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Authors

Leblanc, Yves
Bolduc, François
Martel, Donald

Publication Date

2005-08-29

UPGRADING A 144-KM SECTION OF HIGHWAY IN PRIME MOOSE HABITAT: WHERE, WHY, AND HOW TO REDUCE MOOSE-VEHICLE COLLISIONS

Yves Leblanc (Phone: 418-871-2452, Email: yves.leblanc@tecsult.com) and **François Bolduc** (418-809-1105, Email: francois.bolduc@foramec.qc.ca), Tecsult Inc., 4700, boul. Wilfrid-Hamel, Québec City, Québec G1P 2J9, Canada
Donald Martel (Phone:418-695-7916, Email: dmartel@mtq.gouv.qc.ca), Direction Saguenay-Lac-St-Jean-Chibougamau, Ministère des Transports du Québec, 3950, boul. Harvey 1er étage, Jonquière, Québec G7X 8L6 Canada

Abstract: In Quebec, as throughout North America, the number of vehicles on roads and the daily distances travelled increase continuously. At the same time, populations of moose (*Alces alces*) and white-tailed deer (*Odocoileus virginianus*) have reached unprecedented levels in this province. For example, the moose population increased from 60,000 to 100,000 animals in Quebec between 1990 and 2002. Hence, moose-vehicle collisions have increased and caused numerous human injuries and fatalities in recent years in Quebec. The main objective of our study was to identify roadway, habitat, and moose population features that correlated with the reported number of moose-vehicle collisions (MVCs) and propose measures to reduce risks to motorists. Our study was implemented in the context of a planned project to upgrade a two-lane primary artery to a four-lane divided highway, located north of Québec City that bisects a wide forested area, the Laurentides Wildlife Reserve (LWR). Moose population and habitat variables were obtained from harvest, aerial inventory data, and aerial photos. Other variables were also measured from digital data layers using the ArcView GIS. Habitat suitability was computed using digital layers from ecoforestry maps and ArcView Spatial Analysis. Roadway variables were collected in the field or extracted and computed from digital layers with AutoCad and InRoads software packages. Moose-track surveys were also conducted monthly from June to September 2004 along the major conflict zone.

Moose densities varied between 1.0 moose/10 km^2 in the center of the 144-km Highway 175 to 8 individuals/10 km^2 in its southern and northern portions. We estimated that between 573 and 860 moose were roaming within 5 km on each side of the highway in 2004. A controlled hunt and high quality habitats following forest exploitation and natural perturbations occurring within the LWR are likely to be major contributors to this growing population. Our data analysis using AIC showed that four variables explained most variations in the number of MVCs among 1-km sections. These variables were (1) the slope complexity of the adjacent landscape, (2) the total length of rivers, streams, and brooks located within a 250-m buffer zone on each side, (3) the habitat suitability for forage within a buffer zone of 1 km on both sides, and (4) the proportion of steep (> 3-m high) road cuts. During fall and early winter habitat features were strongly related to the number and location of MVCs, whereas the influence of slope complexity was greater during summer. However, annual and seasonal models explained a limited amount of the variance in the number of MVCs ($R^2 < 0.288$) and could not be used efficiently to identify conflicting sections and set management priority. The longest and the most hazardous section tallied 25 km, which was surrounded by high-quality moose habitat. Track surveys in the summer of 2004 showed frequent movements across the highway, but little clustering. Because we could not find strong relationships between MVCs and road and habitats features, we used the numbers of recorded MVCs to delineate 5-km sections and establish actions to be taken to reduce risks. The top priority hazardous zone, which encompasses 25 km, will be fenced during the upgrading project and combined with two major underpasses.

Introduction

Vehicle-ungulate collisions have increased in North America and Europe, causing an increased number of human injuries and deaths, as well as considerable material damage (Forman et al. 2003). Moose-vehicle collisions (MVCs) have tremendous impacts due to the large size of this species: the individual weight ranges from 360 to 600 kg (794 - 1,323 pounds), and its center of gravity is very high. On a 193-km one-lane highway located north of Québec City, moose accounted for 90 percent of all vehicle collisions with wildlife (n = 346) that caused human injuries between 2000 and 2004. Seventeen percent of MVCs caused severe injuries or were fatal to motorists (Quebec Ministry of Transportation unpublished data).

Given the high probability of injuries and human death resulting from MVCs, the Canadian Provinces, Alaska, and northern countries are implementing mitigation measures along roadsides to eliminate or reduce MVCs in hazardous areas (McDonald 1991, Joyce and Mahoney 2001, Väre 2002, de Bellefeuille et Poulin 2003, Redmond 2005). However, little information is available on road, landscape, moose habitat, and population characteristics that relate to MVCs. Joyce and Mahoney (2001) found a relationship between MVCs and traffic volume, but results remained unclear about their relationship with moose density. An understanding of causes and patterns is deemed necessary to improve our knowledge of features related to MVCs and our design of effective management strategies.

The main objective of our study was to identify roadway, habitat, and moose population features that related to the number of MVCs, and to propose management designs that would help reduce the collision rate. Our study was implemented in the context of a planned project to upgrade a two-lane primary artery to a four-lane divided highway beginning in 2005. This project is located in a large forested area where moose is the dominant ungulate species and of particular concern for road and safety managers.

Study Area

Our research took place in the Laurentides Mountains, located 35 km (22 mi) north of Quebec City in south central Quebec (figure 1). The study area covered approximately 9,000 km2 (3,475 mi^2) where mountainous and rolling landscapes with numerous lakes dominate. Sections of two provincial parks (De la Jacques-Cartier, Des Grands Jardins) and the Laurentides Wildlife Reserve (LWR) also are located in our study area. Altitude varies between 163 and 859 m. Snow precipitations occur between September and April and add up to 593 cm on average. The mean annual temperature varies between 14.8 °C and -15.3 °C.

Our study area presents two distinct ecological regions. The central area shows higher elevations (732 m to 859 m, km 105 to 176) where the vegetation is largely dominated by black spruce (*Picea mariana*) and balsam fir (*Abies balsamea*). North and south of the latter area where elevations are lower, the forest canopy is composed of mixed stands of balsam fir and white birch (*Betula papyrifera*) or trembling aspen (*Populus tremuloïdes*). Forests within the LWR are currently harvested for paper and lumber production, affecting approximately 37 km^2 per year. Spruce budworm outbreaks also significantly affected young forested stands over the past 50 years.

Wolf (*Canis lupus*) and black bears (*Ursus americanus*) represent the other big game species present in the area. White-tailed deer only occur in limited numbers in the most northern and southern part of the study area. A small population of woodland caribou (*Rangifer tarandus*) (approximately 200 individuals) also is present in the eastern section of our study area. Controlled hunting of moose and black bear occurs in the LWR, and harvest levels are relatively low. Human development is limited to the few hunting and fishing cabins provincially owned and rented between May and October. The last aerial inventory of moose in LWR in 1994 revealed density estimates ranging from 1.0 per 10 km^2 in the central part of LWR to around 8 per 10 km^2 in the best habitats located in the northern and southern parts of our study area. We suspect that the density in LWR exhibited an increase as in adjacent territories (2-fold, Portneuf Wildlife Reserve, Banville 2004), and may contain as many as 10 moose/10 km^2 in the most suitable habitats.

A 144-km north/south two-lane highway built in the early 1950s bisects our study area (Highway 175). The annual average traffic volume was between 3,300 to 4,800 vehicles per day in 2000. The summer average traffic volume varies between 4,600 and 6,300 vehicles per day.

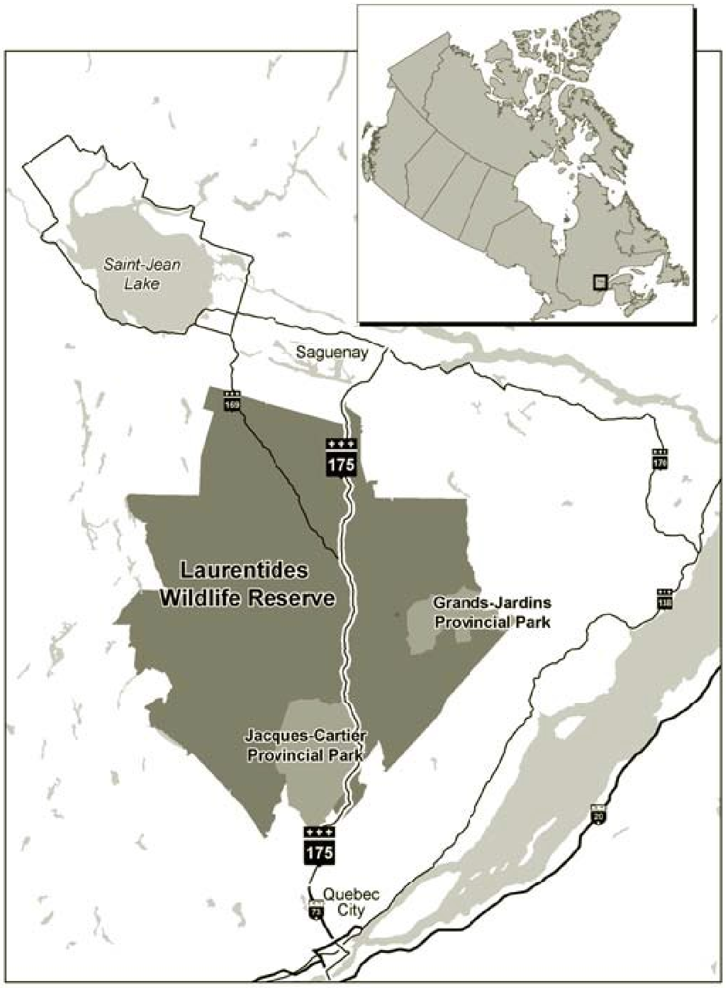

Figure 1. Location of study area and Highway 175 in the Laurentides Wildlife Reserve, Province of Québec, Canada.

Methods

Data collection

Moose-vehicle collisions
We obtained existing MVC data between 1991 to 2001 from the Quebec Ministry of Transportation (QMOT). The QMOT uses and cross validates two sources of data to produce a database on wildlife-vehicle collisions. The first source is the vehicle accident form completed by the Sureté du Québec police officers at each collision site. The second one corresponds to the form completed by QMOT maintenance staff and contractors when collecting wildlife road-kills. In each case, the reported locations of MVCs were to the nearest landmark or to the nearest kilometre posting. Accuracy is unknown, but it is probably similar to that (516 m) reported in Alberta (Gunson and Clevenger 2003).

Road features
The 144-km highway was divided in 1-km sections to which we associated several variables obtained either from the field or derived with the InRoads software using the horizontal alignment database of the existing roadway. Variables derived from field work corresponded to the average distance from the paved road to forest cover, percent length of the 1-km section in road cuts higher than 3 m, percent length of the 1-km section in road fills higher than 3 m, and length of auxiliary lanes. Other variables such as percent length of the 1-km section in light curves (< 500 m radius) or strong curves (> 500 m radius), curve and tangent length within the 1-km section also were obtained using the alignment database of the roadway.

Moose population and landscape characteristics
We obtained data on distance between moose wintering areas in January 2000 and the 1-km section, number of moose seen in wintering areas, distance to the nearest harvest site (1990-2002) from the QMOT and the Québec Ministry of Natural Resources and Wildlife (QMNRW) and incorporated them as spatial data layers into our GIS ARC-INFO geographical database.

Using updated ecoforestry databases from the QMNRW, we modeled a moose habitat suitability index using ArcView GIS (ESRI, Redlands, California, USA) in 1km^2 grid cells 5 km each side of the roadway. The habitat suitability model included two components linked to the forest stand capability to produce forage (radius < 5 km) and to the amount of edges between forage and cover habitats (Dussault et al. 2002). We also obtained the number of ponds, total length of streams and rivers, wetland area, and number of used saltwater pools within 250 m on each side of the 1-km sections from QMOT. We included topographic features such as the mean slope and its standard deviation within a 500-m radius using the Spatial Analyst program extension in ArcView.

Track surveys
We conducted monthly track counts in June, July, August, and September 2004 along the roadway on a 30-km section associated with a high number of recorded MVCs in the northern part of the LWR (km 189.5 to km 220.5). Surveys only occurred <2 days after strong rainfall or thunderstorms to ensure a minimum of detectable fresh tracks. Those weather events tend to improve identification of fresh tracks while erasing old ones. Track counts were conducted on foot or bicycle simultaneously on both sides on the roadway. Each track was either considered to have crossed or to have paralleled the roadway. We used a GPS with a 6- to 10-m accuracy to obtain track locations.

Data analysis

We used multivariate analyses to identify relationships between the total number of MVCs reported for each 1-km section and road characteristics, moose, and landscape features. Prior to MVC modelling, we generated two correlation matrices using variables related to road characteristics and to moose and landscape features, respectively, to avoid autocorrelation among variables and to obtain an acceptable proportion of samples or 1-km section ($n = 143$) to independent variables (Tabachnick and Fidell 2001).

Our first model included all MVCs reported for all seasons to examine the situation globally. We also performed seasonal models to determine if links between variables and MVCs differed between fall and summer.

We used both multiple and logistic regressions to ensure that selection of analytical tools did not influence results and selected management actions. For the multiple regression analyses, we selected the most significant variables related to the number of MVCs using both Akaike Information Criteria (AICc) and least square means (LSM, $P < 0.10$). Variables entered the model using forward selection procedure. R^2 in logistic regressions corresponded to the Nagelkerke pseudo-R^2.

In order to narrow variables that may be related to MVCs and understand why such a relationship exists, we identified variables found significant in at least two of the three regression models. We also set the probability level at 0.10 to ensure inclusion of any variable potentially related to numbers of MVCs. All mean values are presented with their associated standard error. We analyzed data using SPSS 11.5.

Results

Moose-vehicle collisions

Between 1991 and 2001, a yearly average of 38.6 (± 5.9) MVCs were reported for the 144-km section of Highway 175 (figure 2). Of these MVCs, 65 percent occurred between May and August, whereas 26 percent happened during September and October (figure 3). Over 75 percent of all MVCs occurred whether in the southern or the northern part of the roadway (figure 4).

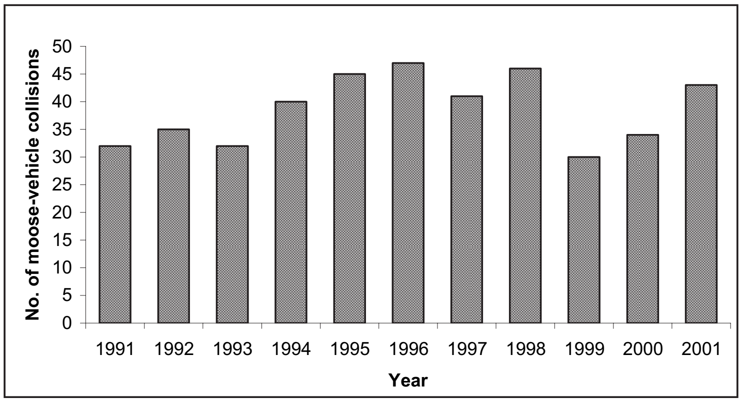

Figure 2. Number of moose-vehicle collisions along Highway 175 between 1990 and 2001 (n = 425).

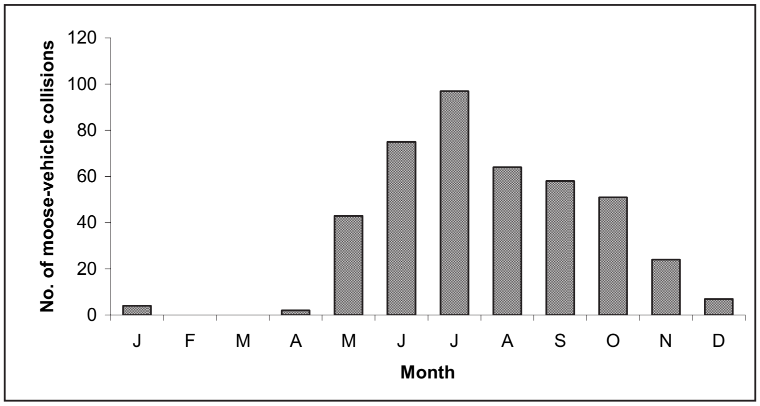

Figure 3. Number of moose-vehicle collisions along Highway 175 by month between 1990 and 2001 (n = 425).

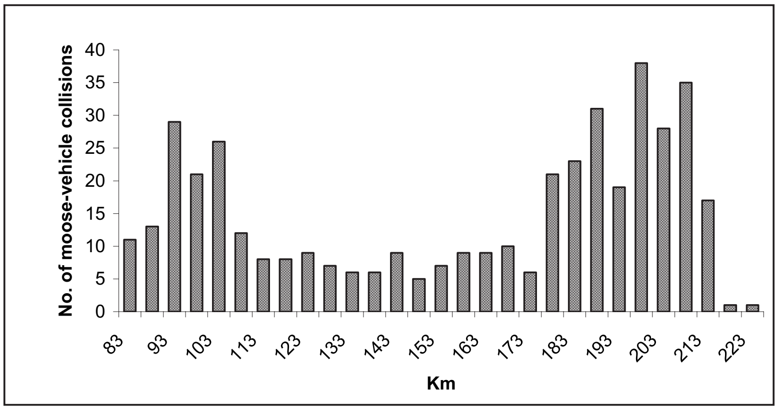

Figure 4. Number of moose-vehicle collisions along Highway 175 by 5-km sections (south to north kilometre mark) between 1990 and 2001 (n = 425).

Variable selection

Correlation analyses revealed a strong relationship among two groups of variables related to roadway characteristics (tables 1 and 2). The first group included total length of guard rail, total length of curve, total length of tangent, percent length of section in light curve (>500m radius), percent length of section in strong curve (<500 m radius), and width of right of way. The second group was composed of percent length of the 1-km section in road cuts lower than 3 m, percent length of the 1-km section in road cuts higher than 3 m, percent length of the 1-km section in road fills lower than 3 m, and percent length of the 1-km section in road fills higher than 3 m. Some variables were highly correlated with others and were kept for further analysis because we believe that they might be specifically influential on the number of MVCs. These variables corresponded to total length of section in curve, percent length of the 1-km section in road cuts higher than 3 m, and percent length of the 1-km section in road fills higher than 3 m (table 1). We also detected a strong correlation among the variables related to moose habitats and population. Following correlation analyses, we selected eight variables to be used in further statistical analysis (table 2).

Global model

Four variables exhibited significant relationships with MVCs at least in two of the regression models (table 3). Globally, we found a negative relationship between MVCs and the percent length of the 1-km section located in road cuts over 3 m and the standard deviation (complexity) of the slope in the vicinity of a given 1-km section. However, we found that MVCs were related positively to the abundance of nearby streams and rivers and the index relating to the forest stand capability to produce forage (radius < 5 km).

Table 1. Pearson correlation coefficients among road variables in each 1-km section of Highway 175 (km 84 to 227)

Variable	A	B	C	*D*	E	F	G	H	*I*	*J*
Total length of auxiliary lanes (A)										
Total length of guardrails (B)	0.13									
Total length of tangent (C)	- 0.04	- 0.10								
Length in curve (D)*	*- 0.03*	**0.15****	**- 0.91**							
% length in curve > 500 m radius (E)	- 0.02	**0.26**	**- 0.24**	***0.28***						
% length in curve < 500 m radius (F)	- 0.01	0.00	**- 0.78**	***0.84***	**- 0.28**					
Mean distance between paved surface and forest cover (G)	0.04	0.24	**- 0.17**	***0.18***	**0.22**	0.06				
% length in road fills <3 m (H)	**- 0.16**	**- 0.49**	0.08	*- 0.09*	**- 0.15**	- 0.01	- 0.10			
% length in road fills >3 m (I)	*0.06*	***0.54***	*0.02*	*- 0.01*	***0.15***	*- 0.08*	*- 0.07*	***- 0.62***		
% length in road cuts <3 m (J)	0.05	**- 0.31**	0.00	*- 0.06*	- 0.08	- 0.01	- 0.06	**- 0.18**	***- 0.31***	
% length in road cuts >3 m	*0.09*	***0.42***	*- 0.12*	*0.19*	***0.13***	*0.11*	***0.25***	***- 0.52***	***0.14***	***- 0.45***

*Correlation coefficients significant at P < 0.05 represented in bold.
**Variables retained for regression analyses represented in bold.

Table 2. Pearson correlation coefficients among moose population and habitat variables in each 1-km section of Highway 175 (km 84 to 227)

Variable	*A*	B	C	D	*E*	*F*	*G*	H	*I*	*J*	K	L	*M*	*N*	O	P	Q	R
Number of salt pools (A)																		
Distance to nearest recorded moose harvest site (B)	*- 0.09*																	
No. of ponds within 250 m of road section (C)	***0.21***	0.02																
Total area of regenerated forest stands within 1 km of row (D)	*- 0.09*	**- 0.13**	0.06															
Habitat suitability index of edges between forage and cover habitats for moose (radius < 5 km) *(E)*	*0.05*	***- 0.39***	*0.00*	***0.42***														
Habitat suitability index related to the forest stand capability to produce forage (radius < 5 km) *(F)*	*- 0.07*	***- 0.62***	*- 0.07*	***0.38***	***0.56***													
Total length of streams and rivers located within 250 m of the 1-km section *(G)*	*0.03*	*- 0.03*	*- 0.13*	*- 0.11*	*- 0.02*	*0.07*												
Mean slope in a 500 m radius (H)	*0.05*	**- 0.22**	- 0.02	0.09	***0.33***	***0.24***	***0.11***											
Standard deviation of the slope (I)	*- 0.05*	*0.03*	*0.03*	*0.05*	***0.23***	*- 0.01*	*0.10*	***0.79***										
No. of wintering areas near each 1-km section in January 2000 (J)	*- 0.02*	***- 0.18***	*0.02*	*- 0.02*	*- 0.01*	*0.10*	*- 0.10*	*- 0.10*	*- 0.04*									
Mean distance of wintering area to road section (K)	*- 0.06*	- 0.02	- 0.04	- 0.08	***- 0.14***	*- 0.10*	*0.00*	- 0.01	*0.03*	***0.44***								
Number of stream and river crossings (L)	*0.00*	0.03	- 0.06	0.05	*0.10*	*- 0.11*	***0.33***	**0.19**	*0.16*	*- 0.10*	- 0.02							
% of ROW in scrubland (M)	*- 0.12*	***- 0.48***	*- 0.07*	*- 0.04*	*0.11*	***0.57***	*- 0.03*	*- 0.01*	*- 0.10*	***0.26***	*0.05*	*- 0.10*						
% of ROW composed of wetlands (N)	*- 0.02*	*- 0.01*	*0.03*	***0.18***	***0.19***	*0.01*	*0.13*	***0.20***	***0.33***	*- 0.05*	*- 0.03*	*0.10*	*- 0.08*					
% of adjacent forest cover in coniferous stands (O)	*0.11*	**0.57**	0.03	0.03	*- 0.13*	***- 0.69***	*- 0.01*	- 0.02	*0.10*	***- 0.22***	0.04	**0.26**	***- 0.66***	*- 0.03*				
% of adjacent forest cover in mixed stands (P)	***- 0.14***	**- 0.39**	- 0.01	**- 0.20**	*0.09*	***0.59***	*- 0.03*	- 0.05	*- 0.11*	***0.15***	- 0.04	**- 0.33**	***0.62***	***- 0.15***	**- 0.81**			
% of adjacent forest cover in deciduous stands (Q)	*- 0.09*	**- 0.32**	- 0.07	- 0.05	*0.00*	***0.46***	*- 0.05*	- 0.11	***- 0.19***	***0.30***	- 0.01	**- 0.23**	***0.53***	*- 0.09*	**- 0.59**	**0.47**		
% of adjacent forest cover in regenerated stands (R)	*0.05*	**- 0.32**	- 0.06	**0.21**	*0.11*	***0.28***	*0.08*	0.09	*- 0.10*	*0.01*	- 0.06	0.11	***0.15***	*- 0.06*	**- 0.35**	- 0.11	0.00	
Total surface area of wetlands within 1 km of road section	*0.03*	**0.26**	- 0.02	- 0.07	***- 0.29***	***- 0.28***	*0.10*	**- 0.44**	***- 0.30***	*0.11*	0.11	0.01	*- 0.12*	*- 0.09*	0.10	- 0.07	- 0.07	- 0.12

*Correlation coefficients significant at P < 0.05 represented in bold.
**Variables kept for regression analyses represented in bold.

Table 3. Probabilities of nonsignificant effects on MVCs (ln transformed) that occurred on Highway 175 for 8 explanatory variables using multiple regression [AIC selection (AIC rank and weight) or LSM] and logistic regression (3 classes : 0-3, 4-7, and 8-16 MCVs; 2 classes (A) : 0-7 and 8-16 MCVs and 2 classes (B) : 0-3 and 4-16 MCVs)

Variable	**Multiple regression**		**Logistic regression**		
	AIC_c	**LSM ddl = 143**	**3 classes dl = 2**	**2 classes (A) dl = 1**	**2 classes (B) dl = 1**
Standard deviation of the slope within a 500 m radius	**1 – 0.05 ***	**t = 3.17** **p = 0.002**	X^2 = 0.58 p = 0.750	X^2 = 1.63 p = 0.201	X^2 = 1.53 p = 0.216
Habitat suitability index related to the forest stand capability to produce forage (radius < 5 km)	**2 – 0.18**	t = 1.44 p = 0.151	X^2 = 5.95 **p = 0.051**	X^2 = 5.98 **p = 0.014**	X^2 = 5.33 **p = 0.021**
% length of 1-km section in road cuts > 3m	**3 – 0.36**	t =1,90 p = **0.059**	X^2 = 2.78 p = 0.249	X^2 = 2.96 **p = 0.085**	X^2 = 1.58 p = 0.209
Habitat suitability index of edges between foraging and cover habitats for moose (radius < 5 km)	4 – 0.29	t =0.72 p = 0.472	X^2 = 0.64 p = 0.727	X^2 = 1.24 p = 0.267	X^2 = 0.05 p = 0.830
% length of 1-km section in road fills > 3m	5 – 0.10	t = 1.65 p = 0.102	X^2 = 2.46 p = 0.292	X^2 = .1.12 p = 0.290	X^2 = 2.37 p = 0.124
Number of used salty pools	6 – 0.02	t =0.02 p = 0.985	X^2 = 2.88 p = 0.237	X^2 = 2.76 **p = 0.097**	X^2 = 0.51 p = 0.477
No. of wintering areas near each 1-km section in January 2000	7 – 0.01	t = 0.98 p = 0.330	X^2 = 1.04 p = 0.595	X^2 = 0.05 p = 0.820	X^2 = 0.02 p = 0.900
Wetland area within 1 km on each side of the 1-km section (km^2)	8 – 0.00	t =1.35 p = 0.179	X^2 = 2.69 p = 0.260	X^2 = 0.85 p = 0.357	X^2 = 2.03 p = 0.155
% area of right-of-way vegetation composed of scrubs	9 – 0.00	t = 0.95 p = 0.343	X^2 = 1.00 p = 0.606	X^2 = 0.45 p = 0.504	X^2 = 0.05 p = 0.830
Total length of 1-km section in curve	10 – 0.00	t =0.91 p = 0.363	X^2 = 1.36 p = 0.506	X^2 = 0.29 p = 0.590	X^2 = 0.18 p = 0.672
Total length of streams and rivers within 250 m on the 1-km section	11 – 0.00	t = 2.79 **p = 0.006**	X^2 = 11.26 **p = 0.004**	X^2 = 0.38 p = 0.534	X^2 = 9.75 **p = 0.002**
R^2	**-**	**0.103**	**0.288**	**0.097**	**0.164**

* Highlighted variables correspond to those included in the selected model (lowest AICc)

The 3-class logistic regression corresponded to the model explaining the highest proportion (about 30%) of the variance in MVCs among 1-km sections along Highway 175 compared to the other models (table 3). Variables related to moose habitat features had the stronger influence on MVCs.

Seasonal models

We noticed no difference in the spatial distribution of MVCs among 1-km sections and among seasons. However, fewer MVCs occurred within the central part of the 144-km Highway on a yearly basis. During summer, only two variables, the standard deviation of the slope within a 500-m radius (P = 0.002) and the total length of streams and rivers within 250 m (P=0.041) were related to MVCs. If the regression model for the summer was significant, it explained very little of the variance in MVCs among 1-km sections (R^2= 0.085).

Our fall model also was significant (P= 0.001), and provided a better predictive power (R^2 = 0.140) than the summer model. Five variables were found to have a significant contribution to the model. The percent length of 1-km section in road cuts > 3 m (P = 0.011), the total habitat suitability units of edge between forage and cover units for moose (P= 0,012), and the percent length of 1-km section in road fills > 3 m (P = 0.029) were negatively related to MVCs. Total habitat suitability units of forest stands to produce forage for moose (P < 0.001) and total length of 1-km section in curve (P= 0.040) were positively related to MVCs. The winter model provided similar results as the fall model, as well as similar proportion of explained variance in MVCs (P < 0.001, R^2 = 0.137). The total number of habitat suitability units of forest stands to produce forage for moose was positively related to MVCs (P < 0.001), whereas the total number of habitat suitability units of edge between forage and cover units for moose and percent length of 1-km section in road fills > 3m had a negative influence on MVCs.

Track surveys

We recorded highest density of moose tracks in June, which decreased by half afterward until September (table 4). We recorded most tracks over the same sections every month (km 205-209 and km 195 to 198, figure 5). There was a highly significant correlation between tracks recorded in July to September 2004 and the total number of MVCs by 1-km sections between 1990 and 2001 ($r = 0.49$, $n = 31$, $p < 0.05$). When counting only fresh tracks and correcting for the number of days since heavy rains, we estimated that at least 50 moose crossed these high-risk sections every day in June, compared to about 30 moose in September.

Table 4. Number and density by km of moose tracks recorded between June and September 2004 along km 189.5 to 220.5 on Highway 175, Province of Quebec

Date	Highway sections surveyed	Total no. of moose tracks	Tracks per km
June 16	km 194.5 to 210.5	173	10.81
July 20	km 189.5 to 220.5	185	5.96
August 26	km 189.5 to 220.5	140	4.52
September 23	km 189.5 to 220.5	134	4.32

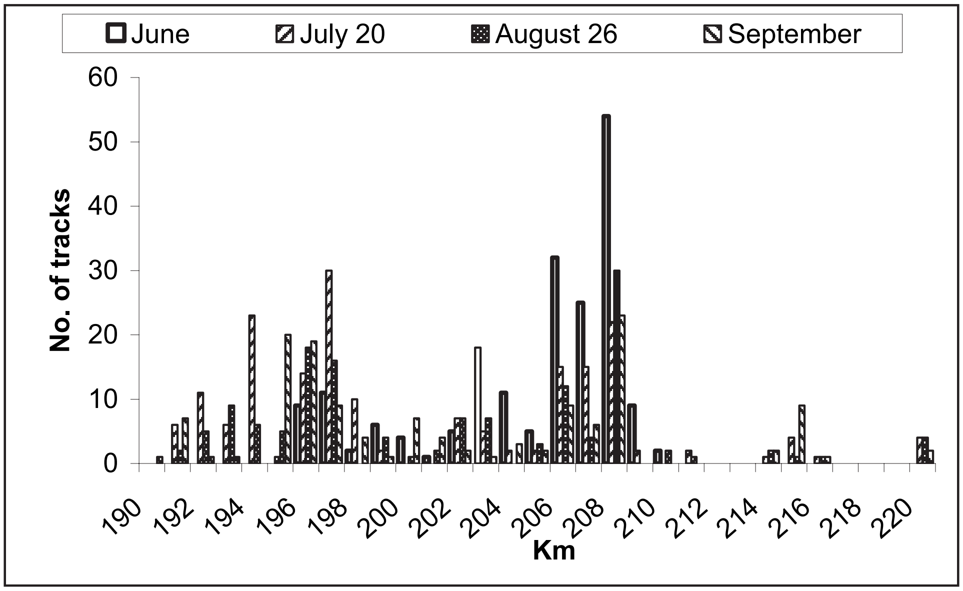

Figure 5. Total number of moose tracks recorded on both roadway shoulders in June to September 2004 between km 189.5 to 220.5 of Highway 175.

Discussion

We found that the number of moose-vehicle collisions along Highway 175 was related to specific moose habitat features, and landscape and road attributes. Most importantly, it seems that more collisions occur where the land surrounding a highway section shows less variation in topography. Moose may prefer to travel on flat or gently rolling landscape and thus are more likely to use highway sections in such varied topographic grounds. However, this relationship might only reflect differences in spatial distribution of preferred habitat and its effect on moose density. Less rugged and gently rolling landscapes are, in fact, predominant in the foothills of Laurentides Mountain range, which corresponds to the southern and northern part of the LWR. As elevation rises above 750 m, steep hills and mountains and broken topographic features become more common, the habitat suitability index decreases, and, consequently, the abundance of moose decreases as well.

Brooks, streams, and rivers seem to represent summer travel corridors for moose. Moose use these land features as they corresponds to areas of greatest food abundance and dense cover where they can protect themselves against thermal stress (Dussault et al. 2004). Del Frate and Spraker (1991) showed that moose sometimes travel along riparian zones during winter in Alaska. In some areas, moose also migrate from summer to winter habitats through river valleys (Sandegren and Sweanor 1988).

Stand productivity in moose forage nearby the highway also was related to MVCs. This variable probably reflects the summer moose density within a 5-km radius of road sections. Moose density adjacent to roadway was related to MVCs in a similar study encompassing Highway 175 and another 64 km of Highway 169 in the LWR (Dussault et al. 2005). MVCs also were related to moose density in Alaska (Modafferi 1991) and Newfoundland (Oosenbrug et al. 1991, Joyce and Mahoney 2001). Given the light hunting pressure and the application of a management plan protecting adult cows in the province of Quebec since 1994, moose density has increased province wide, (Lamontagne et Jean 1999). Forest harvesting of resinous and mixed stands in the northern and southern part of the LWR also has favored young shade-intolerant deciduous stands and, consequently, provided great forage habitat, such as trembling aspen, mountain maple (*Acer spicatum*), pin cherry (*Prunus pensylvanica*), and American mountain-ash (*Sorbus americana*).

Among road attributes, the presence of steeper road cuts was negatively related to the number of MVCs. Moose might not be naturally inclined to move on such slopes unless forage is readily available or they are forced to move in that direction by a predator. It is believed that moose may feel trapped in the ditches adjacent to high road cuts, which probably induces them to retreat in the forest. Steep cut slopes are being tested in Arizona to deter elk from getting access to roadways, but no results on the success of this measure is available so far (Dodd et al. 2003).

We did not find a clear relationship between MVCs and the number of used salt pools located along Highway 175. This is somehow surprising as moose are known to be strongly attracted to salt pools along Highway 175 (Jolicoeur et Crête 1994) and in other areas (Schwartz and Bartley 1991). Dussault et al. (2005) found a relationship between the presence of salt pools and MVCs. Their study including Highway 175 but also Highway 169, we suspect that the additional data encompasses an area of both high density of moose and salt pools due to poor drainage of ditches in this area. The QMOT is actually improving drainage of salt pools where possible, and covering them with rocks to deter moose from using these pools. They are also creating salt pools >1 km from the roadway, in an attempt to attract moose away. Monitoring is under way to test the efficiency of these measures, but such management techniques have given mixed results at best in prior attempts (Jolicoeur et Crête 1994, Child 1998).

Although we found that abundance of high quality habitat and streams and rivers near the roadway are related to MVCs, they explained little of its spatial variation. In a similar study, the statistical model also explained a small share (23%) of the spatial variance in MVCs (Dussault et al. 2004). The latter study identified moose density, the presence of salt pools, the presence of drainages perpendicular to (the roadway), and the mean slope around the road section as the primary variables related to MVCs.

The difficulty in obtaining strong predictive models probably lies within the random movements of moose. Moose travel great distances within 24 hours to find sufficient forage (Renecker et Schwartz 1998). Ongoing research in the LWR shows that mean summer home ranges of adult females and males, respectively, are 24.7 and 28.0 km^2, and daily movements average >1.5 km (UQAR and MNRWP 2004).

Yearlings and sub-adults generally travel greater distances than adults during summer as they disperse away from natal grounds. Courtois et al. (1998) observed that sub-adults travel almost twice the distance that adults do daily. Also, yearlings in the boreal forest of Ontario have shown ''long wandering movements'' toward new areas in which they never return subsequently (Addison et al. 1980). Preliminary data showed that moose hit on Highway 175 often were yearlings and sub-adults. Joyne and Mahoney (2001) also found that yearlings were predominant in reported MVCs in Newfoundland and Labrador.

Dispersion also is more prevalent where moose density is high or increasing (Hundertmark 1998, Courtois et Crête 1988, Rolley and Keith 1980). Hence, movement paths of dispersers are unlikely to be well defined in terms of habitat features or characteristics because they have not established their home ranges yet. Moreover, the presence of predators, like timber wolves and black bears, in LWR is likely to induce greater movements of moose as an anti-predator strategy (Courtois and Crête 1988).

Limited clustering of tracks recorded during summer 2004 in a hazardous zone of Highway 175 was coherent with the results of analyses and the limited capacity of regression models to narrow landscape and road characteristics related to MVCs at the 1-km scale.

Given our inability to find key variables explaining a large share of MVCs occurring on Highway 175, we proposed different levels of mitigation measures based strictly on the number of MVCs recorded from 1991 and 2001. We identified three specific high-risk zones (25, 15 and 14 km long) in the northern and southern portions of LWR where the MVC rate is above 0.50 MVC/year/km. We recommend that these road sections be fenced and underpasses provided and combined with all major river crossings during the upgrade project from a two-lane to a four-lane divided highway. In one of these three zones, specifications and drawings have been prepared and include two underpasses for moose, eight one-way gates near open ends of the fenced section, and Texas gates for forestry operations and most important access to fishing and hunting camps. Trails and salt pools will also be made on each side of the underpasses to attract moose and facilitate their movements under bridges and social interactions near passages.

Finally, given that moose density represents the most important variable related to MVCs, wildlife managers of LWR need to consider increasing harvest quotas. If they remain unchanged in the LWR harvest management plan, the ongoing increase in moose density is likely to continue as recent updated guidelines in timber management will undoubtedly favor conservation and improvement of moose habitats. For example, in northern areas of Highway 175 where the moose habitat is good but hunting pressure is high and not controlled, MVCs remain rare events. This observation demonstrates the importance of harvest regulations on moose density and its potential as a management technique to prevent MVCs.

Conclusion

The spatial distribution of MVCs along Highway 175 in LWR was found very difficult to predict using variables describing road, landscape, and moose population and habitat features. The most significant variables were (1) moose density as reflected by our index of habitat quality; (2) amount of brooks, streams, and rivers nearby; and (3) the importance of pronounced road fills and road cuts. Given our weak predictive power, we identified high-risk zones by looking at distribution of MVCs between 1990 and 2001, and we proposed measures to reduce MVCs within these areas. As the Highway 175 upgrading project begins soon, our management measures were integrated during the planning stage of the upgrade, which clearly is the best way to reduce both MVCs and the cost associated with the mitigation measures.

Biographical Sketches: Yves Leblanc is a senior wildlife research biologist with Tecsult Inc. He is currently under contract with the Quebec Ministry of Transportation to assess and reduce moose and white-tailed deer vehicles collisions in different upgrading and new highway projects. Mr. Leblanc also is involved in many environmental impact assessment of major hydroelectric and road development on ungulates, waterfowl, and fur bearing animals in northern Québec. He has been actively involved in wildlife management and research projects with the Québec Ministry of Natural Resources on beaver, fisher, and woodland caribou. Mr. Leblanc holds a B.S. in biology from Université Laval and an M.S. in zoology from the University of Alberta.

François Bolduc received his B.S. in biological sciences from Université du Québec à Rimouski and his M.S. in natural resources from McGill University. Dr. Bolduc completed his Ph.D. in renewable natural resources at Louisiana State University, working on western Louisiana wetland management efficiency for wintering waterfowl and waterbirds. He presently is a consultant working on a variety of wildlife issues.

Donald Martel is an environmental specialist at a regional office of the Québec Ministry of Transportation. He is currently in charge of the environmental impact assessment of Highway 175. He holds a B.S. in geomatics from Université Laval and is currently a member of the Québec Corporation of land surveyors.

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