Characterizing Moose–Vehicle Collision Hotspots in Northern British Columbia

Roy V. Rea,* Chris J. Johnson, Scott Emmons
Natural Resources and Environmental Studies Institute, University of Northern British Columbia, Prince George, British Columbia V2N 4Z9, Canada
Present address of R.V. Rea: 3333 University Way, Prince George, British Columbia V2N 4Z9, Canada

Abstract

To have a better understanding of the ecological factors that may contribute to moose *Alces alces* and vehicle collisions in northern British Columbia, we analyzed Wildlife Accident Reporting System data that were collected between 2000 and 2005 by highway maintenance contractors. We delineated 29 moose-vehicle collision hotspots and 15 control sites at which we assessed environmental and road infrastructure attributes through field surveys and remotely sensed data. A logistic regression model including both coarse- and fine-scale environmental factors suggested that hotspots were more likely to be characterized by the number of roadside mineral licks and bisection of the highway corridor through black spruce forest–sphagnum bog habitat and swamps. The absence of rivers within 1 km and less lake area within 500 m of the highway also better characterized hotspots than controls. At the fine scale, deciduous forest cover along the highway edge and the proportion of browse to nonbrowse vegetation between the road shoulder and forest edge were also related to collision sites. Based on these data, the mitigation of collision hotspots should include decommissioning roadside mineral licks where they occur and cutting roadside brush to improve driver visibility and reduce browse resprouting and attractiveness. Where new road construction or road realignments are being contemplated, we recommend considering routes with more lake area, more rivers, fewer swamps, and fewer black spruce forest–sphagnum bog habitats to help reduce collisions. We discuss the utility of installing novel warning signage in areas where collisions are recurrent.

Keywords: accident; automobile; collision; highway; hotspot; moose; ungulate

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* Corresponding author: reav@unbc.ca

Introduction

Resource extraction and land development are facilitating the expansion of road networks throughout the circumpolar distribution of moose *Alces alces*. The creation of linear corridors such as gas, power, and other utility right-of-ways provides habitat for moose (Thompson and Stewart 1998, Forman and Deblinger 2000), but attractive habitat in transportation corridors bring moose and high-speed traffic dangerously close to one another. One to two motorists and a minimum of 300–500 (Sielecki 2010), but possibly up to 1,200 (Child et al. 1991) moose are killed each year in British Columbia (BC), Canada in moose–vehicle collisions (MVCs). Material damages and costs associated with patient hospitalization, clean-up, lost time at work and other factors exceed 25 million Canadian dollars annually in BC (Sielecki 2010). Finding ways to characterize areas of high collision frequency is the first step toward developing appropriate mitigation measures to reduce their occurrence and associated costs.

Researchers have reviewed animal–vehicle collision data for numerous locations across North America and Europe (Finder et al. 1999, Malo et al. 2004, Ramp et al. 2005, Gunson et al. 2009) with some attention focused on identifying the factors that characterize locations where MVCs are most likely to occur (Seiler 2005, Dussault et al. 2006, Hurley et al. 2007, Mountrakis and Gunson 2009, Danks and Porter 2010). For example, in

Sweden (where peaks occur in December and January), MVCs were associated with factors such as traffic volume, speed, lack of wildlife fencing, and snow accumulations (Lavsund and Sandegren 1991, Seiler 2005) In eastern North America, temporal peaks in MVCs occur during the summer months (Mountrakis and Gunson 2009, Danks and Porter 2010) and have been linked to the abandonment of calves by cows, peaks in traffic volume (e.g., on holidays), and the use of roadside mineral licks (Joyce and Mahoney 2001, Leblond et al. 2007). Areas in Quebec with fewer lakes and rivers, but with abundant roadside forage and coniferous forest cover, best describe paths used by moose near highway corridors (Dussault et al. 2007).

Moose-related vehicle collisions in Alaska (Garrett and Conway 1999) and British Columbia (Sielecki 2010) peak in mid-winter (December and January). Migration of moose from higher elevation summer ranges with fewer roads to valley bottoms with more roads in winter (Edwards and Ritcey 1956, Boonstra and Sinclair 1984, Seip 1992) may influence MVC risk in western North America in ways that do not occur east of the Rocky Mountain Trench. Regardless of the mechanisms, temporal differences alone suggest that factors associated with MVCs in northwestern North America may be endemic and as such warrant special considerations (Gunson et al. 2011).

We used 5 y of MVC data (2000–2005) to develop a better understanding of the relationship between collision hotspots in northern BC and environmental (potential habitat) and road infrastructure characteristics. Our objectives were to 1) distinguish collision hotspots from areas with no history of collisions (Malo et al. 2004); 2) describe biotic and abiotic factors associated with hotspots, with particular attention given to assessing fine-scale environmental (habitat) characteristics in the field at collision-prone and collision-free sites; and 3) make recommendations for reducing collisions between motor vehicles and moose. Our hypothesis was that both coarse- (geographic information system- [GIS] derived) and fine-scale (site-specific) environmental and road infrastructure variables could help us identify and characterize collision hotspots.

Study Area

Our study area was located in northern BC, Canada, from Quesnel in the south to Wonowon in the north and from Prince Rupert along the Pacific west coast to the provincial border with Alberta. The north and east sections of the study area are characterized by rugged, mountainous terrain with deeply incised valleys (Child 1992), while terrain to the south and west is described as flat to rolling with hundreds of small lakes and wetlands (Heard et al. 1997). Aside from the study area being transected by the Rocky Mountains in the northeast, the majority of the area is a comparatively homogeneous unit occurring on an extensively ridged plateau of glacial till surrounding periglacial lake deposits, and dissected by many rivers, lakes, and wetlands (Child 1992). The landscape is dominated by coniferous forests of hybrid white spruce *Picea engelmannii* × *glauca* and subalpine fir *Abies lasiocarpa*. Lodgepole pine *Pinus contorta* var. *latifolia* and trembling aspen *Populus tremuloides* pioneer secondary successional sites (Meidinger and Pojar 1991), as do many species of willows *Salix* spp. and other woody browse plants used by moose. Moose densities in the region were between 1.2 and 1.5 moose/km^2 at the time of our study (Heard et al. 2001, Walker et al. 2006).

Methods

Identifying and assessing hotspots

We obtained Wildlife Accident Reporting System data from the BC Ministry of Transportation and Infrastructure using their Wildlife Accident Reporting System data use license agreement. Data requested and used to assess collision occurrence were MVC statistics from the most recently available 5-y period (1 January 2000–31 December 2005) for numbered highways in our area of study (approx. 150,000-km^2) within northern BC (Figure 1). The approximately 2,000 km of highway we studied were predominantly two-laned (lane width = 3.6 m; paved shoulder width = 0.5–2.5 m) highway (and were specifically: Highway 16—Prince Rupert to Alberta; Highway 97—Quesnel to Wonowon; Highway 29—Tumbler Ridge to Charlie Lake; Highway 52—Tumbler Ridge to Arras; Highway 49—Dawson Creek to Alberta; Highway 27—Vanderhoof to Fort St. James; Highway 5—Tete Juane Cache to Kamloops; Highway 2—Dawson Creek to Tupper; Highway 35—Burns Lake to Francois Lake; Highway 37—Kitimat to Cassiar; Highway 39—Mackenzie to Mackenzie Junction; Highway 118—Topley to Granisle). We were unable to correct MVC statistics to traffic volumes because such data did not exist for specific highway sections in and around our study sites for the seasons in which most MVCs occurred (British Columbia Ministry of Transportation and Infrastructure 2006). In general, Annual Average Traffic Volumes between 2000 and 2005 were between 3,000 and 24,000 vehicles/day (except Highways 29, 39, 52, and 118 for which there were fewer vehicles or no data existed; British Columbia Ministry of Transportation and Infrastructure 2006) where we conducted site assessments, but varied considerably by highway section under consideration and by day of the year.

Wildlife Accident Reporting System data were generated from carcass collections conducted along numbered highways throughout BC. These data were collected by maintenance contractors who spatially linked carcasses to a Landmark Kilometer Inventory. Data included in these records were species, nearest landmark, and day of the year, but not time of the day. Using these data and local expert opinion (Hurley et al. 2009) from an Interagency Working Group consisting of the Ministry of Transportation, The Royal Canadian Mounted Police, The Insurance Corporation of British Columbia, the British Columbia Conservation Foundation, The University of Northern British Columbia, Road Maintenance Contractors, and Northern Health, we delineated 29 MVC hotspots. The hotspots we identified were highway sections between 0.1 and 5 km in length

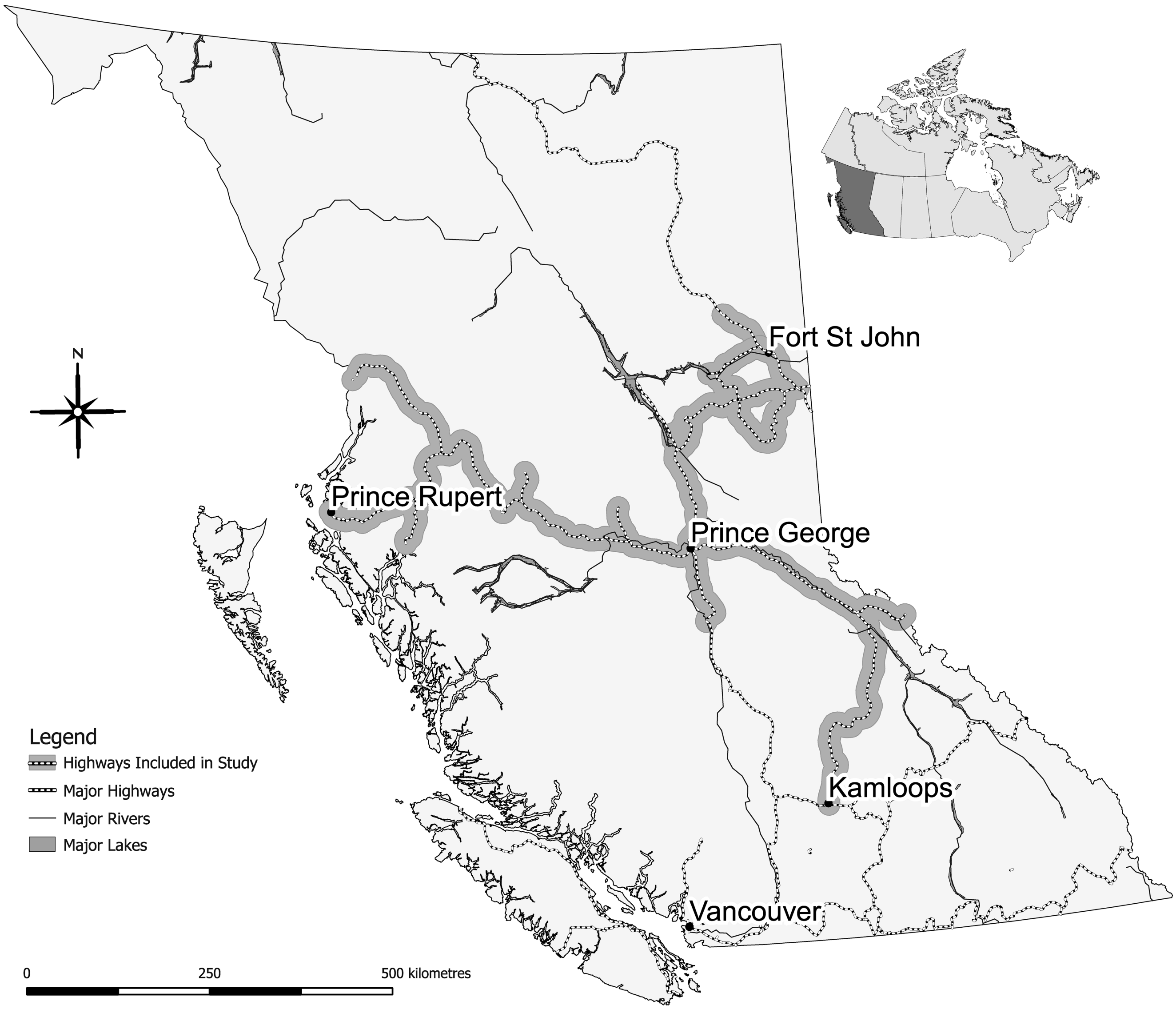

Figure 1. Map of the highways (buffered) within northern British Columbia, Canada, for which we analyzed Wildlife Accident Reporting System data obtained from the British Columbia Ministry of Transportation and Infrastructure for the purpose of identifying hotspots of moose *Alces alces*–vehicle collisions (between 2000 and 2005) and associated control (collision-free) sites.

where four or more carcasses per km had been collected and recorded in the Wildlife Accident Reporting System data base between 2000 and 2005 and verified as a hotspot by local highway maintenance contractors. Sites with fewer than four carcasses/km/5-y period were never deemed as hotspots by contractors and were too common for us to include in our assessments.

In addition to these 29 hotspots, we also delineated control sites based on strict criteria. First, as similarly described by Seiler (2005), we deemed that nonaccident control sites must have no recorded MVCs during the study period (in our case—per km and between 2000 and 2005). Second, control sites had to occur on the same highway segments as hotspots (having similar landscape-level, roadbed, and traffic attributes). Third, surrounding road- and fine-scale-level attributes could not vary significantly in nature from those of hotspots (e.g., the control could not be a bridge across a river or a highway segment within one of the approximately two dozen municipalities within our study area). After identifying candidate control sites, we used the average length of adjacent MVC hotspots to determine the length of linear highway to define the control (so that the linear feature we were assessing was of similar length to the hotspots), then once again checked to ensure that no MVCs had occurred throughout the entire length of that control site. Based on these criteria, we identified 15 control (with no MVCs; Seiler 2005) sites in our study area (which ranged between 0.5 and 3 km in length).

Data collection and analysis

We conducted site assessments at each hotspot and control site. Data from these fine-scale assessments were combined with coarse-scale GIS data and collated for analysis (Table S1). Our choice of individual factors for

Table 1. Fine (measured in the field)-, coarse (measured using remotely sensed data)-scale environment and road infrastructure (measured using field data and a digitized, visual recording of highway travel) variables collected in 2006 and 2007 and used for logistic regression models describing attributes found in areas with a high incidence of moose *Alces alces*–vehicle collisions (≥4 MVCs/km between 2000–2005; hotspot) and collision-free (control; no MVCs between 2000 and 2005) highway sites in northern British Columbia, Canada. Coarse-scale habitat data were sampled within a 500-m and 5-km radius of each site.

Variable name	Description
Fine-scale environment	
Number of licks	Total number of licks within each site
Shrub–grass index	The ratio of browse species to nonbrowse species and bare soil within the verge of each site
Verge vegetation height	Mean (to nearest 0.5 m) height of vegetation growing in the verge
Bog[a]	Presence–absence black spruce bog adjacent to highway sites
Deciduous mixed forest edge	Percentage of forest stand adjacent to road corridor characterized as mature deciduous leading, mixed species composition
Coarse-scale environment	
Elevation	Mean elevation above sea level (m) within each buffer
Aspect	Mean aspect (in degrees) of land within each buffer
Lakes	Total area (m^2) of lakes within each buffer
Swamp	Total area (m^2) of wetlands within each buffer
Tree species[a]	Predominant forest tree species (coniferous vs. deciduous) within each buffer
River	Presence of rivers within 1 km of each highway site
Linear	Total linear forest edge (m) within each buffer
Road infrastructure	
Posted speed	Posted speed limits in km/h
Wildlife warning signs	The number of deer and moose warning signs that identified any portion of the highway section under investigation
Double solid-center line	Percentage of highway site painted with double solid-center lines
Road curvature	Categorized using orthophotographs as no curvature (straight line), slight curvature (between 0 and 100th of a degree curvature/m), or sharp (>100th of a degree curvature/m)
Rumble stripping	Percentage of the site equipped with shoulder and center-line rumble stripping
Corridor width	measured (in m) from corridor edge to corridor edge
Ditch depth	Percentage of the site with ditches >3 m deep

[a] Indicates variable is a categorical variable.

measurement was based on the factors that appeared to contribute to MVCs in the wildlife–vehicle collision literature (e.g., Malo et al. 2004, Seiler 2005, Leblanc et al. 2005, Dussault et al. 2006), expert opinion (of Ministry of Transportation officials, local moose biologists, and maintenance contractors), or that we deemed important from our understanding of the life history of moose.

Fine-scale environmental variables. Fine-scale environmental variables (see Table 1) were measured within the highway rights-of-ways and included 1) roadside vegetation types and height (that could provide forage and impede driver sight lines), 2) the tree composition of forest edge (used by moose to access food and cover) along the transportation corridor, 3) the number of mineral licks (either natural or artificially created by road salt run-off) used by moose to obtain minerals, 4) the presence of wetland features such as bogs used by moose for obtaining aquatic forages, drinking, and insect avoidance. These were variables likely to influence moose movements and habitat-use patterns (Rea 2003, Seiler 2005, Dussault et al. 2006). We counted mineral licks by identifying areas of soil exposure characterized by moose tracks and networks of wildlife trails (Rea et al. 2004). We estimated the percentage of browse species cover and nonbrowse vegetation cover (grasses–forbs–aquatic plants and exposed soils) within the roadside verge (from the road shoulder to the edge of the corridor (approx. 10–20 m/side) at each site. Estimates were made by a trained systematic botanist with 12 y of experience doing moose browse surveys using recommendations provided by Rutherford (1979) for ocular estimates. Estimates were made from the roadbed at 100-m intervals along the verge (for ease of record-keeping) or with each vegetation type change throughout the length of the site; estimates were averaged for both sides of the road then converted to a shrub (preferred)–grass (nonpreferred) index.

We estimated the mean height of verge vegetation to the nearest half meter using utility pole (100-m interval) markers as a guide. We then averaged vegetation height data over the site length for each side of the road and then averaged for each site. Black spruce forest–sphagnum bogs that were bisected by highways and appeared to be of sufficient size to provide habitat for moose (generally $\geq$25% of the linear road distance) were identified as present or absent.

Within each site, we classified the composition of the mature forest edge along both sides of the highway from the roadbed to approximately 300 m into the surrounding forest every 100 m along the highway or when a forest type change occurred. We then calculated the percentage of surrounding forest edge classified as mature deciduous-leading (mixed; Table 1), which is known to be important to moose (Kearny and Gilbert 1976, Peek et al. 1976, Osko et al. 2004) and used locally by moose for bark stripping from late autumn to early spring (Rea and Booth 2012) and browsing throughout the year.

Coarse-scale environmental variables. At the coarse scale, we used a GIS (ArcGIS, Version 9.2, Environmental Systems Research Institute 2006) and remotely sensed data to describe the habitat and road infrastructure features within a 500-m- and 5-km-radius buffer around each site, which according to Seiler (2005) and Leblanc et al. (2005), respectively, were important for characterizing MVC sites. We identified aspect, slope, and elevation using a digital elevation model for the study area. First-order tree species and the area of lakes and swamps were calculated from the BC Vegetation Resource Inventory (British Columbia Ministry of Forests and Range 2007). Because rivers and associated river riparian zones within 800 m of a river are known to be important for predicting moose presence (Jandt 1992), we delineated the presence–absence of rivers within 1 km of our highway sites (Malo et al. 2004) using satellite–aerial imagery. We then categorized road curvature (number of degree changes per meter of highway) and quantified the length of linear edge attributable to anthropogenic disturbances such as forest cut blocks and linear corridors (Table 1).

Road infrastructure and design variables. We used video disc data (digitized visual recordings of highway travel) and site inspections to note the road infrastructure variables of posted speed limit (km/h), wildlife warning signage, and double solid center lines (which indicate areas of low driver visibility; Table 1). Video disc data were measured and assessed to the nearest one hundredth of a kilometer using a Sony Lasermax Laservision Videodisc Player LDP-1500 and laser disks from the project: ''Photolog: A Visual and Geometric Record of B.C. Highways'' at the Prince George Regional office of the Ministry of Transportation and Infrastructure (British Columbia Ministry of Transportation and Highways 1996). We used a vehicle odometer to calculate the percentage of the site containing rumble stripping. Rumble stripping is placed in areas where data suggest drivers are more likely to succumb to drowsiness or become distracted, but can also act as reservoirs of road salt that are attractive to moose, (R.V. Rea, personal observations). While in the field, we also measured and averaged the width of the travel corridor with a laser range finder and wheel tape. We measured and averaged the depth of roadside ditches using an estimate to the nearest meter every 100 m of highway site or whenever the ditch depth changed. We then combined ditch-depth data for all sections and both sides of the highway within the site and calculated the percentage of ditch along the site that was $>$3 m deep and would make it hard for a motorist to detect a moose approaching the roadbed (Table 1).

Statistical analyses

We used logistic regression to test a series of model hypotheses that explained the occurrence of collision hotspots. The binary outcome represented the occurrence of a collision hotspot (1) versus a control location (0). We constructed models that coincided with four broad explanatory themes representing sets of factors generated from different data sources and that may explain clusters of moose–vehicle collisions: coarse-scale environmental factors derived from remotely sensed data, fine-scale environmental factors measured at highway sites, a combination of both coarse- and fine-scale factors, and factors related to road infrastructure and design. We used the published literature (e.g., Malo et al. 2004, Seiler 2005, Leblanc et al. 2005, Dussault et al. 2006) and our observations of the study area and associated hypotheses to develop individual models for each theme. We used tolerance scores to identify excessive multicollinearity. Because of small sample sizes, we used a threshold-score of $<$0.1 when deciding to remove a highly collinear variable (Menard 1995, Tabachnick and Fidell 2001). Again recognizing the small sample size, we fit models with relatively few covariates (i.e., $\leq$7).

We used the Akaike Information Criterion difference (ΔAIC_c) corrected for small sample sizes and Akaike weights ($AIC_c w$) to select the most parsimonious model from each explanatory theme (Anderson et al. 2000). The AIC_c provides evidence for selection of the best model from the set, but does not permit evaluation of discriminatory performance—an important consideration for guiding highway planning and management.

Thus, we used the receiver operating characteristic to assess the classification accuracy of each model (Pearce and Ferrier 2000). We had insufficient sample size to withhold a percentage of the observations that would allow us to generate an independent test of classification accuracy. Thus, we used a one-fold cross-validation routine to withhold each record sequentially from the model-building process and then calculate the probability of that withheld record being a hotspot. We used these independent probabilities ($N = 44$) to generate the receiver operating characteristic test. We considered a model with an area under the curve (AUC) score of 0.7 to 0.9 to be a 'useful application' and a model with a score >0.9 as 'highly accurate' (Boyce et al. 2002).

We used the Akaike weights to average coefficients across the model set representing approximately the top 95% of weights; this included the calculation of the unrestricted variance (Anderson et al. 2000). We calculated initial restricted standard errors that were robust to autocorrelation (StataCorp 2007). We used 95% confidence intervals (unrestricted) to assess the strength of effect of each predictor covariate. All analyses were conducted in Stata v. 10 (StataCorp 2007).

Results

Our data contained 1,972 records for carcass collections of moose between January 2000 and December 2005. On average, 329 (±94) carcasses were collected per year (minimum carcass reports = 246 in 2003; maximum = 509 in 2005). From July 2007 to July 2008, we located and assessed the habitat and road infrastructure attributes of 29 MVC hotspots and 15 control sites. We used these 44 sites to fit 15 logistic regression models that differentiated the two site types. Across the four sets of hypotheses, a model consisting of variables selected from the combined coarse- and fine-scale environmental factors was the most parsimonious ($AIC_c w_i = 0.634$; Table 2). For this model, covariates related to the presence of black spruce forest–sphagnum bogs, area of swamps and lakes within 500 m of the hotspot, the presence of rivers within 1 km of the site, and the number of mineral licks had good predictive power for explaining the location of MVC hotspots (AUC = 0.710) relative to collision-free control sites.

The next most parsimonious model was also selected from the set of hypotheses representing the combined coarse- and fine-scale environmental factors and included covariates for the presence of bogs and an index of shrub (preferred forage) and grass (nonpreferred; $AIC_c w_i = 0.120$). The third- and fourth-ranked models represented fine-scale environmental factors and contained an additional covariate for the number of licks ($AIC_c w_i = 0.094$) and deciduous mixed forest edge ($AIC_c w_i = 0.033$), respectively (Table 2). Consistent with the variables included in the most parsimonious models, the likelihood of a road segment being a hotspot increased near bogs ($\beta = 2.465$, 95% CI = 0.346–4.659 and where there were a relatively large number of licks ($\beta = 1.890$, 95% CI = −0.211–3.990). The unrestricted precision of model coefficients was relatively low, likely as a result of small sample size and model selection uncertainty (Table 3).

The top-ranked models for coarse-scale environment and road infrastructure and design factors had relatively low AIC_c weights. A combination of covariates for posted highway speed and signs advertising wildlife presence had an AIC_c weight of 0.027 and an AUC of only 0.407, suggesting little value of these attributes for characterizing MVC hotspots in northern BC; however, more complex models in the set had larger AUC scores, suggesting some utility for identifying hotspots (Table 2). The averaged coefficients suggested that collision hotspots were more likely at locations with signs cautioning drivers of wildlife activity on the highway ($\beta = 0.098$, 95% CI = −0.123–0.320; Table 3). The best model from those representing coarse-scale factors had an AIC_c weight of only 0.004 and an AUC of 0.483 (Table 2).

Discussion

In partial agreement with our hypothesis, results suggest that MVC hotspots in northern BC in relation to sites that contained no recorded MVCs are best described by a combination of coarse- and fine-scale environmental factors. Of the coarse-scale factors, those that were assessed within a 500-m buffer around the highway sites were more related to hotspots than those assessed within 5 km of the hotspot. Mineral licks, the proportion of early seral roadside browse to nonbrowse species, swamps, and black spruce forest–sphagnum bog habitats better described MVC hotspots than did road infrastructure and design features, which had less power to predict the occurrence of hotspots.

Wetlands and mineral licks

Our results suggest that sphagnum bogs with black spruce were more commonly associated with MVC hotspots than with control sites. Vegetation complexes growing in these habitats tend to grow slowly and are considered of poor nutritional quality for animals such as moose (Mackenzie and Moran 2004) in relation to plant complexes growing in upland sites. However, these types of black spruce forests are also known to be important to moose (Van Ballenberghe and Peek 1971, Peek et al. 1976, Peek 1998) with species such as bog birch *Betula glandulosa*, swamp birch *B. pumila* and bilberry willow *Salix boothii* forming a significant component of the moose diet (Renecker and Schwartz 1998).

Referring to these black spruce bog habitats as open conifer wetlands, Osko et al. (2004) reported that such wetlands were preferred by moose in western Canada relative to other available habitat types. Additionally, current research in our study area suggests that some low-lying black spruce forest–bog habitats along roads are visited with the same frequency and timing as roadside mineral licks because these areas may accumulate road salt following spring run-off (R.V. Rea, unpublished data). These smaller, wet, roadside habitats, although often undetectable at coarser scales, are known

Table 2. Number of model parameter differences (k_i), in Akaike Information Criterion (AIC$_c$) scores (Δ_i) and AIC$_c$ weights (w_i) for logistic regression models representing the occurrence of moose *Alces alces*–vehicle collisions within hotspots compared with collision-free (control) sites on highways in northern British Columbia, Canada, between 2000 and 2005. Predictive ability of each model was tested using the Area Under the Curve (AUC; ± standard error) of the Receiver Operating Characteristic.

Model	k_i	ΔAIC_{ci}	$AIC_c w_i$	AUC (SE)
Coarse-scale environment				
aspect (500m)+elevation (500m)+lakes (500m)+swamp (500)+linear (500m)+tree species (500m)	7	10.1	0.004	0.483 (0.098)
aspect (5000m)+elevation (5000m)+lakes(5000)+swamp (5000)+linear (5000m)+tree species (5000m)	7	17.3	<0.001	0.361 (0.090)
Fine-scale environment				
licks+shrub–grass+verge veg+bog	5	6.1	0.030	0.671 (0.083)
licks+shrub–grass+bog	4	3.8	0.094	0.703 (0.081)
mixed forest+conifer+deciduous+licks+shrub–grass+bog	7	10.2	0.004	0.618 (0.088)
deciduous+licks+shrub–grass+bog	5	5.9	0.033	0.662 (0.083)
deciduous+licks+shrub–grass+bog+verge veg	6	8.4	0.009	0.644 (0.085)
Combined coarse- and fine-scale environment				
bog+swamp (500m)+lakes (500m)+river+licks	6	0	0.634	0.710 (0.081)
shrub–grass+linear (500m)+mixed forest+river	5	11.0	0.003	0.500 (0.101)
mixed forest+bog+shrub–grass+linear (500m)+licks	6	7.5	0.015	0.646 (0.086)
bog+shrub–grass	3	3.3	0.120	0.678 (0.084)
Road infrastructure				
speed+signs	3	6.3	0.027	0.407 (0.088)
curvature+speed+signs+rumble strip	6	6.8	0.021	0.667 (0.083)
corridor+speed+signs+ditch+double solid+rumble strip	7	9.5	0.005	0.662 (0.088)
curvature+verge veg+double solid+rumble strip+ditch	7	13.0	0.001	0.515 (0.092)

to attract moose (Barnum et al. 2007), albeit the specific relationship of bog habitat to MVCs requires further study.

The presence of roadside mineral licks or salt pools has helped to characterize MVC hotspots in many jurisdictions (Fraser and Thomas 1982, Rea and Rea 2005, Dussault et al. 2006, Grosman et al. 2009). Both roadside pools where winter road salts accumulate and naturally occurring mineral licks act as strong attractants to animals that are lacking dietary minerals or require other properties contained in lick-soils (Fraser and Thomas 1982, Jones and Hanson 1985). Salt hunger is a strong motivator for ruminants such as moose (Jordan et al. 1973, Belovsky and Jordan 1981) that tend to use licks most often in early summer (Fraser and Hristienko 1981, Risenhoover and Peterson 1986), but are also known to use licks in winter where lick-water and soils are available through the ice and snow (Jordan et al. 1973, Risenhoover and Peterson 1986, Thompson and Stewart 1998, Rea et al. 2013).

Eight of the 29 MVC hotspots that we assessed contained between one and three (and one had six) mineral licks, while no controls sites contained mineral licks. Site visits to each lick indicated a network of trails (and muddy tracks across the highways) in each area, which clearly indicated that animals were crossing roads regularly during early to mid-summer. The relationship between summer lick use and moose collisions has been reported in Quebec (Dussault et al. 2006). Winter and summer peaks in lick use (Rea et al. 2013) appear to coincide with the large winter and smaller summer peak in moose-related vehicle collisions described by Sielecki (2010) for northern BC. However, moose appear to visit

Table 3. Model-averaged coefficients and respective unconditional standard errors (SE) and 95% confidence intervals for logistic regression models (representing 95.9% of the AIC weights; see Table 2) describing attributes found in areas with a high incidence of moose *Alces alces*–vehicle collisions (≥4 MVCs/km between 2000 and 2005; hotspot) and collision-free (control; no MVCs between 2000 and 2005) highway sites in northern British Columbia, Canada. Coarse-scale habitat data were sampled within a 500-m and 5-km radius of each site.

Covariate	Coefficient	SE	95% CI	
Constant	0.868	1.218	−1.518	3.254
Fine-scale environment				
Number of licks	1.890	1.071	−0.211	3.990
Shrub–grass index	0.005	0.005	−0.005	0.015
Verge vegetation height	−0.007	0.013	−0.033	0.019
Bog	2.503	1.100	0.346	4.659
Deciduous mixed forest	<−0.001	0.001	−0.001	0.001
Lakes	<−0.001	<0.001	<−0.001	<−0.001
Coarse-scale environment				
Swamp	<0.001	<0.001	<−0.001	<0.001
River	−0.150	0.534	−1.198	0.897
Road infrastructure				
Posted speed	−0.004	0.005	−0.014	0.006
Wildlife warning signs	0.098	0.113	−0.123	0.320
Road curvature (slight)	−0.018	0.021	−0.060	0.024
Road curvature (sharp)	0.018	0.021	−0.022	0.059
Rumble strip	<0.001	<0.001	<−0.001	0.002

roadside licks in northern BC to various degrees throughout the year and how closely seasonal collision occurrences mirror lick use is currently under investigation (R.V. Rea, unpublished data).

Lake and river shoreline provides riparian vegetation such as willow and alder *Alnus* spp. that is used intensively by moose for food and cover (Jandt 1992, Peek 1998), while smaller ponds and lakes provide aquatic feeding sites. Our findings, however, suggest that MVC hotspots, when compared with controls, were associated with less lake area and an absence of rivers in the 500-m and 1,000-m area surrounding the highway, respectively. Paths used by moose in areas where they were crossing highways in Quebec had a low proportion of lakes and rivers (Dussault et al. 2007). The surface area of large lakes and rivers reduces overall habitat availability and could act as a natural barrier to movement by moose to roads. The relative absence of habitat where lakes and rivers comprise a large proportion of the landscape, but also the juxtaposition of these habitats next to highways (Davis 2012), may help to explain why MVC hotspots, but not accident-free control sites, were negatively associated with these water features.

Aquatic macrophytes such as pond weeds growing in swamps, are an important component of the diet of moose during summer (Mackenzie and Moran 2004). Sites that support this forage type also are used by moose to avoid biting insects (Peek 1998), and swamps with these attributes were associated with hotspots in our study area. Moose-related vehicle collisions in western Maine occurred at locations closer to wetlands when compared with random points, which as Danks and Porter (2010) suggest, could result in a higher collision occurrence where highways bisect this habitat type.

Forage and cover

Forage has been classified as the most important habitat variable for moose (Puttock et al. 1996, Courtois et al. 2002). Highway corridors are sometimes described as long, narrow pastures bisected by high-speed lanes (Bellis and Graves 1971), and forage availability along transportation routes has been linked to collision occurrence (Gundersen et al. 1998, Dussault et al. 2006, Gunson et al. 2011, Fliflet 2012). Early seral browse plants found in these areas and comprising the shrub component of our shrub–grass index included willow *Salix* spp., birch *B. papyrifera*, aspen *P. tremuloides*, and saskatoon *Amelanchier alnifolia* (Renecker and Schwartz 1998). These plants were more abundant at the hotspots we investigated relative to controls and can serve to attract moose to the transportation corridor and encourage them to remain longer when travelling through such areas (Jaren et al. 1991).

The type of forest adjacent to highways will influence the degree to which ungulates use roadside habitats and come into conflict with traffic (Puglisi et al. 1974, Bashore et al. 1985, Finder et al. 1999, Barnum et al. 2007). We found that the type of forest bisected by the highway varied between hotspots and collision-free controls in our study. The juxtaposition of mature forest cover with an abundance of roadside browse along a linear feature such as a highway produces a relatively large amount of edge. Such edge can act as an ‘‘ecotonal trap’’ for species such as moose (Child et al. 1991) that seek thermal and predator cover in forests that are in close proximity to their food supply.

During winter, moose are often concentrated in coniferous rather than deciduous forest types (Telfer 1970, Eastman 1977, Gillingham and Parker 2008), reflecting the findings of Dussault et al. (2007) and Danks and Porter (2010), who found that moose crossing rates and MVCs, respectively, were higher where highways bisected coniferous forest. However, Barnum et al. (2007) and Gunson et al. (2009) found that moose crossing rates and collision sites in New Hampshire and the central Canadian Rocky Mountains, respectively, were associated with a mix of coniferous and deciduous forest cover. Further, stands dominated by deciduous trees such as birch and aspen, but containing a mix of other species, do receive greater than expected year-round use by moose in some jurisdictions (Kearny and Gilbert 1976, Peek et al. 1976, Osko et al. 2004, Brown 2011) and have been shown here and in other studies (Seiler 2005) to be associated with MVCs.

Road infrastructure and design

Unlike the findings of Seiler (2005), Dussault et al. (2006), and Danks and Porter (2010), none of the road infrastructure factors that we measured (such as speed limits, signage, or road curvature) were significantly more associated with hotspots than controls. Traffic volume data in our study area did not contain the resolution required for a meaningful analysis. However, even in areas where traffic-volume data are available, the influence of traffic volume on ungulate collision risk has been questioned or disregarded (Groot Bruinderink and Hazebroek 1996, Fliflet 2012) or found to be significant only after diurnal activity patterns of moose and day-light levels have been fully taken into account (Huseby 2013)—something we were unable to do because of a lack of collision time data in the Wildlife Accident Reporting System records. Sensitivity to traffic depends on how habituated moose are to vehicles (Garrett and Conway 1999). Speed limits of 100 km/h are standard throughout the study area and appeared to play no role in characterizing hotspots.

Wildlife warning signage also poorly characterized hotspots relative to controls. Specifically, nine of the MVC hotspots in northern BC were equipped with previously installed wildlife warning signs that accurately described the hotspot, while many of the hotspots had no warning signs. Others had signs that only delineated a portion of the hotspot and presumably represented installations that were based on old data. Some MVC hotspots were equipped with deer *Odocoileus* spp. warning signs, while none of the control sites were equipped with wildlife warning signage.

Summary and Management Implications

Moose–vehicle collision hotspots in northern BC were described best by a mix of fine- and coarse-scale habitat attributes when compared with collision-free sites. Hotspots were juxtaposed by black spruce forest–sphagnum bog habitat, associated with the absence of rivers and less lake area, associated with more roadside mineral licks, and had more surrounding swamp habitat than control sites. Hotspots were also more likely than controls to contain a higher proportion of browse to nonbrowse (shrub–grass index) species and to bisect deciduous forests. Moose were not collared for this study. Therefore, we had no data on animal movement rates or crossing probabilities (Dussault et al. 2006), nor were we able to determine what moose were doing prior to being killed by vehicles. Despite this, higher MVC rates in hotspots suggest the presence of better habitat (or some attractant) in hotspots than in control sites or that moose moving through hotspots were more likely to be struck by vehicles.

Road design features may be related (Seiler 2005, Danks and Porter 2010) or unrelated (Dussault et al. 2006) to MVCs. Surrounding road densities may also influence seasonal moose behavior and movement rates near roads (Beyer et al. 2013). Road curvature, speed limits, shoulder and center-line rumble-stripping, corridor width, and other such factors in our study area were unrelated to concentrations of MVCs. This does not suggest that driver habits and behaviors do not contribute to MVC. For example, simple reductions in nighttime driving speeds from 90 down to 70 km/h can generally provide sufficient reaction and braking time to avoid collisions with moose on highways (Rodgers and Robins 2006).

Although one-third of hotspots contained appropriate wildlife warning signage (these sites contained fewer collisions on average than other hotspots), most hotspots had inaccurate or no warning signs. To mitigate collision occurrence in MVC hotspots, we recommend the installation of appropriate wildlife warning signage at each MVC hotspot; such signs have since been installed at MVC hotspots in our study area. Highway sites with slightly fewer MVCs could also be considered for sign installation, but such decisions should weigh site-specific collision risk with the overall number of signs erected along highways in a region and the tendency of drivers to become desensitized to signs when commonplace (Al-Ghamdi and AlGadhi 2004, Gunson and Schueler 2012).

Roadside mineral licks should be decommissioned by excavating lick-soils and filling licks with rock or other materials (Rea and Rea 2005, Leblond et al. 2007, Grosman et al. 2011), and roadside brush should be managed to reduce its attractiveness to moose (Jaren et al. 1991, Rea 2003), but only where these factors lead to MVCs (Neumann et al. 2012). Although wetland features are unlikely to be managed for wildlife collision mitigation, highways through such areas could be fenced (Danks and Porter 2010) and crossing structures built (Olsson et al. 2008). Meanwhile, plans for new road construction and realignments in northern BC might consider routes with more lake area, more rivers, fewer swamps, and fewer black spruce forest–sphagnum bog habitats where MVCs are of major concern.

As habitats change, road safety planners must regularly consider how such changes influence moose population densities, habitat use, and activity patterns along roads. Heavier road salt applications along certain stretches of road today may contribute to the formation of roadside licks that were not there in the past. Alternatively, habitat that may have contributed to a collision hotspot in the past may no longer support moose. This is particularly true in northern BC, where large tracks of lodgepole pine *P. contorta* have been recently killed by mountain pine beetle *Dendroctonus ponderosae* and mature pine forests are being quickly converted to early seral willow and aspen stands following salvage logging (Ritchie 2008). This may help to explain the apparent misplacement of warning signs representing historical hotspots (and important moose habitat) that, in light of changing habitats, are now less relevant.

Contemporary collision data warehousing and analysis can help to pinpoint problematic highway sections (Hesse et al. 2010) and can lead to assessments that may help to explain what factors contribute to collision occurrence. Because MVC hotspots in northern BC appear to be defined more by habitat than infrastructure, working to understand the ecological factors associated with moose–vehicle collisions will aid managers in finding ecologically based management solutions to reduce the occurrence of moose along roadsides and the interactions of those moose with vehicular traffic.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

Table S1. Data file containing those variables used for describing attributes found in areas with a high incidence of moose– *Alces alces* vehicle collisions (≥4 MVC/km between 2000 and 2005; hotspot) and nonhotspot (control; no MVC between 2000 and 2005) highway sites in northern British Columbia, Canada. Variables are site type (Type), classification of site (hot_not), Degree of curve per meter of road (Degree/m), presence of river within 1 km of site (River), highway segment and nearest landmark to site (SITE ID), length of the site (road length), latitude of way-point of site start (latitude start), longitude of way-point of site start (longitude start), latitude of way-point of site end (latitude end), longitude of way-point of site end (longitude end), proportion of site with ditch >3 m deep (Deep ditch), number of licks within a site (No. Licks), percentage of the site with a double solid center line (% double solid line), an index of the amount of browse cover relative to nonbrowse cover within the site (Shrub–grass index), percentage of the site with rumble stripping (% rumble strip), height of the vegetation growing in the roadside verge averaged over the site (Average verge veg height), posted speed limit of the site (Posted speed), the number of moose warning signs within the site (# moose signs), the number of deer warning signs within the site (# deer signs), percentage of the forest edge along the highway corridor consisting of mature mixed forest (% mature mixed), field identification of bog presence within the site (Bog presence), the physical width of the highway corridor in meters (Corridor width), area of swamp within 500 m of the site (area swamp 500), area of swamp within 5,000 m of the site (area swamp 5000), area of lakes in meters squared within 500 m of the site (Area of Lakes 500), area of lakes in meters squared within 5,000 m of the site (Area of Lakes 5000), site elevation above sea level (Elevation), site aspect in degrees (Aspect), first-order (predominant) tree species within 500 m of site using forestry codes (first-order tree species 500), first-order tree species within 500 m of site, numerically coded (first-order tree species 500 No.), linear distance in meters of forest edge within 5,000 m of site (Linear_5000), linear distance in meters of forest edge within 500 m of site (Linear_500).

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Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Ethical Standards

The investigation described complies with the current laws of Canada. The authors declare that they have no conflict of interest

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