A SPATIAL ANALYSIS OF MOOSE-VEHICLE COLLISIONS IN MOUNT REVELSTOKE AND GLACIER NATIONAL PARKS, CANADA

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ABSTRACT: Moose (*Alces alces*)-vehicle collisions (MVC) can be costly ecologically by affecting population numbers, economically by vehicle damage, and socially through human injury or mortality. The purpose of this paper is to identify factors related to moose ecology, driver behaviour, and road design that are useful for predicting the spatial location of MVC on the Trans Canada Highway dissecting Mount Revelstoke and Glacier National Parks. We identified 6 subsets of logistic regression models and used Akaike's Information Criteria (AIC) to determine the most parsimonious model within each subset. In addition to this study being the first to examine collisions within these 2 parks, each of these 6 modelling procedures is unique in predicting MVC. Five of the six subsets modelled local-scale/field-based hypotheses of driver visibility, moose evidence, highway design, roadside vegetation, and moose habitat, while the sixth subset examined landscape-scale hypotheses through the use of a Geographic Information System (GIS). The Receiver Operator Characteristic (ROC) discriminated between MVC and random reference sites in order to validate the best fit model from each of the 6 subsets. A MVC probability map along the highway was created using the GIS model, providing a powerful and relatively efficient and inexpensive planning tool. The moose evidence model correctly classified the most MVC among the local-scale models. In relation to the spatial analysis, highway planning to reduce MVC risk within the parks should begin by assessing landscape-scale variables with emphasis on distance to wetland and landscape slope. This landscape-scale analysis should be followed by field-based modelling using moose evidence and habitat-related modelling with important predictors of moose tracks, game trails, and coniferous forest habitat. If highway planning cannot be effective in decreasing MVC, mitigation measures should include a public awareness program, speed reduction, and consideration of an alternative intercept foraging plan.

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Wildlife-Vehicle Collisions (WVC) are a serious problem in North America (Bashore et al. 1985, Child et al. 1991, Del Frate and Spraker 1991, Oosenbrug et al. 1991, Romin and Bissonette 1996, Finder et al. 1999). Nearly 3,000 moose-vehicle collisions occur annually in North America (Child 1998) and 200 – 300 moose are killed on major British Columbia highways each year (Child et al. 1991, Sielecki 2000). These figures are conservative and do not take underreporting into consideration or the unknown number of mortalities on mining, logging, and rural roads. If the impacts of trains are included, this number is approximately doubled within British Columbia (Child et al. 1991). Collisions can be costly ecologically by affecting population numbers, economically by vehicle damage and lost hunting opportunities, as well as socially through human injury and mortality.

Current statistical models are insufficient for predicting areas of high MVC. Seiler (2005) stated that more detailed knowledge of occurrence of preferred moose forage (Ball and Dahlgren 2002, Seiler 2005), embankment of the road (Clevenger et al. 2003), and driver visibility (Bashore et al. 1985) would increase the predictive power of past modelling attempts. Seiler (2005) noted how new mitigation policies require improved knowledge of the spatial distribution of collisions. Malo et al. (2004) suggest that WVC models should be used at both the landscape and local scales during the process of road design and implementation of mitigation measures.

The purpose of this paper is to predict the spatial occurrence of moose-vehicle collisions (MVC) along the Trans Canada highway through Mount Revelstoke and Glacier National Parks along with the associated correlated factors. MVC rates along this stretch of highway range from approximately 0.016 to 0.045 per kilometre per year (Sielecki 2004) for a total of 0.5 – 3 MVC per year within the parks. This MVC rate is relatively similar to outside of the park boundary; however, the reporting procedure within the park is more accurate for modelling purposes. The area is of high concern due to both the Trans Canada Highway and wildlife having limited movement options through narrow and high mountain passes. In addition, Parks Canada has a management objective to reduce the environmental impact of the transportation corridor, particularly on wildlife, vegetation, and aquatic ecosystems within the two National Parks.

To predict MVC and determine the related process, models were developed using factors that are measurable in either the field or using a Geographic Information System (GIS) (Finder et al. 1999, Malo et al. 2004, Seiler 2005, Gunson et al. 2006). Factors were included based on their contribution to ecological processes, moose biology, and driver attributes. The predictive capability of MVC was assessed by testing 6 different model subsets. The model with the best predictive ability within each subset was used as the final representative model to be compared among the 6 models. A landscape-scale model subset tested variables using GIS. Five field-based local-scale model subsets included highway design, moose evidence, roadside vegetation management, moose habitat, and driver visibility. By predicting MVC locations, their reduction could be looked upon from a proactive perspective. By focusing on preventative measures as opposed to relying on mitigation measures, the implementation is not as costly, ecologically, economically, or socially.

STUDY AREA

The study site was restricted to the Trans Canada Highway dissecting Glacier and Mount Revelstoke National Parks within the Rocky Mountain Highway district in South-Eastern British Columbia, Canada (Fig. 1). Rugged, steep terrain and frequent snow avalanches have resulted in limited transportation corridor alignment (Woods and Munroe 1996). The operation of this segment of the Trans Canada Highway therefore faces numerous challenges including steep grades, extreme and variable weather, slope, rock instability, and collisions with wildlife (Woods and Munroe 1996). Parks Canada is responsible for the planning,

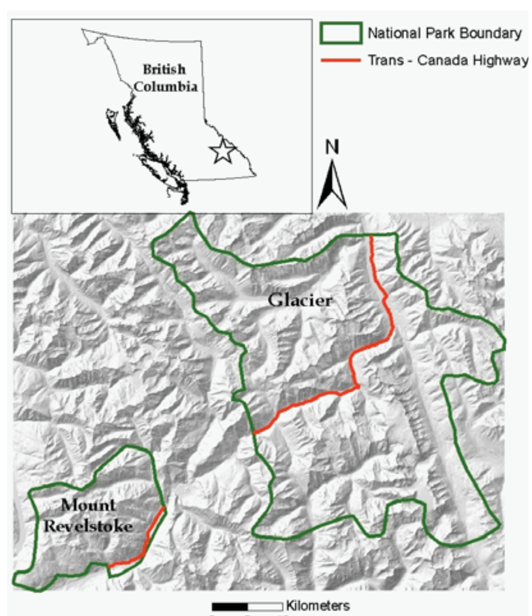

Fig. 1. Regional setting of Glacier and Mount Revelstoke National Parks

construction, and operation of the highway within the National Park Boundaries.

Glacier and Mount Revelstoke National Parks encompass 3 biogeoclimatic zones, the Interior Cedar Hemlock (ICH), Englemann Spruce-Subalpine Fir (ESSF), and the Alpine Tundra Zone (AT). The ICH is primarily comprised of old-growth cedar (*Thuja plicata*) and mountain hemlock (*Tsuga mertensiana*). In the ESSF, the lower subalpine forests are dominated by Englemann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), and mountain hemlock. Mean annual precipitation is 700-3,000 mm, most of which (70 – 80%) falls as snow (Meidinger and Polar 1991).

METHODS

Data Collection

MVC data were contributed by Mount Revelstoke and Glacier National Parks (John Flaa, personal communication, Parks Canada). MVC records date back to 1968. The location of each MVC was recorded by park wardens by either marking the collision on a map or by recording the collision location using a Global Positioning System (GPS) unit. An assumption was made that the reporting system has remained consistent throughout its existence. The primary reporting method transformation was from map marking to GPS use in the year 2000, representing 80% and 20% of MVC locations using each respective method. The UTM co-ordinates were recorded in a database along with date of kill, hour of kill, and information regarding the number and species of wildlife. The UTM coordinates for each MVC were plotted onto the highway layer within the study area using ArcGIS (ESRI 2005).

The study encompassed a spatial analysis of 55 MVC locations along with 60 randomly generated reference points so that logistic regression could be used to contrast highway points with and without MVC (Fig. 2). Reference points were created by randomly generating numbers that represented distances along the highway. Road distances started at 0 km from the southern entrance of Mount Revelstoke National Park and extended to the Northern entrance of Glacier National Park. Random reference points that shared the coordinates with a snow shed were not included.

Changes in land cover due to natural or human disturbance over time were assessed using Parks Canada stand origin data. This assessment explored the assumption that correlations could be studied between independent variable data collected in one season with MVC data spanning nearly 4 decades. Both coniferous and deciduous cover has regenerated since the right of way was cleared for highway construction in 1962. This effect on the assumption does not warrant concern as the first recorded collision was 6 years after highway construction. Since highway construction there have not been significant alterations of the highway with the exception of routine roadside brushing. No significant natural disturbances have occurred within the 500 m highway buffer area since highway construction.

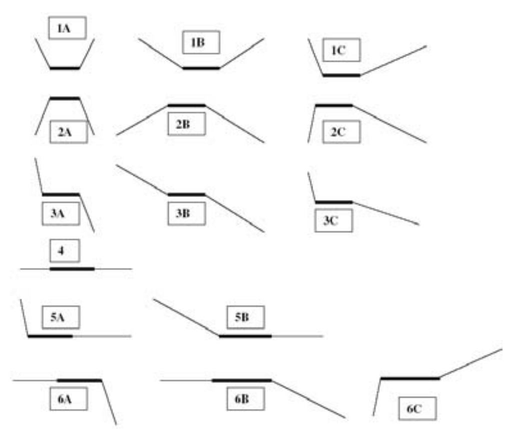

Fig. 2. Topographical Slope Classes assessed at each point. The thick lines represent the highway and the thin lines represent the adjacent land slope. 1A, 1B, 1C, 2A, 2C, 6A, and 6B were excluded from model development due to their infrequent occurrence. Source: Gunson et al. 2006.

Depending on accuracy and availability of spatial data, each variable was either measured in the field (local scale) or using GIS (landscape scale). We chose variables based on their potential to influence moose distribution and collision frequency. Although a large number of factors might explain MVC, we used past studies and our knowledge of the study area to select potentially relevant explanatory variables.

Landscape-scale Variable Analysis (GIS)

We used a GIS to measure 15 landscape-scale variables (500 m radius) (Table 1). All continuous variables were averaged within the 500 m radius buffer centered on each collision and random point. A 500 m buffer around each location represented the road-effect zone (Forman and Alexander 1998). The road-effect zone is the area that encompasses the majority of ecological effects resulting from road construction and use and is typically the focus of planning and mitigation (Forman 1999). A minimum of 500 m was kept between random reference points upon creation in order to ensure independence. The 500 m radii represented the area over which collision attributes were sampled using a GIS at the landscape-scale.

We used British Columbia Provincial Government Terrain Resource Information Management (TRIM) spatial data in GIS to represent highway segments, elevation, slope, and aspect. All TRIM data had a scale of 1:20,000 with a resolution of 25 m by 25 m cell size. Topographical criteria were included due to the inherent nature of moose migration from hills to valleys during the winter (Gundersen et al. 1998, Hundertmark 1998). Thus, measures of slope and aspect were included in an effort to gain insight into the effects of moose movement on MVC.

The distance to water bodies and wetland were measured due to the fact that moose seek aquatic habitats for drinking water, insect relief, aquatic forage, and thermoregulation

Table 1. Landscape-scale variables measured at each MVC site and reference point to model the factors that determine moose-vehicle collision locations within Mount Revelstoke and Glacier National Parks from 1962 to 2002.

Variable	Definition	Unit
Aspect (GIS)	Mean aspect within 500 m buffer	degrees
Built (GIS)	Distance to the nearest human development	m
Crossroad	Distance to nearest crossroad (maximum 500 m)	m
Elevation (GIS)	Elevation above sea level generated using a digital elevation model	m
Forest Edge	Distance to nearest forest edge perpendicular to road (maximum 500 m)	m
Hiking (GIS)	Distance to the nearest hiking trail	m
High Use Habitat (GIS)	Area of high moose habitat within 500 m buffer as per Parks Canada data	m^2
Land Cover (GIS)	Dominant land cover type within 500 m buffer	Shrub/ Coniferous/ Mixed
Lines (GIS)	Distance to the nearest communication line	m
Rail (GIS)	Distance to the nearest railway line	m
Risk Sign (GIS)	Distance to nearest wildlife-risk sign	m
Slope (GIS)	Mean slope within 500 m buffer	degrees
Water (GIS)	Distance to the nearest water body boundary	m
Water Int	Distance to nearest water intersection with the road (maximum 500 m)	m
Wetland (GIS)	Distance to the nearest wetland boundary	m

(Peek 1998). The distance to water and wetland criteria were extracted from British Columbia TRIM data. We measured the presence/absence of high use habitat at each collision and reference point to determine the relationship of MVC with critical habitat range. The dominant land cover type was determined within a 500 m buffer to further assess habitat-related attributes and also potential effects on driver visibility. Habitat classification and land cover data within Mount Revelstoke and Glacier National Parks were based on Parks Canada Ecological Land Classification (ELC) at a scale of 1:50,000 (Achuff et al. 1984).

We used GIS to record the distance from each MVC to rail lines, power lines, hiking trails, and built areas. The distance to rail and power lines was based on Parks Canada spatial data while the distance to built areas was extracted from British Columbia TRIM data. Rail lines are plowed in the winter, providing a potential movement corridor. In addition, the vegetation clearance within rail line and power line corridors creates the potential for the presence of early seral forage. The distance to built areas was examined to see if human development affects the occurrence of MVC by means of habitat alteration, human activity, and potential predator avoidance (Malo et al. 2004, Seiler 2005). Hiking trails were included in the models to examine the potential for increased movement, predation, and effect of human use on moose distribution. For example, Kunkel and Pletscher (2000) found moose to be more vulnerable to wolves at sites closer to trails and streams.

We used a GPS in the field to measure the distance of each MVC location from the nearest wildlife risk sign and highway curvature. We used the distance to wildlife risk sign criteria to assess the role of driver awareness on MVC. The distance to highway curvature was analyzed to assess driver visibility at a landscape-scale.

Spatial representation of GIS model — Using landscape-scale GIS data, we developed a model with the structure:

$$Y = \frac{\exp(\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k)}{1 + \exp(\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k)}$$

where Y is the predicted probability of a MVC and β_k are coefficients based on environmental variables x_k (Manly et al. 1993). The predictive MVC probability surface was created using 25-m x 25-m pixel resolution (Fig. 3).

Local-scale Variable Analysis

From June to August 2005, we collected data for local-scale analyses. We used a GPS to locate each MVC and random reference sites in the field and then we recorded 29 local-scale variables (Table 2). Variables ranged from habitat related to driver and highway attributes, each contributing to one of the 5 local-scale model subsets.

Habitat — At each site, habitat characteristics were measured using a variety of methods. These data served as proxy measures of

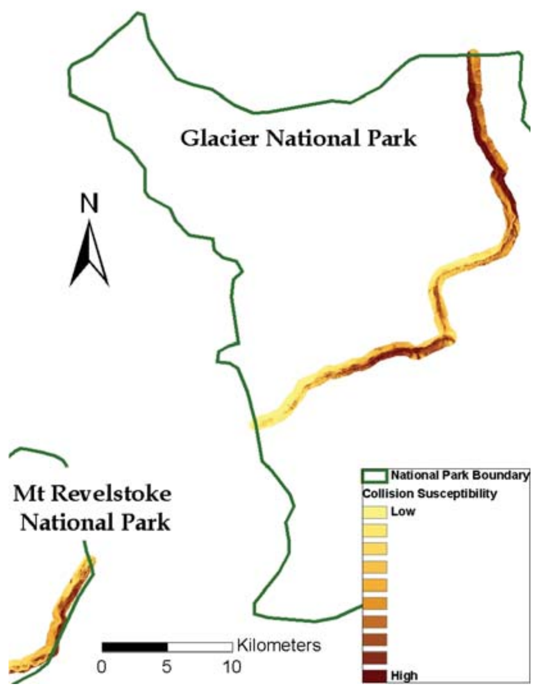

Fig. 3. Probability surface showing the likelihood of MVC for Mount Revelstoke and Glacier National Parks using the GIS model.

Table 2. Local-scale variables measured at each site and reference point to model the factors that determine moose-vehicle collision locations.

Variable	Definition	Unit
Ang 5 m	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	m
Ang 10 m	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	m
Browse	Presence of browse within 100 m transect	P/A
Browse (Roadside)	Presence of browse within 25 m transect	P/A
Corridor Width	Width of highway corridor clearance including pavement	m
Dist Cover	Mean distance to vegetative cover (trees and shrubs >1 m high) taken from both sides of the road	m
Ditch	Presence of ditch adjacent highway	P/A
Ecotone	Presence of an ecotone	P/A
Game Trail	Absent/Low/High	A/L/H
Habitat Class	Within a 100 m radius: percent cover type being Mixed Forest (MF)/Coniferous Forest(CF)/Wetland(W)/Shrub(S)	OFM/CF/W/S
Inline	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	m
Jersey Barrier	Presence of jersey barrier	P/A
Median	Presence of median	P/A
Passing Lane	Presence of a passing lane	P/A
Pellets	Presence of pellets within 100 m transect	P/A
Pellets (Roadside)	Presence of pellets within 25 m transect	P/A
Roadside Age Class	Highest age of shrub within 25 m transect	(1-3 yrs) (4-6 yrs) (7-10 yrs)
Roadside Vegetation	Type of vegetation species within 25 m transect	P/A
Slope (0-5 m)	Mean slope of the land 0-5 m perpendicular to the pavement edge taken from both sides of the road	degrees
Slope (5-10 m)	Mean slope of the land 5-10 m perpendicular to the pavement edge taken from both sides of the road	degrees
Slope (10-30 m)	Mean slope of the land 10-30 m perpendicular to the pavement edge taken from both sides of the road	degrees
Speed	Mean recorded speed of passing vehicle	km/h
Topo	Terrain slope category	
Tracks	Presence of tracks within 100 m transect	P/A
Tracks (Roadside)	Presence of moose tracks within 25 m transect	P/A

Note: The levels used in distinguishing the qualitative variables were presence-absence (P/A), continuous-discontinuous-absent (C/D/A) and those presented in the corresponding definitions.

forage quantity and quality and thus potential attractants of moose to highway corridors. We placed 25 m transects perpendicular to the highway and measured plant species presence and age at 5 m intervals within 4 m^2 quadrats. Shrub ages were assessed to determine the most recent year of roadside clearing. The highest age of a shrub within the 25 m transect was used as an indicator of time since the roadside was cleared. We also recorded evidence of browsing, moose tracks, and pellets within each quadrat.

Some roadside vegetation species were grouped into families due to their low occurrence. Western mountain ash (*Sorbus scopulina*) and saskatoon berry (*Amelanchier alnifolia*) were grouped into the rose family. Narrow-leaved hawkweed (*Hieracium umbellatum*), common dandelion (*Taraxacum officinale*), pearly everlasting (*Anaphalis margaritacea*), yarrow (*Achillea millefolium*), and oxeye daisy (*Leucanthemum vulgare*) were classified under the sunflower family. Species that were rarely present (1 – 3 occurrences) and could not be grouped into a family were excluded from modelling. The remainder of roadside vegetation was modelled at the species level (Table 3).

We placed a 100 m transect perpendicular to each side of the road to quantify land cover and assess the roadway for presence of moose. Land cover was defined as Mixed Forest (MF), Coniferous Forest (CF), Wetland (W), or Shrub (S). We recorded the dominant land cover class at 10 m intervals on the transect. Evidence of moose included wildlife trails, pellets, tracks, or browse. If the highway bisected two habitat types, this ecotone was noted. Ecotone was used as a variable to investigate any habitat edge effect that could potentially be correlated with MVC. The distance to the nearest forest edge perpendicular to the road was measured up to a maximum buffer zone radius of 500 m. The distance to crossroads and water bodies intersecting the road were also measured in the same manner. The distance to crossroads was tested to determine whether intersections with potential movement routes influence the opportunity of a collision.

Human and wildlife movement — We recorded a number of highway attributes that might influence the movement of wildlife and the ability of drivers to avoid a MVC. We used an inclinometer to measure the slope immediate to the roadbed (0 – 5 m), the verge (5 – 10 m), and the adjacent land (10 – 30 m). We also identified each site as occurring within one of 6 local topographic classes identified by Gunson et al. (2006) (Fig. 2). The slope and topographic measurements tested whether embankments had positive or negative relationships with moose-vehicle collisions.

Driver visibility — Driver visibility was measured as the shortest distance to the point at which a car becomes out of sight of an observer from 3 different locations adjacent the highway. Field visibility variables measured the extent to which a motorist could see moose on the right-of-way. Since it could

Table 3. Roadside vegetation species present within quadrats and included in modelling.

Species	Modelling Name
Common Horsetail *(Equisetum arvense)*	HORSETAIL
Grass	GRASS
Willow *(Salix* sp.*)*	WILLOW
Red-Osier Dogwood *(Cornus stolonifera)*	DOGWOOD
Sitka Alder *(Alnus crispa)*	ALDER
Western Red Cedar *(Thuja plicata)*	CEDAR
Spruce *(Picea* sp.*)*	SPRUCE
Thimbleberry *(Rubus parviflorus)*	THIMBLEBERRY
Common Red Paintbrush *(Castilleja miniata)*	PAINTBRUSH
Black Twinberry *(Lonicera involucrata)*	TWINBERRY
Spreading Dogbane *(Apocynum androsaemifolium)*	DOGBANE
Lupine *(Lupinus* sp.*)*	LUPINE
Aspen *(Populus tremuloides)*	ASPEN

not be determined from what side or which direction a vehicle struck an animal, 4 visibility measurements were taken at each site, 2 facing each direction, on each side of the highway. One in-line (from road edge) and 2 angular measurements were measured (5 m and 10 m from the road edge). Recognising that trucks were more visible at greater distances than cars or motorcycles, visibility distances were always measured using trucks. The mean distance to vegetative cover (trees and shrubs > 1 m high) was measured on both sides of the road to determine driver visibility. The corridor width was the total area cleared for the highway including a combination of roadside clearance on both sides of the highway and the highway pavement width.

Highway and driver influence — The presence/absence of roadside ditches was recorded because they might influence visibility and animal movement. The presence/absence of jersey barriers, passing lanes, and medians were tested to explore additional barrier effects resulting from highway design and construction. The average speed limit was read by means of a Bushnell Radar Gun. Highway speed was recorded as the mean of 20 vehicles (10 vehicles going in each direction). Actual vehicle speed was recorded as opposed to speed limit due to the inherent nature of vehicles surpassing posted limits. Traffic volume was not included in model development due to the absence of variability within the study area. All distances were measured using a range finder (Bushnell Yardage Pro 1000). Presence/absence and continuous/discontinuous variables were estimated visually.

Data Analysis

Due to the binary nature of the dependent variable (0 = reference, 1 = collision), and the inclusion of categorical independent variables, the data were analyzed using bivariate logistic regression. The variables were grouped into 6 different logistic regression model subsets and Akaike's Information Criteria (AIC) was used to determine the most parsimonious model within each subset. The use of model selection criteria enabled inference to be drawn from several models simultaneously, so that a 'best set' of similarly supported models could be chosen (Johnson and Omland 2004). We identified subsets of models that contained related sets of variables so that unique phenomena explaining MVCs could be more easily isolated, understood, and adapted to mitigation strategies. Five subsets modelled local-scale/field-based hypotheses and one subset examined GIS landscape-scale hypotheses. The first local-scale subset consisted of parameters that affected the driver visibility of moose. The second subset included the variables that indicated the evidence of moose in the terrain perpendicular to the highway. Highway design was assessed in the third subset. The fourth subset examined roadside vegetation species and age in order to relate MVC to roadside management practices in the parks. The fifth local-scale subset tested moose habitat features and influences. A final AIC comparison was completed among the best AIC local-scale models previously identified from each subset in order to identify the most parsimonious model overall. This round of AIC did not include the landscape-scale GIS models in its comparison due to the difference in scale relative to the 5 local-scale models.

In addition to the 6 models which explored variables grouped into common hypothesized subsets, 2 combination models were developed to help further reveal the MVC phenomena. We recognise that these interaction models were not initial hypotheses, but arose as exploratory analyses of results from the 6 model subsets. Variables chosen for interactions included those that previously showed significance in the original models (Hosmer and Lemeshow 2000).

To reduce multicollinearity among the modelled variables (Zar 1998), correlation screening was completed prior to model development using a Pearson correlation matrix which compared each variable combination, and removed those that were highly correlated ($r > 0.75$) (Seiler 2005). In the GIS model subset, the distance to communication lines was omitted from further analysis as it was highly correlated (Pearson correlation coefficient of 0.89) with the distance to railway and showed a lower correlation with MVC points (Pearson correlation coefficient of 0.45 as opposed to 0.49). In the driver visibility model subset, angular visibility 5 m was eliminated as it was highly correlated with inline visibility. Angular visibility 5 m was chosen to be eliminated as opposed to inline as angular visibility 5 m is measured in between inline and angular visibility 10 m thus providing a larger range of measurements. In addition, inline is also taken from the road edge closer to where a collision occurs. Also in the driver visibility model subset and the highway design model subset, slope (5 – 10 m) was highly correlated with slope (0 – 5 m). To provide a greater range of slope measurements, slope (5 – 10 m) was eliminated as it is intermediate to the other two slope measurements (0 – 5 m and 10 – 30 m).

Odds ratios were examined to assess the contribution that a unit increase in the independent variable made to the outcome probability (Tabachnick and Fidell 1996). Wald statistics were used to test the significance of the individual independent variables. We used the sign of the coefficient to determine the direction of influence of the independent variables on the collision probability.

Each topographic and distance variable was modelled as a simple linear and then a quadratic term. We used the quadratic form for further model comparisons if the more complex variant had an AIC score of <2 points relative to the simple linear form. For the GIS variables, quadratic terms were included in further modelling for the 3 topographic variables of elevation, slope, and aspect. For the driver visibility variables, the quadratic terms for inline visibility and angular visibility at 10 m were included for further modelling.

We used the change in deviance to assess the model fit and the Cook's distance to examine high-leverage points which may have been influential to the analysis (Menard 2001). The 3 points with the highest leverage were investigated to determine the location in the parks, and the corresponding change in coefficient when excluded in the analysis. After both statistical and biological consideration, the points remained in the model as 95% of the cases were within +/- 2 (Menard 2001).

Autocorrelation had to be corrected, as the significance and corresponding inferences of the explanatory variables was important (Neilsen et al. 2002). Autocorrelation was assessed using PASSaGE by calculating the Moran’s I using the unstandardized model residuals and distance between points. Robust standard errors were estimated using the Huber/White sandwich estimator in the program STATA (2002) to correct for autocorrelation (Huber 1967, White 1980). The Huber/White sandwich estimator is robust to clustering (Bifulco and Ladd 2006) and decreased the potential for type I errors by correcting to more conservative significance levels (Lennon 2000).

Model Validation

The Receiver Operating Characteristic (ROC) was used to determine the degree of correct classification. ROC uses an approach that is independent of probability cut-off levels (Boyce et al. 2002). ROC validation was developed using independent data not included during model creation. Twenty percent of the total data points were excluded for model validation. To represent the variance associated with the process of choosing validation data, we repeated the ROC procedure 5 times. Each iteration used a different set of randomly selected collision and reference points. This validation procedure was followed for each of the 6 different models.

RESULTS

AIC Model Comparison

The use of AIC in model comparison showed selection uncertainty being within plus or minus 2 ΔAIC between two of the best models in certain subsets meaning a small difference in performance. This development of small ΔAIC should be acknowledged as the first and second best AIC models could be interchanged as the model of choice were replication to occur. This small ΔAIC was, however, expected due to the model hypotheses often only differing in one variable to assess whether that certain factor is of critical importance to the susceptibility of MVC.

Driver visibility model subset — Of the 10 driver visibility candidate models, the Vehicular/Human Influenced hypothesis provided support as the most parsimonious with an AIC_w of 0.436 (Table 4). This final model included the variables of vehicle speed, corridor width, and presence/absence of passing lanes. Adding variables of roadside slope or visibility distance to this model did not contribute to the AIC_w (AIC_w = 0.283 and 0.224, respectively). The AIC_w for the additional hypotheses were approximately zero and were therefore excluded from Table 4. Speed was essential in explaining MVC in the Driver Visibility model, exerting a positive influence on the odds of MVC (Table 5). Corridor width displayed a significant effect in both the Driver Visibility models; MVC were more likely with increasing corridor widths.

GIS model subset — The Topographic Influence and Water Body hypothesis was selected as the final model of the 9 candidate models within the GIS subset (AIC_w = 0.537) (Table 6). Within this model, topographic variables included slope, aspect, and elevation while water bodies included lakes, rivers, and wetlands. The Topographic Influences and Wetland model hypothesis resulted in the next highest AIC_w (AIC_w = 0.299) while Topographic Influences and Moose Movement was also included in Table 6 with an AIC_w of 0.159. Five models were excluded from Table 6 due to low AIC_w such as the Human Built model using variables of hiking trails, distance to rail, and distance to built area. When slope was examined as an individual variable within the GIS model, a similar influence was found with MVC being correlated to flat slopes (Table 7). Additional topographic variables which were significantly correlated to MVC in the GIS/Driver Visibility model but not the GIS model alone included elevation and aspect. The distance to wetland had the most influence in the GIS model, ahead of slope, with MVC occurring significantly closer to wetland. The GIS model produced the highest ROC score at 96%.

Roadside vegetation model subset — Of the Roadside Vegetation Models, the Forage Species hypothesis had the greatest AIC_w, although the weight was only 0.504, suggesting

Table 4. Results of driver visibility AIC candidate model selection within Mount Revelstoke and Glacier National Parks.

Hypothesis/Model	Variables	K	-2LL	AIC	AIC_w
Vehicular/Human Influenced	SPEED + PASSING LANE + CORRIDORWIDTH	4	132.7	140.71	0.44
Adjacent Roadside Slope and Vehicular/Human Influenced	SLOPE(0-5M) + SLOPE(10-30 M) + PASSING LANE + SPEED + CORRIDORWIDTH	6	129.53	141.53	0.28
Vehicular/Human Influenced and Visibility	INLINE + INLINE$_2$ + ANG10 + ANG10$_2$ + PASSING LANE + SPEED + CORRIDORWIDTH	8	125.93	141.93	0.22

Note: Shaded row represents the final model to be used.

Table 5. Logistic regression analysis results for the best driver visibility AIC model.

Variable	β	S.E. (Robust)	*W*	*P* (Robust)
Speed*	0.16	0.05	10.05	0.00
Corridor Width*	0.05	0.02	7.26	0.03
Passing	-0.13	0.49	0.07	0.80
Constant	-16.97	4.7	12.09	0

*$P < 0.05$

Table 6. Results of GIS AIC candidate model selection within Mount Revelstoke and Glacier National Parks.

Hypothesis/Model	Variables	K	-2LL	AIC	AIC_w
Topographic Influences and Water Bodies	ELEVATION + ELEVATION^2 + SLOPE + SLOPE^2 + ASPECT ASPECT^2 + WETLAND + WATER	9	44.08	62.08	0.54
Topographic Influences and Wetland	WETLAND + ELEVATION + ELEVATION^2 + SLOPE + SLOPE^2	6	51.35	63.35	0.3
Topographic Influences and Moose Movement	ELEVATION + ELEVATION^2 + SLOPE +SLOPE^2 + ASPECT + ASPECT^2 + HIKING + RAIL	9	46.52	64.52	0.16

Note: Shaded row represents the final model to be used.

Table 7. Logistic regression analysis results for the best GIS AIC model.

Variable	β	S.E. (Robust)	*W*	*P* (Robust)
Wetland*	-0.00	0.00	9.80	<0.0001
Slope*	-1.05	0.30	7.44	<0.0001
Slope^2*	0.02	0.01	4.96	0.00
Aspect^2*	3.0×10^4	1.0×10^4	4.31	0.04
Elev^2	-4.0×10^5	2.0×10^6	3.309	0.058
Aspect	-0.085	0.0479	2.664	0.076
Elev	0.055	0.034	2.475	0.112
Water	0.001	0.003	0.135	0.707
Constant	0.958	16.380	0.004	0.953

*$P < 0.05$

considerable uncertainty in model selection (Table 8). Variables included in this model were selected to approximate moose browse as reported in the literature. Shrub Age alone or when combined with Forage Species did not help to explain further variation. Four model hypotheses were not included in Table 8 due to each exhibiting a low AIC_w. One of the four models excluded from Table 8 was based on non-forage species with an AIC_w of 0.041. Within the Roadside Vegetation model, the presence of grasses was positively correlated to MVC sites, while the presence of alder significantly decreased the likelihood of a kill (Table 9).

Moose habitat model subset — The Land Cover Type hypothesized model was the most parsimonious of the Moose Habitat candidate models ($AIC_w = 0.479$) (Table 10). The addition of the distance to water inter-

Table 8. Results of roadside vegetation AIC candidate model selection within Mount Revelstoke and Glacier National Parks.

Hypothesis/Model	Variables	K	-2LL	AIC	AIC_w
Forage Species	WILLOW + DOGWOOD + ALDER + CEDAR + ASPEN + HORSETAIL + GRASS + SPRUCE + ROSE	10	139.09	159.09	0.5
Forage Species and Shrub Age	ROADSIDE AGECLASS + WILLOW + DOGWOOD + ALDER + CEDAR + ASPEN + HORSETAIL + GRASS + SPRUCE + ROSE	11	138.48	160.48	0.25
Shrub Age	ROADSIDE AGECLASS	2	157.4	161.42	0.17

Note: Shaded row represents the final model to be used.

Table 9. Logistic regression analysis results for the best roadside vegetation AIC model.

Variable	*β*	S.E. (Robust)	*W*	*P* (Robust)
Grass*	1.08	0.52	5.19	0.04
Alder	-0.98	0.52	4.05	0.06
Spruce	1.15	0.63	3.70	0.07
Horsetail	-0.88	0.47	3.62	0.06
Dogwood	0.76	0.62	1.67	0.22
Willow	0.73	0.61	1.41	0.23
Rose	-0.31	0.54	0.41	0.57
Cedar	-0.56	1.03	0.37	0.59
Aspen	-0.14	0.48	0.08	0.78
Constant	-0.91	0.62	2.26	0.14

$*P < 0.05$

sections to this Land Cover model decreased the AIC_w (AIC_w = 0.441). The remainder of the candidate hypotheses all had AIC_w under 0.01 and were excluded from Table 10. For example the distance to water and wetland alone resulted in an AIC_w of 0.004. Coniferous forest exerted a significant positive influence on the odds of a MVC within the Moose Habitat model (Table 11).

Moose evidence model subset — The AIC_w was 0.529 for the Trails and Transect Evidence hypothesized model, providing support as the most parsimonious of the Moose Evidence candidate models (Table 12). This model included moose evidence within the 100 m transect as well as the presence/absence of game trails. The candidate models with only Trails (AIC_w = 0) or only Transect evidence (AIC_w = 0.048) performed poorly on their own and were not included in Table 12. The inclusion of roadside tracks, browse, and pellets did not help to explain variance of the best model (AIC_w = 0.315) nor were the roadside variables effective predictors on their own (AIC_w = 0). Evidence of moose was positively correlated with MVC sites with the presence of tracks being the most important, followed by the presence of game trails (Table 13). This best AIC moose evidence model of Trails and Transect Evidence correctly classified 86% of MVC using ROC.

Highway design model subset — The comparison of the 9 Highway Design candidate models resulted in the Highway Corridor Engineering hypothesis as being the final (AIC_w = 0.553) (Table 14). The Full Model, which included the additional variable of distance to crossroad, was no more parsimonious

Table 10. Results of moose habitat AIC candidate model selection within Mount Revelstoke and Glacier National Parks.

Hypothesis/Model	Variables	K	-2LL	AIC	AIC_w
Land Cover Type	CF + OFM + WETLAND + SHRUB	5	141.53	151.53	0.48
Proximity to Aquatic Habitat and Land Cover Type	OFM + CF + SHRUB + WETLAND + WATERINT	6	139.68	151.68	0.44
Full Model	ECOTONE + FORESTEDGE + WATERINT + CF + OFM + WETLAND + SHRUB	8	137.6	155.62	0.06

Note: Shaded row represents the final model to be used.

Table 11. Logistic regression analysis results for the best moose habitat AIC model.

Variable	β	S.E. (Robust)	*W*	*P* (Robust)
Coniferous forest*	0.04	0.01	8.68	0.00
Shrub	-0.04	0.02	3.42	0.05
Wetland	0.04	0.03	2.71	0.18
Mixed forest	0.00	0.01	0.05	0.80
Constant	-0.97	0.81	1.22	0.23

*$P < 0.05$

Table 12. Results of moose evidence AIC candidate model selection within Mount Revelstoke and Glacier National Parks.

Hypothesis/Model	Variables	K	-2LL	AIC	AIC_w
Trails and Transect Evidence	TRAIL + TRACKS + BROWSE + PELLETS	5	94.43	104.43	0.53
Full Model	TRAIL + TRACKS + BROWSE + PELLETS + TRACKSROAD + BROWSEROAD	7	91.4	105.42	0.32
Roadside Evidence and Transect Evidence	BROWSE + TRACKS + PELLETS + TRACKSROAD + BROWSEROAD	6	95.73	107.73	0.1

Note: Shaded row represents the final model to be used.

Table 13. Logistic regression analysis results for the best moose evidence AIC model.

Variable	β	S.E. (Robust)	*W*	*P* (Robust)
Tracks*	1.89	0.60	10.63	0.00
Pellets	2.47	1.62	5.53	0.13
Trail			6.72	
Trail(high)*	1.62	1.33	2.04	0.02
Trail(low)	0.21	0.60	0.04	0.88
Browse	0.96	0.59	1.95	0.11
Constant	-2.93	0.50	4.91	<0.0001

*$P < 0.05$

Table 14. Results of highway design AIC candidate model selection within Mount Revelstoke and Glacier National Parks.

Hypothesis/Model	Variables	K	-2LL	AIC	AICw
Highway Corridor Engineering	TOPO + SLOPE(0-5 M) + SLOPE(10-30M) + MEDIAN + JERSEY + PASSING LANE + CORRIDORWIDTH + DITCH	9	130.89	148.89	0.58
Full Model	TOPO + DITCH + SLOPE(0-5 M) + SLOPE(10-30M) + MEDIAN + JERSEY + PASSING LANE + CROSSROAD + CORRIDORWIDTH	10	130.8	150.84	0.22
Moose Movement	TOPO + SLOPE(0-5 M) + SLOPE(10-30 M) + CROSSROAD + JERSEY + CORRIDORWIDTH + DITCH	8	135.71	151.71	0.14

Note: Shaded row represents the final model to be used.

Table 15. Logistic regression analysis results for the best highway design AIC model.

Variable	*β*	S.E. (Robust)	*W*	*P* (Robust)
Corridor width*	0.06	0.03	10.05	0.03
Passing lane	0.75	0.49	2.07	0.13
Slope (0-5 m)	-0.03	0.02	1.85	0.13
Median	-1.16	1.02	1.50	0.26
Ditch	-0.29	0.53	0.34	0.58
Jersey barrier	0.20	0.47	0.14	0.67
Slope (10-30m)	0.00	0.01	0.01	0.93
Topo			8.87	
Topo(2b)	0.57	1.24	0.51	0.64
Topo(3a)	-1.35	0.87	-1.59	0.12
Topo(3b)	-1.57	0.90	-1.7	0.08
Topo(3c)	0.91	1.31	0.81	0.49
Topo(4)	0.35	0.91	0.41	0.70
Topo(5a)	-0.42	0.89	-0.44	0.64
Topo(5b)	-0.41	0.98	-0.44	0.67
Topo(6C)	-1.21	1.18	-1.03	0.30
Constant	-2.24	1.37	-1.94	0.10

$^*P < 0.05$

(AIC_w = 0.215). The hypothesis that variables associated with moose movement resulted in a model with a lower AIC_w (AIC_w = 0.144). The additional highway design hypotheses modelling smaller variable groupings were all under AIC_w of 0.1 and not included in the tables. One example of a highway design model under an AIC_w of 0.1 was using the variables of topographic class, slope, and presence of ditches. Corridor width displayed a significant effect in both the Driver Visibility and the Highway Design models (Tables 5 and 15, respectively). In each model, MVC were more likely with increasing corridor widths. The Highway Design model showed the poorest performance among the model subsets with a 46.2% ROC score.

Interaction models — The first model combined GIS and driver visibility models to explore both human/animal effects and the 2 scales at once (Table 16). Slope-speed, slope-corridor width, wetland-speed, and wetland-corridor width were included as interactions. In the GIS/Driver Visibility interaction model, MVC were more likely to occur in flat areas with greater speeds. When GIS was combined with Driver Visibility, the interaction model was lower than GIS alone, yet still impressive, correctly classifying 92.4% of points. The second combination model included variables from the moose habitat and driver visibility models. Interaction terms consisted of coniferous forest with both speed and highway corridor width (Table 17). No factors were found to show significance in the Moose Habitat/Driver Visibility interaction model. When Driver Visibility was combined with moose habitat, the interaction model had a higher ROC score than the Driver Visibility model alone, yet was still poor; only correctly classified 65.7% of the points.

ROC Validation

Swets (1988) identifies 70 – 90% discrimination ability as reasonable and rates higher than 90% as very good discrimination because the sensitivity rate is high relative to the false positive rate. Using this 70% as a minimum threshold, the acceptable models after ROC validation in descending order include GIS, GIS + Driver Visibility, Moose Evidence, and Moose Habitat. Highway Design, Roadside

Table 16. Logistic regression analysis results for the best GIS/driver visibility interaction AIC model.

Variable	β	S.E. (Robust)	W	P (Robust)
Slope x Speed*	-0.02	0.01	6.21	0.02
$Elev^2$	-9×10^{-5}	5.0×10^{-5}	5.513	0.050
$Aspect^2$	4.36×10^{-4}	1.7×10^{-4}	5.343	0.008
Elev	0.138	0.077	5.073	0.072
$Slope^2$	0.023	0.012	4.098	0.053
Aspect	-0.129	0.053	3.920	0.015
Slope x Width	0.008	0.004	3.537	0.053
Wetland x Speed	-2.0×10^{-5}	7.8×10^{-6}	2.825	0.026
Wetland x Width	1.0×10^{-5}	9.3×10^{-6}	0.381	0.326
Water	-0.002	0.003	0.127	0.611
Passing	-0.047	0.961	0.002	0.961
Constant	-27.371	29.065	1.856	0.345

*$P < 0.05$

Table 17. Logistic regression analysis results for the best moose habitat/driver visibility interaction AIC model.

Variable	β	S.E. (Robust)	W	P (Robust)
Wetland	0.044	0.028	3.395	0.124
Shrub	-0.036	0.022	2.333	0.102
Coniferous Forest x Width	0.001	3.0 x 10-4	2.215	0.117
Passing	-0.511	0.438	1.327	0.243
Coniferous Forest x Speed	2.0 x 10-4	2.0 x 10-4	0.879	0.307
Mixed forest	0.009	0.014	0.345	0.520
Constant	-1.254	0.900	1.573	0.050

*$P < 0.05$

Vegetation, Driver Visibility and the Moose Habitat/Driver Visibility models were below the 70% threshold (Table 18). The final AIC test among the best local-scale model from each of the 5 subsets strongly supported the Moose Evidence model as the most parsimonious (AIC_w = 1.0), adding further support to its ROC score of 86% as the strongest field-based MVC predictive model.

DISCUSSION

Model Performance

Although ROC scores for the GIS, GIS and Driver Visibility Interaction, Moose Evidence, and Moose Habitat models exhibited reasonably high discrimination, results should be interpreted with caution. As the study area is within a National Park, the land processes outside park boundaries, such as forestry, may have exerted a greater influence on areas close to the park entrance over those near the centre of the park. As the study area is situated within both a high mountain pass and a protected area, the transportation challenges and ecological processes are unique. The model results should therefore not be directly extrapolated to other areas. If the models were to be used elsewhere, the structure could be kept intact with site-specific variables appropriately adapted to the location and species. We assumed that land-use remained constant over the reporting period, although minor changes were most likely inevitable despite the National Parks having been managed in a relatively constant ecological state.

Additional caution should be used when interpreting these models as not all of the collisions that have occurred in the past were reported. The total number of collisions involving motor vehicles and large animals in Canada has generally been underestimated by 20 – 30% (Damas and Smith 1982). Examples of these reporting discrepancies include the unknown taking of carcasses before highway contractors are alerted, carcasses falling out of sight or animals moving away to die at unknown locations. In addition, drivers may report the collision to another jurisdiction or fail to report a minor collision, instead paying for the damages privately (Sielecki 2004).

The varying degrees of unexplained variation present among the models can be attributed to a complex array of other potential factors. The models were developed using the data and techniques available and were not inclusive of all possible variables. Examples include traffic volume or moose density measures previously shown to have successfully explained WVC (Bashore et al. 1985, Finder et al. 1999, Clevenger et al. 2003, Malo et al. 2004). Notwithstanding the inclusion of additional variables, unexplained variation may be due to one simple factor such as weather, driver alertness, or moose behaviour. There is a possibility that the inclusion of Mount Revelstoke MVC in the overall model affected prediction accuracy due to the 16 km distance gap between parks. The two parks

Table 18. Model ROC Validation results on the best AIC model from each subset.

Model	ROC Validation	S.E.	AIC_w
GIS	96%	0.035	n/a
GIS + Driver Visibility	92.4%	0.061	n/a
Moose Evidence	86%	0.076	1.0
Moose Habitat	70.2%	0.115	0
Moose Habitat + Driver Visibility	65.7%	0.117	0
Driver Visibility	63%	0.12	0
Roadside Vegetation	59.2%	0.123	0
Highway Design	46.2%	0.126	0

do, however, share ecosystem characteristics and are managed under one division of Parks Canada. In addition, the spatial error in reporting MVC locations may have affected local-scale analysis which relied on fine-scale measurements based on the assumption that locations were accurate.

Interpretation of Contributing Factors

Speed was found to have a significant relationship with MVC in the Driver Visibility model. Higher speeds leading to a greater chance in MVC is a logical finding and provides support to the literature, although Seiler (2005) and Malo et al. (2004) modelled speed limit as opposed to actual radar speed. The width of the road was significantly correlated to MVC in both the Driver Visibility model and the Highway Design model, although these 2 models were poor predictors overall. MVC sites were found at highway locations with greater corridor width than reference sites. Clevenger and Waltho (2000) found that wildlife use of highway passages was positively correlated with road width. Improved visibility due to greater vegetation clearance may not have displayed importance as the bulk of accidents in the 2 parks occurred at night. A similar trend could explain the low correlation of MVC with distance to road curve, inline visibility, and angular visibility. Gunson et al. (2006) accredited the lack of MVC explanation at curved highway sections to a decrease in vehicle speed while Joyce and Mahoney (2001) found more MVC at night due to increased moose activity. Furthermore, roadside brushing likely augments the risk of collision by maintaining early seral vegetation, which attracts wildlife to the highway (Child et al. 1991, Rea 2003). Other studies have provided support for animals preferring to cross highways that are closer to vegetation cover (Jaren et al. 1991, Clevenger et al. 2003, Malo et al. 2004, Seiler 2005). These contradicting theories of increased visibility and increased moose attraction may have led to the poor predictive abilities of the Driver Visibility and Highway Design models. The positive correlation between a wider highway corridor width and MVC may simply be a function of the highway being reduced to narrow widths along steeper sections. Both corridor width and speed no longer showed significance when combined with coniferous forest. This interaction finding compliments Seiler (2005) where the distance between forest cover and the road was significantly correlated to MVC; however, if vehicle speed was increased, the effect of forest proximity was weakened. Coniferous forest as a single variable in the Habitat model was, however, significant. Coniferous forest has been found to be an important habitat type, with moose use ranging from 31 – 49% use per season in central British Columbia (Perry 1999). Mixed forest was, however, not found to be a significant contributor to the Habitat model. Perry (1999) found mixed coniferous/deciduous forest to be of slightly less important moose habitat, being selected 26 – 41% per season. In addition, moose avoid wolves by spacing out and escaping into patches of conifers (Kunkel and Pletscher 2000).

The largest influence on MVC in the GIS model was observed in the slope variable which had a negative influence on the probability of a MVC. A relatively flat slope has been related to MVC in previous studies (Gunson et al. 2006, LeBlanc and Martel 2006). Clevenger et al. (2003) found that mammals were more likely to cross when the highway was level with the adjacent terrain. Where the two national parks are within the Selkirk Mountain range, this effect may be magnified due to the narrow valley corridors and limited gentle sloping landscapes. Snow accumulation is less in the valley bottoms, providing important ungulate habitat in the late autumn, winter, and early spring (Woods and Munroe 1996). The rugged mountain terrain forces both wildlife and human movement through the valley passes (Woods and Munroe 1996). The majority of

MVC within Mount Revelstoke and Glacier National Parks have occurred in winter months providing support for this theory.

Distance to wetland showed a significant correlation to MVC within the GIS model whereas the distance to water did not. Moose seek aquatic habitats for drinking water, insect relief, aquatic forage, and thermoregulation (Peek 1998). The distance from water to MVC locations may not show a correlation simply due to the general fact that there are lakes and rivers dispersed throughout the parks and not in one particular area.

The poor prediction ability of the roadside vegetation model may be attributed to a relatively homogeneous highway corridor throughout the 2 parks. Moose are browsing specialists with 90% of average diets being shrubs and trees (Perry 1999). Many of the preferred shrub species for moose were relatively common at both MVC and reference locations. The presence of grass was the only significant variable within the Roadside Vegetation model and this may have been due to the overall scarcity of grasses in the steeper, higher elevation reference point locations, instead being more prevalent within the flat valley highway segments. Shrub age most likely did not contribute to the AIC_w in Roadside Vegetation candidate models due to the majority of roadside shrubs being toward the 4 to 6-year-old range throughout the entire park.

Moose tracks and high-use game trails significantly contributed to MVC. Although a 100 m transect perpendicular to the highway on either side requires time and effort, moose sign can be a simple indicator of MVC locations. Roadside moose evidence was not included in this final model as its AIC_w was not improved after inclusion in the full model or on its own. Roadside evidence may not have improved the model due to the presence of roadside browsing at the majority of both MVC locations (89%) and reference points (75%).

Scale-dependent Factors

Similar to Gunson et al. (2006), models at the landscape-scale can be a powerful first step in assessing contributing variables within the process of explaining where MVC occur. This landscape-scale/GIS approach shows promise due to its relatively efficient and inexpensive operation. The field-based models may have shown less predictive ability than the landscape-scale model, but were nevertheless important for examining local-scale processes and revealing factors important at both scales of analysis. For this reason, we created the GIS and Driver Visibility interaction model; although, the ROC score for this interaction model was no higher than that of the GIS model on its own.

Although the Moose Habitat and Moose Evidence models suggested that habitat was a strong predictor of MVC, the distance to high use habitat and land cover variables in the GIS model subset were not present in the AIC best GIS model. The explanation for this difference in predictability between the different models seems to be a scale-dependant issue where local effects within 100 m such as forest type and moose evidence are more proficient in their prediction of MVC when using direct habitat variables. Often, availability of habitats is defined by multiple scales; however, the actual use of the habitat is restricted to one scale (Johnson et al. 2002). In addition, the landscape-scale area identified as high use habitat or land cover type might not have been selected for by moose and if so it may be so only at certain times of the year, thus introducing a temporal aspect to the model. Joyce and Mahoney (2001) suggest that MVC occur in areas of low and high moose density. High-quality habitat might be vacant or only occupied by a certain sex and this can counter model suggestions, being explained only by a concept called "Umwelt" (Von Uexkull 1921, 1937). Predictions from an anthropogenic perspective are thus complex as the Umwelt concept states that animals have programmed neurohormonal cues in how the environment is interpreted which can be species, gender, social, or season dependant (Bubenik 1998). The models were created using variables stemming from an anthropogenic perspective, however, human impressions on where moose should live do not ultimately determine where a moose will be.

An opposite scale-related phenomenon may have occurred within the Highway Design model where the poor predictive ability may be attributed to the local-scale variables being overshadowed by landscape-scale factors. The 100 m transect examined using the topographic class variable may not have been large enough to exhibit an influence on moose movement, instead requiring the use of landscape-scale topographic factors as seen in the GIS model. Linear landscape elements such as riparian corridors, ditches, steep slopes, and ridges may funnel animals alongside or across the roadway and thereby increase the risk of collisions (Malo et al. 2004, Seiler 2005). The importance of highway corridor width decreased when combined with landscape-scale factors of slope and wetland in the GIS/Driver Visibility interaction model. The speed and slope interaction variable did, however, show significance when the models with two different scales were combined, suggesting MVC are correlated to locations with higher vehicle speeds and lower slope values.

Management Implications

GIS is a powerful tool in the initial identification of high risk areas for highway planning with field work only being required where local-scale mitigation measures are needed. If the need for local-scale analysis is required, the Moose Evidence and Habitat should be modelled due to their reasonably high predictive abilities. Attention should be focused on highway segments close to wetland, at flat slopes, adjacent wider highway corridors, presence of coniferous forest, moose evidence, and at higher vehicle speeds.

Improved road planning is the primary practice that should be regarded as the means to reduce the ecological effects that transport infrastructure impose. This study has helped observe some of the underlying processes that contribute to MVC within the parks. The Trans Canada Highway in Mount Revelstoke and Glacier National Parks, is a well established transportation route and mitigation measures will be the only option unless road alteration or new construction occurs. Although the processes within the predictive models are best suited for highway planning, the knowledge can be used as a basis for mitigation decisions. An effective and acceptable countermeasure should reduce animal-vehicle interactions while still allowing for necessary animal behaviour and movements (Bashore et al. 1985). Suggested measures include reductions in vehicle speed and intercept foraging. Reduction in vehicle speed may be difficult to implement in practice due to a requirement of additional enforcement which can be costly. Intercept foraging involves the development of alternative feeding sites away from the transportation corridor (Schwartz and Bartley 1991). Wood and Wolfe (1988) determined that intercept foraging was an effective short-term solution (reducing collisions by <50%); however, they cautioned that wildlife may become dependant on the supplemental food resulting in the attraction of additional wildlife. A fencing and wildlife underpass combination could be effective along the highway adjacent the Beaver River. Whenever possible, these mitigation techniques should be coupled with a public awareness program such as the Wildlife Collision Prevention Program in British Columbia. Complete reliance should not be put into educational programs to enhance public awareness about WVC as their success has not yet proven effective (Romin and Bissonette 1996), however these programs can be a starting point.

The models presented here may provide useful tools for road planners, but effective mitigation against MVC will require a more concrete approach that includes consideration of the landscape outside of park boundaries and more in-depth knowledge of the local moose populations. An example of further work would be to investigate actual moose movement in the study area using telemetry data to map key crossing points. These data in combination with the collision points and modelling could provide invaluable information helping to explain the process of MVC in the national parks.

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