Analyses of Wildlife-Vehicle Collision Data: Applications for Guiding Decision-Making for Wildlife Crossing Mitigation and Motorist Safety

I. Limiting effects of road-kill reporting data due to spatial inaccuracy

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1. EXECUTIVE SUMMARY

To properly mitigate road impacts to wildlife and increase motorist safety, transportation departments need to be able to identify where particular individuals, species, taxa, and vertebrate communities are susceptible to high road-kill rates along roads. Research on wildlife-vehicle collisions has demonstrated that they do not occur randomly but are spatially clustered (Puglisi et al., 1974; Hubbard et al., 2000; Clevenger et al., 2001; Joyce and Mahoney, 2001). The presence of wildlife tends to be linked to specific habitats and adjacent land use types. Thus, landscape spatial patterns would be expected to play an important role in determining road-kill locations and rates (Forman and Alexander, 1998). Explanatory factors of wildlife road-kills vary widely between species and taxa. Thus, to understand the importance of such factors and processes, it is first necessary to be able to measure and describe the spatial pattern of road-kill aggregations.

A variety of methods have been used by transportation and natural resource agencies to reduce road-related wildlife mortality (see reviews in Romin and Bissonette 1996, Putman 1997). However, the effectiveness of these mitigation measures is uncertain, as few studies have rigorously tested the efficacy of the suite of mitigation measures (Romin & Bissonette 1996). Measures of performance may include changes in the frequency of wildlife-vehicle collisions, and/or number of motor vehicle accidents (wildlife or non-wildlife related) before and after mitigation has been applied (Hardy et al. 2003). Because the function of wildlife crossings is to reduce road-related mortality and increase habitat connectivity for wildlife, performance measures will ultimately need to be combined to fully determine the conservation value of mitigation. Societal benefits of mitigation can be directly measured in terms of savings in property damage from accidents when comparing adjacent sections of highway with and without mitigation in place (Clevenger et al. 2001).

Through this project, researchers at the Western Transportation Institute (WTI) at Montana State University (MSU) utilized wildlife-vehicle collision data to demonstrate how this information can be used to aid transportation management decision-making and mitigation planning for wildlife. The team investigated the relative importance of factors associated with wildlife road-kills using two different datasets: one based on spatially accurate location data (<3 m error) representing an ideal situation; and a second dataset created from the first, that is characterized by high spatial error (≤0.5 mile or 800 m) and is likely typical of most transportation agency data. The goal of this project was to summarize how well these models identify causes of wildlife-vehicle collisions.

The primary result of this analysis was that a UVC model developed with spatially accurate location data had high predictive power in identifying factors that contribute to collisions. But perhaps more noteworthy from this exercise was the vast difference in predictive ability between the models developed with spatially accurate data on one hand and less accurate data obtained from referencing UVCs to a mile-marker system. The results have important implications for transportation agencies that may be analyzing data that has been referenced to a mile-marker system, or unknowingly is spatially inaccurate. These findings lend support to the development of a national standard for the recording of animal-vehicle collisions, as well as further research into new technologies that will enable transportation agencies to collect more accurate data.

This project also investigated the types of variables that explain wildlife-vehicle collisions, in particular whether they are associated with landscape and habitat characteristics or physical features of the road itself. In two different types of analyses, researchers identified more significant variables related to landscape and habitat than significant variables identified to road characteristics.

2. INTRODUCTION

Wildlife-vehicle collisions do not occur randomly along roads but are spatially clustered (Puglisi et al., 1974; Hubbard et al., 2000; Clevenger et al., 2001; Joyce and Mahoney, 2001), because wildlife movements tend to be associated with specific habitats, terrain, and adjacent land use types. Thus, landscape spatial patterns would be expected to play an important role in determining locations where the probability of being involved in an animal-vehicle collision is higher compared to other locations (Forman and Alexander, 1998). Explanatory factors of wildlife road-kill locations and rates vary widely between species and taxa, yet, to properly mitigate road impacts to wildlife and increase motorist safety, transportation departments need to be able to identify where particular individuals, species, taxa, and vertebrate communities are susceptible to high road-kill rates along roads. Quality field data documenting locations and frequencies of wildlife-vehicle collisions can offer empirical insights to help address this challenging safety and ecological issue.

As part of maintaining state and provincial highway systems, transportation departments often collect information on the location of animal-vehicle collisions. Typically, maintenance personnel do not conduct routine surveys of animal road-kills, but instead collect information opportunistically while carrying out their daily work. Occasionally the information may be referenced to wildlife species and specific geographical landmarks such as 1.0-mile-markers or 0.1-mile-markers; however it is commonly believed that opportunistically collected road-kill data are not spatially accurate. One study has shown that errors in road-kill reporting may be 500 m or greater (Clevenger et al. 2002). The inherent spatial error in most agency datasets limits the types of applications for which the data can be used in transportation planning and mitigation efforts.

In this report we demonstrate how wildlife-vehicle collision data can be analyzed to guide transportation management decision-making and mitigation planning for wildlife crossings. We investigate the relative importance of factors associated with wildlife road-kills using two different datasets: one with highly accurate location data (<3 m error) representing an ideal situation and another dataset with high spatial error (≤ 0.5 mile or 800 m), which is likely more characteristic of the average transportation agency dataset. The end product illustrates how spatial accuracy of the data affects the process of identifying variables that contribute to wildlife-vehicle collisions. Based on these outcomes, we make recommendations for collecting road-kill data more systematically and accurately, emphasizing the value of spatial accuracy in identifying and prioritizing problematic areas for highway mitigation projects. The intent of this effort is to provide an overview of considerations regarding the quality and application of wildlife-vehicle collision data to aid in assessing and mitigating wildlife-vehicle collisions.

3. STUDY AREA

This study was carried out in the Central Canadian Rocky Mountains approximately 150 km west of Calgary, straddling the continental divide in southwestern Alberta and southeastern British Columbia (Figure 1). The study area encompasses 11,400 km2 of mountain landscapes in Banff, Kootenay and Yoho national parks and adjacent Alberta provincial lands. This region has a continental climate characterized by long winters and short summers (Holland and Coen 1983). Vegetation consists 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.

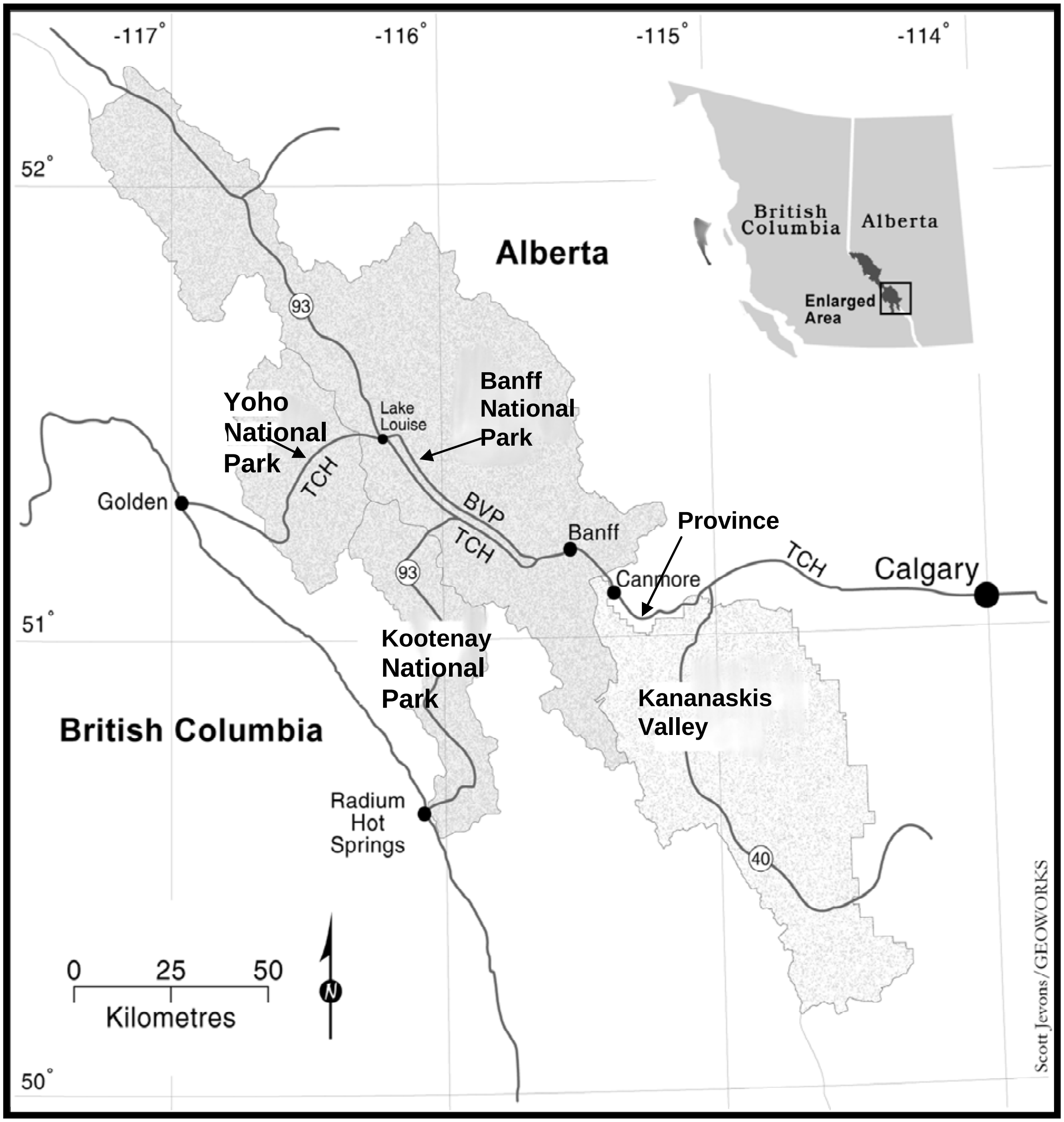


Figure 1: Location of Study Area

Geology influences the geographic orientation of the major drainages in the region, characterized as north-south valleys delineated by steep shale mountains. Regional-scale, east-west movements of animals across and between these valleys are considered vital for long-term sustainability of healthy wildlife populations in the region. The transportation corridors associated with the major watersheds influence the distribution and movement of wildlife in the region. As the most prominent drainage, the Bow Valley accommodates the Trans-Canada Highway, one of the most important and, hence, heavily travelled transportation corridors in the region.

Highways in the study area traverse montane and subalpine ecoregions through four major watersheds in the region (Figure 1). Table 1 describes the location and general characteristics of the five segments of highways that were included in this study.

Table 1: Characteristics of the major highways in the study area

Highway	**Watershed**	**Province**	**Road length (Km)**	**Traffic volume (ADT[1])**	**Posted vehicle speed (Km/hr)**
Trans-Canada Highway	Bow River	Alberta, east of Banff National Park	37	16,960	110
Trans-Canada Highway	Bow River	Banff National Park, Alberta	33	8000	90
Trans-Canada Highway	Kicking Horse River	Yoho National Park, British Columbia	44	4600	90
Highway 93 South	Kootenay River	Kootenay National Park, British Columbia	101	2000	90
Highway 40	Kananaskis River	Alberta	50	3075[2]	90

[1]ADT: 2005 annual average daily traffic volume. Data from Parks Canada Agency, Banff National Park and Alberta Transportation, Edmonton, Alberta.

[2] 1999 summer average daily traffic volume. Data from Alberta Transportation, Edmonton, Alberta.

4. METHODOLOGY

4.1. Data Collection

4.1.1. Spatially accurate dataset

In January 1999, efforts were initiated to maximize data collection of wildlife vehicle collisions (WVCs) and improve the spatial accuracy of reported locations of WVCs occurring on the highways in the study area. To do this, we worked with the agencies and highway maintenance contractors that were responsible for collecting and reporting WVCs. The agencies consisted of Parks Canada (Banff, Kootenay and Yoho National Parks), Alberta Sustainable Resource Development (Bow Valley Wildland Park and Kananaskis Country) and Volker-Stevin, maintenance contractor for the Trans-Canada Highway (TCH) east of Banff National Park in the province of Alberta. Cooperators included national park wardens, provincial park rangers and maintenance crews of Volker-Stevin.

We provided cooperators with colored pin-flags to carry in their vehicles to mark the sites in the right-of-way where road-killed wildlife were observed and collected. After placing a pin-flag, they were asked to report back to us via telephone, fax or email. Most WVCs were pin-flagged and reported within 48 hours.

The collaborators recorded the location of WVCs by describing the location with reference to a nearby landmark (e.g., 0.3 km west of Banff National Park east entrance gate). Each reported WVC site was relocated by measuring the odometer distance from the reported landmark to the pin-flagged site, where researchers recorded the actual location in Universal Transverse Mercator (UTM) grid coordinates using a differentially- correctable global positioning system (GPS) unit (Trimble Navigation Ltd., Sunnyvale, California, USA) with high spatial accuracy (<3 m). The UTM coordinates were recorded in a database along with the original date of each reported road-kill, and information regarding the species, sex, age, and number of individuals involved.

For this study, we only used ungulate-vehicle collision (UVC) data, because ungulate species comprised 76% of the total wildlife mortalities. In addition, these species are often the greatest safety concern to transportation agencies given their size and relatively common occurrence in rural and mountainous landscapes. Ungulate species included white-tailed and mule deer (Odocoileus virginianus and O. hemionus, respectively), unidentified deer (Odocoileus sp.), elk (Cervus elaphus), moose (Alces alces), and bighorn sheep (Ovis canadensis). The UVC data obtained from the methods described above are hereafter referred to as the 'spatially accurate' dataset and serve as a benchmark for the analysis.

4.1.2. Mile-marker data set

To investigate the influence that spatial accuracy and scale may have on the results and interpretation of the data, we created a "mile-marker" dataset using the spatially accurate dataset, shifting each UVC location to the nearest hypothetical mile-marker. To do this, we divided each of the five highways in the study area into 1.0 mile-marker segments using ArcView 3.3 (Environmental Systems Research Institute 1999). All spatially accurate UVC data were plotted onto each road network and then moved to the nearest mile-marker reference point. Each observed data point was moved an average distance of 163.9 m ± 163.5 (min=7.3 m, max=789 m), to its nearest mile-marker. We recorded the UTM coordinates of each mile-marker location, and summed the number of UVCs in that mile-marker segment, defined as 800 m (0.5 mile) up- and down-road of the given mile-marker.

4.1.3. High and low kill locations

We categorized each mile-marker segment as a "high kill" or "low kill" zone by comparing the total number of UVCs associated with a single mile-marker segment to the average number of UVCs per mile for the same stretch of road, for each of the five highways in the study area. If the summed number of UVCs associated with a single mile-marker segment was higher than the average calculated per mile for the same highway, that mile-marker segment was considered a "high kill zone". Similarly, if the summed number of UVCs within a mile-marker segment was lower than the average for that highway, the mile-marker segment was listed as a "low kill zone". Each spatially accurate UVC location was classified as a high kill or low kill zone according to which mile-marker segment it fell within.

4.2. Variables and Models

4.2.1. Site-specific variables

We collected data on site-specific attributes at spatially accurate UVC locations and at mile-marker locations along the five highways. Using a differentially-correctable GPS unit to locate each sampling site in the field, we measured 14 variables to be used as possible factors explaining UVC occurrence (Table 2). A range finder (Yardage Pro® 1000, Bushnell® Denver, CO) was used to measure distance to nearest vegetative cover and the inline and angular visibility measurements. Vegetative cover, habitat, topography, and slope were all estimated visually.

Field visibility variables estimated the extent to which a motorist could see ungulates on the highway right-of-way, or conversely how far away an oncoming vehicle could be seen from the side of the highway. Field visibility was measured via a rangefinder as the distance that an observer, standing at one of three positions (at the edge of the pavement, 5 m or 10 m from the pavement edge), lost sight of a passing vehicle, representing the distance that an approaching driver might be able to see an animal from the road. 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 each position (two facing each direction of traffic on both sides of the highway). These four measurements were averaged to provide mean values estimating visibility at the edge of the road, 5 m away from the edge of the road, and 10 m from the edge of the road (referred to as "in-line visibility", "angular visibility 1", and "angular visibility 2" in Table 2).

Spatial and elevation data were collected along each highway approximately every 25 m, by driving at 50 km/hr and recording a GPS location every second. Elevation was obtained on-site from a GPS unit for the spatially accurate data locations, whereas elevation for the mile-marker points was extracted from the GPS-created highway layer.

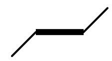
Table 2: Definition and description of variables used

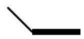
Variable Name	**Definition**
Field variables	
Habitat class*	Dominant habitat within a 100m radius on both sides of the highway measured as open (O)-meadows, barren ground; water (W)-wetland, lake, stream; rock (R); deciduous forest (DF); coniferous forest (CF); open forest mix (OFM)
Topography* °	Landscape scale terrain measured as flat (1), raised (2), buried-raised (3), buried (4), part buried (5), part raised (6)
Forest cover	Mean percentage (%) of continuous forest cover (trees >1m height) in a 100m transect line perpendicular to the highway, taken from both sides of the road
Shrub cover	Mean percentage (%) of shrub cover (trees and shrubs <1 m high) in a 100m transect line perpendicular to the highway, taken from both sides of the road
Barren ground	Mean percentage (%) of area devoid of vegetation (rock, gravel, water, pavement etc.) in a 100m transect line perpendicular to the highway, taken from both sides of the road
Vegetative cover	Mean distance (m) to vegetative cover (trees and shrubs >1 m high) taken from both sides of the road
Roadside slope	Mean slope (°) of the land 0-5 m perpendicular to the pavement edge taken from both sides of the road
Verge slope	Mean slope (°) of the land 5-10 m perpendicular to the pavement edge taken from both sides of the road
Adjacent land slope	Mean slope (°) of the land 10-30 m perpendicular to the pavement edge taken from both sides of the road
Elevation	GPS height (m)
Road width	Distance (m) from one side of the highway pavement to the other
In line visibility-field*	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
Angular visibility 1	Mean distance at which an observer standing 5m from the pavement edge could no longer see passing vehicles taken from each direction on both sides of the highway
Angular visibility 2	Mean distance at which an observer standing 10m from the pavement edge could no longer see passing vehicles taken from each direction on both sides of the highway
Distance to landscape features	
Drainage	Distance (m) to the nearest waterway (river, stream, or creek) which crossed the road
Human use	Distance (m) to the nearest human use feature along the highway
Barrier-guardrail	Distance (m) to the nearest Jersey barrier or guardrail

GIS generated buffer variables	
Road curvature	Length (m) of each highway segment within each buffer
Open water	Area (km2) of open water within each buffer
Human use	Area (m2) of human use features within each buffer
River length	The length (m) of all rivers within each buffer
Barrier length	The length (m) of all Jersey barriers and guard-rails in each buffer

* Variable measure obtained from field measurement

Variable measure obtained from a geographic positioning system and geographic information system or other source

° (1)flat (2)raised  (3)buried-raised 

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

4.2.2. GIS-derived variables

Most variables were measured in the field; however some measurements were obtained using ArcView 3.3 GIS (Environmental Systems Research Institute, 1999). Distance from each sampling site to landscape features (Table 2) was calculated using a GIS. We generated 800 m (0.5 mile) radius buffers around each spatially accurate and mile-marker sampling site and laid various landscape feature layers over the buffers to calculate the area or length of each within each buffer. The road network was used to calculate the length of each highway segment within each buffer to measure curvature of the highway (Table 2).

4.3. Data Analysis

4.3.1. Cluster analysis

We tested whether the spatially accurate UVCs 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 & Getis 1988). We divided each highway in each watershed into 100 m segments and recorded presence (1) or absence (0) of the observed points in each segment. We used a Kolmogorov-Smirnoff one-sample test to determine whether the empirical distribution differed from a Poisson distribution. We also used a $\chi 2$ test based on overall highway length to determine if an obvious UVC aggregation was significant along the cleared section or low valley bottom of highway on 93S. Finally we determined the aggregation, (i.e. whether the kills were evenly spread along the highway) of UVCs within each highway by determining the percentage of mile-markers associated with an UVC location.

We used univariate analyses to identify which of the continuous variables (unpaired t-tests) and categorical variables ($\chi 2$ contingency tests), significantly ($p<0.05$) differed between high and low kill sites within the spatially accurate and mile-marker datasets. The significance of each differentiated class within the categorical variables was evaluated using Bailey's confidence intervals (Cherry 1996).

We used logistic regression analyses to identify which of the significant parameters best predicted the likelihood of UVC occurrence within the spatially accurate and mile-marker datasets (Hosmer & Lemeshow 1989). 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 used the log-likelihood ratio test (Hosmer and Lemeshow 1989) to determine the significance of each model to discriminate between high and low kill zones based on location attributes. Significance of explanatory variable coefficients was based on $\chi 2$ 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 an UVC occurring (Tabachnick & 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 each model generated from the two datasets. Each model was validated with 20% of the data not included in their development and these cross- validation classification accuracies are included.

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. We used the SPSS statistical package version 13.0 for all statistical analyses (SPSS 2004), and Microsoft Excel and ArcView GIS 3.3 (Environmental Systems Research Institute 1999) for all other analyses.

5. RESULTS

5.1. Summary of Ungulate-Vehicle Collision Data

A total of 546 UVC observations were recorded between August 1997 and November 2003 on all highways in the study area. Deer (mule deer, white-tailed deer and unidentified deer) were most frequently involved in collisions comprising 58% of the kills, followed by elk (27%), moose (7%) bighorn sheep (3%) and "other ungulates" (including mountain goats, unknown species of ungulates -- 5%).

The majority of UVCs occurred on the Trans-Canada Highway (TCH) east of Banff National Park in the province of Alberta (46%), followed by Highway 93 South in Kootenay National Park (22%), Highway 40 in Kananaskis Country (12%), the TCH in Yoho National Park (10%), and the TCH in Banff National Park (10%). Calculating the average number of kills per mile for each highway in the study area, the majority of UVCs occurred on the TCH in the province of Alberta (13.6 kills/mile), followed by the TCH in Banff National Park (2.6 kills/mile), the TCH in Yoho National Park (2.1 kills/mile), Highway 40 in Kananaskis (2.1 kills/mile) and Highway 93 South in Kootenay National Park (1.8 kills/mile). These UVC rates followed traffic volume trends, which were highest on the TCH east of Banff National Park in the province of Alberta, followed by the TCH in Banff National Park, TCH in Yoho National Park, Highway 40 in Kananaskis Country, and Highway 93 South in Kootenay National Park. The road-kills/mile calculated for each highway in the study were rounded to the nearest whole number and used to classify each mile-marker segment (and the individual spatially accurate locations within that mile-marker segment) as a high or low kill zone (i.e. a mile-marker segment with greater than or equal to 2 road-kills in Kananaskis was a high kill zone, while less than 2 road-kills was a low kill zone).

5.2. Spatial Distribution of Road Kills

The spatial accuracy of the location where site related variables were measured for the spatially accurate locations was approximately $\leq$10 m. The UVC distributions from the spatially accurate dataset differed significantly from random distributions along all five highways in the study area (Kolmogorov-Smirnov one-sample test: TCH-Bow River Valley, $d=0.715$: Highway 93 South in Kootenay, $d=0.940$; TCH-Yoho, $d=0.892$; Highway 40 in Kananaskis, $d=0.874$; all $p<0.01$). The distribution of UVCs on Highway 93 South in Kootenay showed a significant aggregated distribution where the highway traversed the low valley bottom with 60% of the kills occurring along a 24 km (23%) stretch of road ($\chi2=63.9$, $p<0.0001$). The TCH in the province had the majority of mile markers associated with a road-kill (89%), followed by the TCH in BNP (86%), followed by highway 40 (84%), followed by 93S in KNP (61%), and the TCH in YNP (57%). Due to the non-random pattern and aggregation of UVCs, we addressed specific questions as to which landscape and road-vehicular factors contribute to this non-random distribution of collisions in the study area.

5.3. Models

5.3.1. Univariate tests

We measured site-specific variables at 499 sites from the spatially accurate data and 120 sites from the mile-marker dataset between April 2003 and July 2005. Only 499 UVC locations were used, because 47 UVC reports from Kootenay were excluded. These reports occurred prior to roadside vegetation clearance along a 24-km stretch of the Kootenay Highway 93 South. Table 3 shows the results of the univariate comparison of each environmental variable contributing to the probability of UVCs in each dataset. Both datasets had variables in each group that were significant in detecting differences between UVC high and low kill zones within all the datasets.

To reduce intercorrelation between the variables (Zar 1999), we omitted the percentage forest cover from further analyses as they were highly correlated ($r>0.70$) with percent cleared ground.

Within the spatially accurate dataset, Table 3 shows six of the field-based variables (habitat class, topography, forest cover, cleared ground, adjacent land slope, and road width), while only two of the field variables (road width and topography) were significant from the mile-marker dataset. In both datasets, more UVCs occurred when the topography was flat, and when the roads were wide. In the spatially accurate dataset more UVCs occurred than expected in open forest habitat and fewer UVCs occurred than expected in coniferous forest and rocky areas.

Within the landscape features variables, distance to drainage and barrier-guardrail were significant (negatively correlated) in the spatially accurate dataset; i.e., more UVCs occurred than expected closer to drainages perpendicular to the roadway and closer to barriers-guardrails (including Jersey barriers). No distance to landscape features were significantly correlated to the low or high kill zones in the mile-marker dataset.

Within the GIS-derived variables, area of open water was significantly negatively correlated to the dependent variable in the spatially accurate dataset, while only measure of barrier length was significantly negatively correlated in both datasets. Less open water and shorter lengths of barriers were associated with high kill zones.

Table 3: Results from the univariate comparison of factors contributing to UVCs

Variable	**Spatially accurate**			**Mile-marker**		
	High	Low	p-value	High	Low	p-value
Field Variables						
Habitat			<0.0001			
Rock	2	11				
Coniferous forest	144	177				
Open forest mix	112	54				
Topography			<0.0001			0.0035
Flat	241	172		24	12	
Buried-raised	32	71				
Forest cover	46.7	53.3	0.0256			
Openness	47.3	41.6	0.0496			
Adjacent land slope	11.4	15.9	0.0059			
Road width	34.1	24.8	0.0001	19.51	15.2	0.0300
Distance to Landscape features						
Drainages	2389.9	3068.9	0.0003			
Barrier-guardrail	627.0	1052.2	0.0003			
GIS generated buffer variables						
Barrier length	272.7	353.2	0.0182	336.51	548.4	0.0036
Open water	49.2	109.8	0.0001			

This table shows comparison using a spatially accurate dataset (n=499; 391 high and 108 low density points) and mile-marker dataset (n=120; 63 high and 57 low density points). 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 at $p<0.05$ are displayed.

5.3.2. Logistic regression analysis

Both models ranked differently in their ability to predict the observed likelihood for UVCs (Table 4). The log likelihood ratio test for the two datasets showed the spatially accurate model was statistically significant ($p<0.0001$), but the mile-marker model was not significant ($p=0.584$). For the spatially accurate model, the Hosmer and Lemeshow statistic was higher than the mile-marker model. The predictive capabilities of the spatially accurate model correctly classified 81.8 %, while the mile-marker model correctly classified only 64.4% of the selected UVC data. Model validation accuracies were 76.9 % for the spatially accurate model and 63.3% for the mile-marker model.

Type of habitat was the most important variable in explaining UVCs in the spatially accurate dataset. Ungulate-vehicle collisions were less likely to occur near open water, deciduous forest, closed coniferous forest, and open forest mix relative to open habitat. Kills were 2.7 times less likely to occur in wet habitat relative to open habitat areas. Further, distance to drainage was a significant negative correlation on the occurrence of UVCs in the spatially accurate model. The distance to barrier-guardrail had a negative correlation on UVCs and the length of barriers within the buffer was a negative correlation. In the mile-marker model, barrier length was significantly negatively correlated with more UVCs.

Table 4: Results from the logistic regression analyses for modeling the factors contributing to UVCs

Variable	Spatially accurate		Mile-marker	
Habitat				
Water	1-			
Coniferous forest	4-			
Deciduous forest	5-			
Open forest mix	2-			
Distance to drainage	3-			
Barrier-guardrail	N/A+			
Road width	N/A+			
Barrier length	N/A-		1-	
Open water	N/A-			
Hosmer and Lemeshow test	0.764		0.512	
Model development & validation accuracies (%)	81.8	76.9	64.4	63.3

Results from the logistic regression analyses for modeling the factors contributing to UVCs using two datasets; a spatially accurate dataset (n= 499 locations; 391 high and 108 low density points) and a mile-marker dataset (n=120; 63 high and 57 low density points) 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 and overall cross-validation accuracies are included. (*N/A the standard deviation in the logistic regression output was = 0.)

6. DISCUSSION

6.1. Summary of UVC data

For our analysis, we used the largest database of its kind with spatially accurate information on the occurrence and specific location of WVCs. The traffic mortality database is also unique in that it spans a relatively short time period (1999-2005), whereas other databases, regardless of their spatial accuracy, often contain road-kill information from a decade or more. The short time span used in this analysis is important because over long time periods, environmental variables may change (e.g., roadside vegetation and motorist visibility, habitat quality), as can road-related variables (guardrail and Jersey barrier installation, road widening and improvements, lighting), thus confounding analysis and resulting in spurious results.

The clustering of WVCs previously has been explained by parameters such as animal distribution, abundance, dispersal, and road-related factors including local topography, vegetation, vehicle speed, and fence location or type (Puglisi et al. 1974, Allen and McCullough 1976, Case 1978). But few studies have demonstrated that WVCs are correlated with traffic volume (McCaffery 1973, Allen and McCullough 1976, Case 1978, Hubbard et al. 2000). The majority of UVCs in our analysis took place in the provincial section of the TCH followed by Highway 93 South in Kootenay National Park. However, when the road-kill frequencies were standardized by highway length in our study area, we found that the rate of road-kill was positively correlated with traffic volume.

Other factors besides traffic volume alone may influence collision rates, but may be masked if a more detailed and rigorous analysis is not conducted. Previously, we found that elk-vehicle collision rates were significantly different between road types in our study area and declined over time on the TCH in Banff and Yoho National Parks and Highway 93 South (Clevenger et al. 2002). In this analysis, we isolated the effects of traffic volume and elk abundance on elk-vehicle collision rates, the latter being particularly important. Significant interactions indicated that road type influenced these effects and greater elk abundance led to increased elk-vehicle collisions. Of the five highways included in our study, the relative abundance of ungulates is highest in the provincial section of the TCH and Kootenay River Valley along Highway 93 South. The other highways (TCH-Banff, TCH-Yoho, Highway 40) are situated at higher elevations and have lower ungulate densities. Few studies investigating factors influencing WVCs have included data on animal abundance (but see Bellis and Graves 1971, Puglisi et al. 1974, Clevenger et al. 2002).

6.2. Models of UVCs

6.2.1. Spatial distribution and aggregation

The spatial distribution of UVCs on all five highways in the study area was not random. The most notable aggregation was along the 24 km stretch of highway on 93 South. This segment of highway bisects key ungulate ranges in the valley bottoms of the montane region, with elevation less than 1240 m (Poll et al. 1984).

Several environmental and road-related variables had high explanatory power in describing UVCs on all highways and these variables were dependent on the spatial accuracy of the dataset. Results of the univariate analysis demonstrated that the spatially accurate dataset had substantially more significant variables (n=10 variables) explaining the factors associated with UVCs than the mile-marker dataset (n=3 variables).

6.2.2. Predictive ability of datasets

Univariate tests

Among the field-based variables, only two were identified in the mile-marker dataset as being significant in detecting differences between UVC high and low kill zones. The same variables were also identified among the six significant variables in the spatially accurate dataset. Two of the variables from the distance to landscape features and GIS-generated buffer variables were significant from the spatially accurate dataset, whereas the mile-marker dataset had none.

Univariate tests are often used as a preliminary step to identify variables (or combinations of them) that are most likely good predictors of responses to include in an a priori logistic regression analysis (Hosmer and Lemeshow 1989). The results of the univariate tests of significance provide an interesting comparison of how well each dataset is able to describe the relationship between predictor variables and the location of UVCs. Of the 22 variables used in the initial univariate test to identify variables that differed significantly between high and low UVC kill zones, 10 or roughly half of the spatially accurate variables compared to only 3 (ca. 10%) of the mile-marker variables were statistically significant.

Logistic regression analysis

Results of the logistic regression analysis for the two datasets analysed in this study showed the spatially accurate model was statistically significant, however, the mile-marker model was not. Further, both of the models differed considerably in how well they predicted the likelihood of UVCs. The same results and strong support of the predictive ability of the spatially accurate model compared to the mile-marker model was found when they were validated with 20% of the data not included in their development. These results provide overwhelming evidence of the accuracy and utility of spatially accurate data on UVCs when investigating factors that are likely to explain accidents.

6.2.3. Factors that explain collisions

Our spatially accurate model indicated that adjacent habitat type was the most important variable in explaining UVCs. The proximity to open habitat increased the likelihood of UVCs as opposed to habitats characterized by open water, deciduous forest, closed coniferous forest, and open forest mix. Gunther et al. (2000) reported that elk were involved in accidents significantly more often than expected in non-forested cover types. Many deer-vehicle accidents in Pennsylvania were concentrated around woodland-field interfaces in predominantly open habitat (Bashore et al. 1985). On the other hand, some studies have not found an association between habitat type and UVCs (Allen and McCullough 1976, Biggs et al. 2004). Wildlife tends to be associated with specific habitats that provide resources and environmental conditions that promote occupancy and survival (Morrison et al. 1992). Thus, the spatial distribution of habitat types adjacent to or bisected by a highway transportation corridor would likely influence the extent, severity and locations of vehicle collisions with wildlife.

Landscape variables other than habitat and topography may also be important attributes determining UVCs. For example, distance to nearest drainage was significant and negatively correlated with the occurrence of UVCs in the spatially accurate model. Ungulates had a greater tendency to be involved in traffic accidents close to drainages systems. Drainage systems are known travel routes for wildlife, particularly in narrow glacial valleys such as Banff's Bow Valley (Clevenger et al. 2001). Furthermore, research has shown that topography, particularly road alignment with major drainages, strongly influences the movement of ungulates toward roadways and across them (Bellis and Graves 1971, Carbaugh et al. 1975, Mansfield and Miller 1975, Feldhammer et al. 1986, Reeve 1988).

The proximity to potential barriers such as Jersey barriers and guardrails was an important predictor of UVCs in the study area. The same result was found when measuring the length of Jersey barrier or guardrail within the 800 m buffer in high and low UVC kill zones. UVCs were found to occur closer to barriers such as jersey barriers and guardrails, which may be because animals are funneled to the ends of the barriers and cross the highway at this point. Furthermore, animals were killed when the length of barriers within the 800 m buffer decreased. These results suggest that the barrier is obstructing animal movement and funneling animals to barrier ends, or particular features in the landscape associated with barriers such as lakes and steep topography are deterring animals from approaching the highway at these locations. Barnum (2003) found that animals crossed more frequently at culverts, bridges, and at-grade crossings with no guardrail or median barrier. The only study modeling UVCs that included guardrails in the analysis also found that animals tended to avoid highway sections with these potential barriers, i.e. collisions were less likely to occur where barriers were present (Malo et al. 2004).

The results have important ecological implications as they suggest that median barriers and guardrails may obstruct animal movement across highways. Further, the results have important management implications because state transportation agencies are constructing highway median barriers with virtually no information on how they affect wildlife movement and mortality. Despite these potential impacts, the 2003 AASHTO Roadside Design Guide does not address the impact of median barrier installation. Resource managers and transportation biologists have identified this as a severe shortcoming that needs immediate attention. A recent Transportation Research Board report highlighted the urgent need to better understand how wildlife respond to and are potentially impacted by highway barriers (Transportation Research Board 2002).

6.2.4. Spatial accuracy and interpretation of results

In the mile-marker dataset few landscape variables were significant. For example level or gentle topography, which would have been due to the flat terrain, is bisected by the TCH in the province of Alberta. Further, road width was a significant explanatory variable due to the twinning of the TCH in the province of Alberta. Both these variables were not as dependent on spatial accuracy, because they were broad scale measurements with low variability occurring on large sections of the highway.

None of the distance to feature variables were significant in the mile-marker dataset. These types of variables are strongly dependent on spatial accuracy of reporting UVCs. For example, if an UVC location has an error up to 800 m this will be evident in the measurement of these variables.

The GIS-generated buffer variables could be used to measure factors associated with UVCs in a mile-marker dataset (Malo et. al 2005). The buffer encompasses the entire area in which the UVCs would have occurred, thus the factors associated with that road-kill are incorporated into the measurement of the variables. Barrier length was a significant explanatory variable in both datasets and area of open water was marginally significant in the mile-marker dataset. These variables would have to be a broad scale landscape feature such as the area of a feature within the buffer.

6.2.5. Conclusions from dataset comparison

The primary result of this analysis was that a UVC model developed with spatially accurate location data had high predictive power in identifying factors that contribute to collisions. But perhaps more noteworthy from this exercise was the vast difference in predictive ability between the models developed with spatially accurate data on one hand and less accurate data obtained from referencing UVCs to a mile-marker system. This lends strong support to a categorical distinction between high kill vs. low kill UVC zones (or where they are less likely to occur) when modelling is performed with spatially accurate UVC data.

Modelling animal-vehicle collisions has been carried out at a range of spatial scales, from local to state- and nation-wide analyses (Hubbard et al. 2000, Nielsen et al. 2003, Malo et al. 2004, Saeki and Macdonald 2004, Ramp et al. 2005). Previous studies have used readily available data (carcass or collision statistics) to identify variables that influence the risk of animal-vehicle collisions and recommend measures to reduce their numbers. These studies have largely relied on referencing collision data several ways: (1) accepting and using location data (point data) or highway segments with animal-vehicle collisions ("hotspots") without knowledge of the inherent spatial error (Bellis and Graves 1971, Bashore et al. 1975, Finder et al. 1999, Biggs et al. 2004, Seiler 2005), (2) referencing to a highway mile-marker system (Hubbard et al. 2000), (3) referencing to a 0.1-mile-marker (or 0.1-km) system (Puglisi et al. 1974, Malo et al. 2004, Saeki and Macdonald 2004, Huijser 2006a), or (4) using spatially accurate UTM locations (<10 m error) obtained by a GPS unit at the location of accident (Clevenger et al. 2002; Ramp et al. 2005, 2006).

The above review of published studies illustrates that many studies that modeled animal-vehicle collisions typically have used data with a significant amount of spatial error, by relying on a mile-marker system, or equally flawed approach by not being able to verify the degree of spatial error associated with the collision data being used. One study that rigorously measured the reporting error in the Canadian Rocky Mountain parks found it was on average 516 + 808 m, and ranged from 332 ± 446 m to 618 + 993 m (see Clevenger et al. 2002, section 4.2). The average distance reporting error of the Royal Canadian Mounted Police (highway patrol) animal-vehicle collision records in the same study area was 2154 ± 1620 m (n = 26 records).

Plotting animal-vehicle collisions on maps using grid coordinates may not improve spatial accuracy. In the above study the average distance reporting error, associated with road-kill records with UTM grid, coordinate references on occurrence reports and mortality cards from the mountain national parks was 969 ± 1322 m (Clevenger et al. 2002). The work we present here is the first to our knowledge to test the value of spatially flawed data by comparing model performance results with a spatially accurate dataset. Besides learning about the parameters that contribute to UVCs in our study area, we discovered here that spatially accurate data does make a significant difference in the ability of models to provide not just statistically significant results, but more importantly biologically meaningful results for transportation and resource managers responsible for reducing UVCs and improving motorist safety. Modelling collision-related parameters with spatially inaccurate data will inevitably lead to spurious results at best and thus not produce properly directed or applied mitigation of traffic-related accidents with wildlife.

The results have important implications for transportation agencies that may be analyzing data that has been referenced to a mile-marker system, or unknowingly is spatially inaccurate. These implications are equally important for statewide analyses or even the smaller districts. Spatially inaccurate data would be suitable for coarse scale analysis to identify UVC hotspots, but for finer scale needs (project or district level) more accurate data will be essential for a rigorous analysis and development of sound mitigation recommendations.

A national standard for the recording of animal-vehicle collisions would not only stimulate transportation departments and other organizations to collect more spatially accurate road-kill data, but it would also allow for a better integration and analyses of the data. Some transportation agencies are also beginning to use Personal Data Assistants (PDA's) in combination with a GPS for routine highway maintenance activities (eg, Washington State; Huijser et al. 2006b). These two initiatives can help agencies to collect more spatially accurate and standardized data that will eventually lead to more informed analyses for transportation decision-making.

6.2.6. Landscape vs road-related variables

Wildlife tends to be associated with specific habitats, terrain, and adjacent land use types. Thus, landscape spatial patterns would be expected to play an important role in determining road-kill locations and rates (Forman and Alexander, 1998). Explanatory factors of wildlife road-kills vary widely between species, which are often explained by habitat preferences and species abundance patterns (Clevenger et al. 2003, Ramp et al. 2005). Increasingly studies are beginning to look at the types of variables that explain wildlife-vehicle collisions, whether they are associated with landscape and habitat characteristics or physical parameter related to the road environment (Seiler 2005, Saeki and Macdonald 2004, Gunson et al. in prep). In our study 22 variables were evaluated; 11 associated with landscape or habitat attributes and 9 associated with the road environment. In the univariate analysis, 10 variables were significant in explaining UVCs; 8 were related to landscape, while only 2 were associated with the road environment. In the logistic regression analysis, 3 explanatory variables were significant, 2 were landscape-based and 1 was from the road environment. These results demonstrate the importance of ecological attributes in our analysis and suggest that analyses failing to adequately consider ecological variables in UVC analyses, in addition to road-related variables, logically will provide spurious results.

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