas. Kills were also less likely to occur in coniferous forest and rock in the combined and landscape models. Further, width was a significant positive correlation of the occurrence of UVCs in the combined model. In the Bow, the presence of rock decreased the likelihood of kills occurring by 92 percent relative to open areas. In the Bow, ungulates were 95 percent less likely to be killed in areas of lower traffic volumes (Banff National Park versus provincial lands). Elevation was a significant factor in the combined, landscape, Bow, and Kootenay models, having a negative influence on ungulate mortality. In the Kicking Horse, openness was the only variable significant in the model and had a negative influence on UVC probability.

Discussion

Spatial distribution

We are not aware of any published analyses that have used collision data with such a high degree of accuracy (< 10 m). Our study is unique in that we adopted a site-based approach to data collection in order to preserve the high spatial accuracy of kill sites. Many studies estimate their reporting error to be > 500 m, and, as a result, look at road sections as hotspots of road mortality (Bashore, Tzilkowski, and Bellis 1985; Finder, Roseberry, and Woolf 1999; Hubbard, Danielson, and Schmitz 2000; Joyce and Mahoney 2001; Nielsen, Anderson, and Grund 2003; Seiler 2003). Clevenger et al. (2003) showed that the range of scales of small mammal road kill clustering differ on road types and is dependent on the intensity of the distribution. Our results show that UVCs are not occurring randomly in each watershed, and the degree of aggregation depends on the local characteristics within each watershed. Other studies show road kills tend to be spatially aggregated with a small percentage of locations accounting for a large proportion of kills (Puglisi et al. 1974, Bashore et al. 1985, Hubbard et al. 2000, Malo et al. 2004). This was evident in Kootenay where the road-kill rate was low relative to the other watersheds; however, when viewed at a finer scale, the majority of kills (60%) occurred on a small section of highway (22.9%). Clevenger et al. (2003) and Spooner et al. (2004) used a more sophisticated approach to analyze spatial data, which would be useful here to further explore the spatial distribution of the UVCs in our study area and in each watershed.

Factors contributing to ungulate-vehicle collisions

The combined and Bow watershed models shared many of the same significant variables. Factors contributing to road-kill occurrence in the Bow watershed weighted heavily in the combined model since the majority of kills (62%) occurred in the Bow. For this reason, reduced models were used to examine each watershed separately. However, sample sizes were low along the extensive roadways in the Kooteney, Kananaskis, and Kicking Horse watersheds, which may explain the lack of significant variables. Kootenay originally had a relatively high number (n=114) of mortalities; however, 47 kills were excised from analysis since they occurred prior to the clearing of the highway. The cleared section was within the valley bottom of the Kootenay River where terrain was less steep and the highway was notably straighter (Poll 1989). By removing these kills from only this location, some of the significant variables characteristic of this region may have been lost in the analysis.

The degree of habitat variability was much less in the Kootenay, Kananaskis, and Kicking Horse watersheds when compared to the Bow watershed. None of these watersheds had open habitat on both sides of the highway, and the Highway 93S in Kootenay only bisected pine spruce forest and open water. Other studies have shown that where preferred habitat is extensive common deer kills have been more randomly distributed (Bellis and Graves 1971, Allen and McCullough 1976, Bashore et al. 1985, Feldhamer et al. 1986). Kills in these three watersheds may have occurred more randomly in the road network due to the apparent homogeneous habitat, especially in Kananaskis and Kicking Horse where there was not an obvious aggregation of road kills.

The majority of UVCs occurred in the Bow Valley provincial region and were positively associated with all open habitat variables. Open grassland habitat was abundant from high levels of development and a wide transportation corridor that would attract animals to the highway corridor (Bellis and Graves 1971, Puglisi et al. 1974, Carbaugh et al. 1975, Bashore et al. 1985, Lehnert and Bissonette 1997). Bashore et al. (1985) had a similar result in that as the overall habitat became less wooded, the chances that the highway would be a high kill area increased. Further, Bellis and Graves (1971) showed that animals along an interstate in Pennsylvania are attracted to cleared areas associated with the highway right of way and increased development, which provide a valuable source of forage in forested regions.

Conversely, the extent of openness was a negative factor on UVCs in the Kicking Horse, although very little open grassland habitat existed in this region. This result can be interpreted as fewer kills than expected occurring at human-use areas, highway pull-outs, and open wet areas that were classified as open areas. Other studies have also shown that animals avoid the proximity of humans at points where they cross roads, preferring to approach roads hidden by tree and shrub cover (Bashore, Tzilkowski, and Bellis 1985; Jaren et al. 1991; Clevenger et al. 2003; Seiler 2003; Malo et al. 2004).

Elevation was the only significant variable in the Kootenay logistic regression model, and more kills than expected occurred in lower elevations characteristic of the lower montane habitat. The sheer number of collisions in this section of habitat underscores the importance for mitigation across the highway valley bottom to allow for safe east-west movement of ungulates across a critical habitat range (Poll 1989). The already existing highway right of way was cleared of forest growth on both sides of a 23.9-m section of highway within the low montane habitat with the intention of creating more visibility for motorists to react to animals crossing the highway (Alan Dibb, Parks Canada, pers. comm.). Studies have shown that clearing of vegetation provides an alternative source of forage for ungulates (Poll et al. 1984) and attracts animals to the road (Bellis and Graves 1971, Puglisi et al. 1974, Carbaugh et al. 1975, Bashore et al. 1985, Lehnert and Bissonette 1997). Clearing vegetation may improve driver line-of-site; however, if the majority of accidents occur at night (Joyce and Mahoney 2001, Gunson et al. 2001), then this effort remains futile.

More kills than expected occurred on flatter grades of highway right of way from 0-30 m away from the road. In addition, there was a higher probability of collisions where the landscape terrain was flat, rather than raised or buried on either side. This is a similar result to Clevenger et al. (2003), which showed that optimum crossing points for small mammals were situated where roads run level with the adjacent landscape, and Malo et al. (2004), which showed collisions are rare where roadsides have high embankments (> 2 m). This was the only region where kills occurred at flat grades in relation to the highway. In the Bow region, provincial land has a higher area of lower montane habitat across the valley bottom, i.e., 92 percent of a 2-km section of landscape surrounding the roadway is < 1,240 m. Animals in the other watersheds have to navigate a relatively more constricted valley lending to steeper landscapes close to the roads, i.e., less than 70 percent of the landscape was < 1,240 m.

Barriers are used by highway planners when the likelihood of a vehicle leaving the road is greater than in other locations, e.g., curvature in the highway or where conditions in the landscapes present a higher risk of injury for vehicles leaving the highway, such as open water and steep topography (Terry Hale, NYDOT engineer, pers. comm.). Kills occurred closer to jersey barriers and guardrails in the Bow where these barriers were frequently used along the roadway due to high traffic volumes and speeds. Because the presence or absence of barriers was not a significant variable in the Bow this result suggests that animals are funneled toward road crossing points close to barrier ends by features within the landscape, i.e., open water areas. This variable would have to be further explored, i.e., where are the barriers in relation to landscape features to better interpret if this result is a function of road-motorist factors or due to features evident in the surrounding landscape.

It was expected that UVCs would occur at points in the highway where the driver visibility is impaired by changes in elevation and curvature along the road network. In this study, all the field in-line and angular visibility measurements did not contribute to the occurrence of UVCs probably for several reasons. Vehicles tend to slow down along these sections of highway, which allows more time for drivers to react to crossing animals even though the driver may not see the animal as quickly as in a straight, flat section. Secondly, more animal-vehicle collisions occur at night (Joyce and Mahoney 2001, Clevenger et al. 2001) when deer activity (Kinley and Newhouse 2003) and moose activity (Joyce and Mahoney 2001) are higher than in midday. The line of sight may not be a factor for drivers at night when in most cases the animal is not seen before the collision occurs. Bashore et al. (1985) also had unexpected results where the in-line visibility was positively correlated to the occurrence of road kills, and related this to an increase in speed at straighter sections of highway. However, when the shortest distance of all the angular and in-line measurements was used, it was negatively related to the probability of vehicle-deer accidents (Bashore et al. 1985).

Many studies have shown that linear landscape elements, such as riparian corridors, ditches, steep slopes, or ridges, as well as fences, may funnel animals alongside or across the roadway, increasing the probability of collision (Bashore et al. 1985, Feldhammer et al. 1986, Madsen et al. 1998, Finder et al. 1999, Hubbard et al. 2000). In this study, we found that the presence of a waterway drainage perpendicular to the roadway was not significant in all watersheds. This can largely be explained due to the presence of a bridge associated with some of the water crossings, which may have provided a tunnel for wildlife to traverse the highway (e.g., in the Kicking Horse, 53 percent of the waterways used in the analysis allowed underground passage for animals). Similarly, Seiler (2003) found that the risk of collision was higher where private roads connected to the main road, but the risk decreased where tunnels or bridges separated the intersecting roads. In addition, many of the water crossings were associated with steep topography typical of mountain landscapes, which may cause animals to travel the highway corridor in search of more level crossing locations.

Model building

It is interesting that the majority of variables that were significant were the landscape-animal interaction variables and the Akaikes weights and goodness of fit scores were higher for the landscape model than the road-related model. However, the Akaikes weight was highest for the combined model, indicating all variables were important in determining road-kill occurrence. This suggests that there may have been some important road-related variables, i.e., driver behavior, signage, traffic speed, etc., not included in the analysis, which may strengthen the applicability of the road-vehicular model.

The combined model did not perform as well as the individual Bow model probably because the model had more difficulty predicting which variables were associated with kills since the landscape heterogeneity differed between the provincial lands and the National Parks. The validation accuracies were not as high in this analysis as in other similar studies analyzing road-kill occurrence (Clevenger et al. 2003, Seiler et al. 2004). Typically, habitat type is homogeneous in the National Parks of the CCRMs, which may have made it difficult to predict spatial patterns of UVCs with fine-scale variables, such as differing habitat types and extent of forest measures. However, broad-scale landscape variables, such as elevation, were excellent predictors of collisions within the CCRMS. Further, there may have been several pertinent variables missed from the model, such as animal abundance measurements.

Summary

The predictors of UVCs found in this study might be extrapolated to other areas of mountain parks with similar landscapes and mammal species. Models must be extrapolated to other study areas with caution and should be used as a starting point to predict vehicle collisions, but they may need to be refined at each study area. The scale of measurements is important, as well as the scale of the region being modeled. Variables can be described and measured in an infinite number of ways, especially between different observers. The initial selection of road- and landscape-related factors should be done by biologists who know their study area and target species well. Sensitivity analyses should be performed to determine how scale and measurement of variables change the outcome of the model.

Management implications

This study has shown that the more open habitat in the Bow watershed led to key ungulate-vehicle collision hotspots. Further, the high Akaike's weighting of the landscape model suggests managers should concentrate on factors in the landscape that draw animals to the roadside; however, most of the time this is not possible since local flat terrain and habitat funnel animals to roadsides. In this case, mitigation measures such as fences and crossing structures should be used that have proved effective in decreasing animal collisions while allowing animals to safely traverse transportation corridors in the Mountain Parks (Woods 1990, Clevenger and Waltho 2000, Clevenger et al. 2001) and in Spain (Mata 2004). At the very least, managers can limit the area of cleared palatable grasslands within transportation corridors that would attract animals to roadsides regardless of local topography and habitat.

The high cost of physical structures such as overpasses limits their installation to a few sites (McGuire and Morrall 2000), which may make it difficult to place these structures along an extensive stretch of highway. The aggregations of kills in the Kootenay and the Bow provincial lands along certain stretches of highway make it easier to pinpoint the location of effective mitigation measures, such as fencing, crossing structures, or infra-red animal detection systems (Kinley and Newhouse 2003).

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Tony Clevenger is a wildlife research ecologist at the Western Transportation Institute, Montana State University (Bozeman, Montana) and has been studying road effects on wildlife populations in the Banff-Bow Valley and the surrounding national and provincial parks since 1996. Dr. Clevenger is a graduate of the University of California, Berkeley, and has a master's degree in wildlife ecology from the University of Tennessee, Knoxville, and a doctoral degree in zoology from the University of León, Spain. He is currently a member of the U.S. National Academy of Sciences Committee on Effects of Highways on Natural Communities and Ecosystems.

Bryan Chruszcz completed his B.S. in biology at Queen's University in Kingston, Ontario, and his M.S. in ecology at the University of Calgary. His M.S. research examined the foraging, roosting, and thermoregulatory ecology of bats in the badlands of southeastern Alberta and in eucalypt forests in Queensland, Australia. Mr. Chruszcz has spent the past six years working as a wildlife ecologist for the Trans-Canada Highway Wildlife Research Project in Banff National Park. He is currently working as a wildlife ecologist and consultant on a variety of projects across western North America.

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