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Temporal and spatial distribution of moose-vehicle accidents in the Laurentides Wildlife Reserve, Quebec, Canada

Christian Dussault, Marius Poulin, Réhaume Courtois & Jean-Pierre Ouellet

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Deer-vehicle accidents are an increasing problem in many regions of the world. To elaborate effective mitigation measures, it is necessary to determine environmental factors associated with the occurrence of such accidents. The Laurentides Wildlife Reserve in Quebec, Canada, is a prime example of an area having a long-lasting problem of moose-vehicle accidents (MVAs). We tested the effect of the spatial and temporal variables most likely to influence MVAs in this area based on accidents recorded over a 13-year period. Data collected included the date and time of each collision as well as the position of the accident relative to the closest 1-km road marker. We calculated 10 variables to assess moose habitat suitability, moose density, topography and road design for every 1-km road segment. There was a total of 754 MVAs during 1990-2002. The period with the highest number of accidents was the second half of June but accident frequency remained relatively high from mid-May to late August. The risk of accident per vehicle was at least 2-3 times higher at night (when traffic volume was lowest) than during any other time of the day. Also, MVAs were over 42% more frequent on Fridays, when road traffic levels were highest. The probability of an MVA increased when air temperature and atmospheric pressure were high. The MVA rate increased with moose density, in the presence of at least one brackish pool (by 80%) and when a valley traversed the road (by 120%). Implications of our results in the choice of appropriate mitigation measures are discussed. Future work should aim to describe habitat characteristics at the actual collision site.

Key words: accident, habitat, moose, period, road, brackish pools, weather

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Deer-vehicle accidents (DVAs) are an important problem in many regions of the world, especially in North America, Scandinavia and Japan. Such accidents almost always result in considerable material damage, in death of the wounded animal and physical injury or death of human beings (Lavsund & Sandegren 1991, Haikonen & Summala 2001). Groot-Bruinderink & Hazebroek (1996) estimated the annual number of road accidents involving an ungulate in Europe (excluding Russia) at 507,000, which resulted in 300 human deaths, 30,000 other injured persons and material damage of 1 billion US$. In the United States, DVAs have increased from 200,000 in 1980 to 500,000 in 1991 (Romin & Bissonette 1996a) and cost more than 1 billion US$ annually (Conover 1997). These numbers alone explain why the reduction of DVAs is a priority for wildlife and transportation agencies in many regions (Sullivan & Messmer 2003).

One of the first steps necessary in elaborating effective mitigation measures is to determine environmental factors and conditions associated with the occurrence of DVAs (Malo et al. 2004, Seiler 2004, 2005). Significant regional variations exist in the timing and causes of DVAs (Groot-Bruinderink & Hazebroek 1996). Once local parameters are known, it should be possible to identify risky road sectors and propose measures to improve drivers' safety (Putman 1997). We can identify four potential components to the DVA problem: wildlife-related causes (e.g. animal density or behaviour), habitat-related factors (e.g. availability of food), weather conditions (that affect visibility or animal behaviour) and human causes (e.g. driver distraction or fatigue and level of road traffic).

Rate of DVAs is clearly related to deer density (Modafferi 1991, Oosenbrug et al. 1991, Joyce & Mahoney 2001, Mysterud 2004); therefore it is not surprising that most European countries and United States have reported an increase in DVAs during recent decades. Many studies have also found increased collision frequencies at dawn and dusk when deer activity peaks (Gundersen & Andreassen 1998, Haikonen & Summala 2001). In terms of habitat, DVAs have been reported to occur in areas where forest cover is dense (Madsen et al. 2002, Seiler 2004) or diverse (Malo et al. 2004). Rights-of-way, such as roads, may be attractive to cervids in many respects. Roads offer abundant food resources that are spatially more concentrated than in the nearby forest (Finder et al. 1999, Rea 2003). The presence of minerals, particularly sodium, is likely to attract cervids along roads (Fraser 1980, Jolicoeur & Crête 1994). Sodium is usually rare in the environment, but it is required by mammals for many reasons, including regulation of osmotic pressure, reproduction, lactation and moulting (Belovsky & Jordan 1981, Robbins 1993). The sodium originating from road de-icers in boreal regions can concentrate in brackish pools that are as attractive to cervids as natural mineral licks (Fraser et al. 1982, Jolicoeur & Crête 1994, Bechtold 1996).

Since annual peaks in DVAs often coincide with peaks in animal activity, one could expect certain weather variables to be associated with DVAs. Indeed, weather (such as temperature) may directly affect animal and drivers' behaviour (Dussault et al. 2004, Mysterud 2004). To our knowledge, the influence of weather and human-related factors on DVAs is, however, poorly understood (but see Gundersen & Andreassen 1998) and most analyses to date have focused on habitat-related factors. Increasing darkness may reduce drivers' ability to detect a traversing animal (Haikonen & Summala 2001). Also, one could expect driver distraction and fatigue as well as vehicle speed to modify a driver's reaction time when attempting to avoid a collision, but there is little published literature on this topic (Seiler 2005).

During 1990-2002 in Quebec, Canada, road accidents with large mammals involved 161-310 moose *Alces alces*, 1,847-2,803 white-tailed deer *Odocoileus virginianus* and 18-77 black bears *Ursus americanus*, annually (Sebbane & Courtois 2000). As in other jurisdictions, the number of accidents could have been underestimated by as much as 50% (Child et al. 1991, Lavsund & Sandegren 1991). The Laurentides Wildlife Reserve is a prime example of an area having a persistent problem of vehicle accidents involving moose (Grenier 1974). Moose-vehicle accidents (MVAs) constitute over 50% of all vehicle accidents on some road segments. Past studies indicated that accidents in the reserve occurred mostly in summer (Grenier 1974) and that these accidents were in part associated with the presence of brackish pools along the roadway (Jolicoeur & Crête 1994). As in most jurisdictions having similar problems, analyses in this wildlife reserve have mostly been restricted to a descriptive analysis of the phenomenon and the general habitat without an assessment of other associated factors. MVAs

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could also be related to moose distribution or behaviour with respect to topography (Bellis & Graves 1971, Carbaugh et al. 1975, Modafferi 1991, Gundersen et al. 1998, Finder et al. 1999, Joyce & Mahoney 2001). Alternatively, MVAs could depend for instance on drivers' inability to detect moose presence under twisting road conditions or reduced light availability (Del Frate & Spraker 1991) or even on weather conditions (Reed 1981, Andersen et al. 1991, Gundersen & Andreassen 1998).

In this paper, we examine the effect of spatial and temporal variables most likely to influence MVAs in the Laurentides Wildlife Reserve, using data from accidents recorded over a 13-year period. We discuss how the results from our study could be used in the elaboration and choice of appropriate mitigation measures.

Material and methods

Study area

The Laurentides Wildlife Reserve is a large forested area (7,861 km^2) located north of Quebec City, Canada, that is traversed by two major provincial roads in a north-south direction (Routes No. 175 and 169; Fig. 1). These roads are paved and mostly one-way in each direction. In 2002, mean daily traffic was estimated to be 1,460 vehicles on Route 169 (sector 1, length of 60 km), 2,800 vehicles on Route 175 N (sector 2, 48 km) and 4,800 vehicles on Route 175 S (sector 3, 82 km; see Fig. 1). The maximum speed allowed in the study area is 90 km/hour.

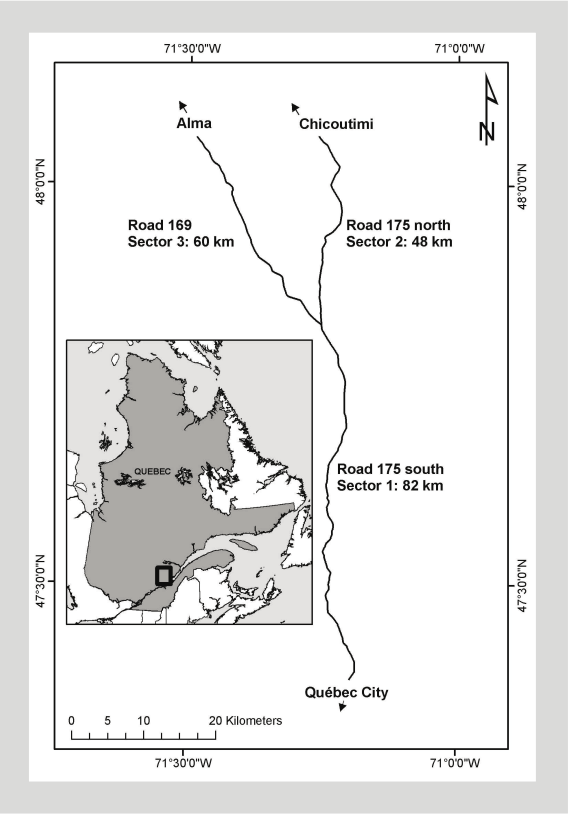


Figure 1. Study area with the two provincial roads (Routes No. 175 and 169) that traverse the Laurentides Wildlife Reserve in a north-south direction. Three sectors of differing lengths and levels of traffic volume were defined (see text).

Forest stands are typical of the boreal forest (Dussault et al. 2001). Coniferous stands with balsam fir *Abies balsamea* and black spruce *Picea mariana* are dominant on high plateaus whereas lower altitudes and river valleys are covered with mixed and deciduous stands, mostly white birch *Betula papyrifera*, trembling aspen *Populus tremuloides*, yellow birch *B. alleghaniensis* and maples *Acer* spp. Forest harvesting existed in the study area for several decades, resulting in a heterogeneous mosaic of mature and regenerating stands. A severe spruce budworm *Choristoneura fumiferana* outbreak occurred approximately 20 years ago and contributed to rejuvenating the forest. The topography along the two roads is broken with many hills rising > 150 m above the road surface and some major river valleys falling off to 300 m below.

The forest mosaic of young and mature stands provides high-quality habitat for moose. Moose density in the reserve is relatively high and was 2.2 moose/10 km^2 in the winter of 1994 (including 8.0 moose/10 km^2 in some sectors; St-Onge et al. 1995, Dussault 2002), but density is likely increasing due to the adoption of restrictive hunting regulations for the last decade. Caribou *Rangifer tarandus*, white-tailed deer and black bear are the other large mammals found in the study area. Natural predators of moose are timber wolf *Canis lupus* and black bear.

Winters in the Laurentides Wildlife Reserve are especially harsh since this area receives among the highest annual snowfalls in the world. Snow begins to accumulate on the ground in early November, reaches its maximal depth of over 100 cm around mid-March and persists until early June under forest cover (Québec Ministry of Environment). Minimum and maximum daily temperatures are, respectively, -21.7 and -9.0°C in January, and 9.5 and 21.7°C in July.

Moose-vehicle accident data

We used the MVA database compiled by the Quebec Ministry of Transportation (QMT) during 1990-2002. Data collected for each accident included the date and time of collision as well as the position of the accident with respect to the closest 1-km road marker. We evalu-

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ated the temporal distribution of accidents by year, semi-monthly period and time of day, including the influence of atmospheric pressure, air temperature and precipitation.

Temporal distribution of moose-vehicle accidents

We examined the temporal distribution by classifying each accident according to: 1) year; 2) semi-monthly period (i.e. period 1 = 1-15 January inclusively; period 2 = 16-31 January; …; period 24 = 16-31 December); 3) day of the week (Sunday, Monday, ...); and 4) time of day (dawn = from 1 hour before to 1 hour after sunrise; dusk = from 1 hour before to 1 hour after sunset; day = between dawn and dusk; night = between dusk and dawn). Times of sunrise and sunset were obtained on a daily basis at a weather station located in the centre of the study area. This allowed us to precisely categorise each accident relative to the time of day, given that sunrise and sunset varied according to time of the year (Haikonen & Summala 2001).

We also evaluated the influence of several weather variables on the probability of MVAs by day. Weather was assessed using mean conditions recorded on a daily basis at 12 weather stations located < 2.5 km from and evenly distributed along Routes 169 and 175. The number of weather variables available restricted our analyses to the 11 variables of atmospheric pressure, temperature and precipitation presented in Table 1.

The rate of accidents by hour corrected for traffic volume can be used as a measure of risk (measured as mean probability of an individual vehicle having an accident by hour; Haikonen & Summala 2001). We created this variable by dividing the number of MVAs by average traffic level and duration of day period, by annual period. To do so, we identified three homogeneous zones or sectors with regard to traffic level in the Laurentides Wildlife Reserve (see Fig. 1). In sector 3, there was a permanent station that systematically recorded traffic volume throughout the day during the entire study period. For sectors 1 and 2, only estimates of mean daily traffic levels on a yearly basis were available. We supposed that semi-monthly and daily variations in traffic volume in these sectors were similar to those measured in sector 3. We calculated the mean traffic level within the entire study area by taking the average of traffic levels for the three sectors using relative sector length as a weighting factor.

Table 1. Weather variables included in statistical analysis of the effect of temporal variables on probability of MVAs to occur on a given day in the Laurentides Wildlife Reserve during 1990-2002.

Variable
Atmospheric pressure (kPa)
Daily minimum
Daily maximum
Daily variation (maximum - minimum)
Difference between maximum of the actual day and that of the preceding day
Difference between minimum of the actual day and that of the preceding day
Temperature (°C)
Daily minimum
Daily maximum
Daily variation (maximum - minimum)
Difference between maximum of the actual day and that of the preceding day
Difference between minimum of the actual day and that of the preceding day
Daily precipitation (mm of water)

Spatial distribution of moose-vehicle accidents

MVAs were located to the closest 1-km road marker and projected using the ArcMap program (ESRI Inc. 1996) onto a 1:20,000 forest map that included topography, vegetation, rivers, streams, lakes and roads. Similar to Seiler (2005), we calculated 10 variables of moose habitat suitability (three variables), moose density, topography (four variables) and road design (two variables) for every 1-km segment of Routes 175 and 169, to determine their influence on the occurrence of MVAs. In order to precisely characterise each road segment, habitat-related variables were calculated every 100 m and we used mean and extreme values to describe each segment that was centred on a 1-km road marker (see below).

To evaluate variations in moose density across the study area, we used results from four winter aerial surveys conducted during 1994-1998 in the Laurentides Wildlife Reserve (St-Onge et al. 1995, Dussault 2002). Even though moose density was not measured each year, sample plots were well distributed across the study area which allowed us to obtain a relative index of moose density. Surveys were conducted according to the method proposed by Courtois et al. (1994). Moose density for each 1-km road segment was considered to be that of the closest survey plot among the 45 plots available. We also determined the distance between the roadway and the closest forest stand offering high food availability to moose. As suggested by Dussault et al. (2001), food stands were defined as mixed or deciduous regeneration (e.g. cutovers at least five years old, insect outbreaks, windthrow and burns). Similarly, we also calculated the distance between the roadway and the closest permanent waterway (rivers and streams) or water body.

Brackish pools located along Routes 169 and 175 that showed signs of utilisation by moose were counted dur-

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ing the fall of 2003. A brackish pool was defined as water or a muddy area with obvious signs of moose utilisation (recent tracks, track networks and dead or mutilated vegetation). Salinity was always > 300 ppm in the pools that were sampled (N = 50 over the 190 km stretch of roadway) and usually > 1,000 ppm. Such a mineral concentration was tens or hundreds of times higher than those measured in ponds located far from the road (Jolicoeur & Crête 1994).

We first determined mean altitude with respect to sea level to describe the topography of each 1-km road segment. Then we calculated the slope over a distance of 1 km in six different directions relative to the road axis (at bearings of 45, 90, 135, 225, 270 and 315 degrees) using a digital elevation model. We used the mean and range of slopes to characterise the topography on either side of each 1-km road segment. A high mean slope value indicated that the road in that area was enclosed between hills.

Because the topography in the study area is very broken and slopes were often elevated on either side of the road, we expected moose to travel across the landscape by selecting areas with relatively low slopes. We therefore identified valleys that crossed the roadway. These valleys were likely to allow moose to move across the landscape at reduced energetic costs, i.e. by avoiding steep slopes (Gundersen et al. 1998). The presence of valleys crossing the road was assumed when at least one slope < 2%, among the six slopes measured as described above, existed on both sides of the road at a given sampling point. Following visual examination of the topography along roads, we determined that a 2% slope threshold was adequate to identify where the valleys were. For statistical analyses, we classified each 1-km road segment according to presence/absence of a valley.

We also developed two indices that were related to drivers' visibility or ability to detect moose along the roadway. Road twisting and undulation were indexed by calculating the horizontal and vertical changes in road angle between sample points distributed every 100 m along the roadway. We considered the undulation index to be zero when the angle was concave or flat because we did not expect drivers' visibility to be reduced. In the case of a convex angle, we determined the undulation index to be equal to the vertical angle of the road.

Statistical analyses

We first utilised separate χ^2 tests to determine the effect of year, semi-monthly period and time of day on the number of MVAs (PROC FREQ; SAS Institute Inc. 2000). Then, the effect of weather variables on occurrence of MVAs by day was tested using a logistic regression (PROC LOGISTIC; SAS Institute Inc. 2000). In the temporal analysis, each record in the database consisted of a day (i.e. day is the sampling unit; N = 4,745 days) to which was associated a binary variable indicating whether an accident occurred or not during that day. The following independent variables were tested: year, semi-monthly period, day of the week and 11 weather variables (see Table 1). Weather variables were categorised into three classes (i.e. low, medium and high) with the 33 and 66% percentiles being used as cut-off points. We used a stepwise logistic regression with an alpha-to-enter level of $P \leq 0.1$. This method allowed the identification of the best model while eliminating variables that were highly correlated. Model fit was assessed by calculating the area under the Receiver Operating Characteristic (ROC) curve, which can vary between 0.5 (worst fit) and 1 (best fit; Hosmer & Lemeshow 2000).

To test the relationship between number of MVAs along 1-km road segments and the spatial variables considered, we utilised a general linear model with a Poisson distribution (PROC GENMOD, SAS Institute Inc. 2000). The total number of MVAs that occurred during the study period (13 years) at a given 1-km road segment divided by average traffic level along that road segment was used as dependent variable. The 10 variables describing moose density, moose habitat suitability, topography and road design were used as independent variables. Similar to the analysis of temporal distribution, we utilised a stepwise approach with an alpha-to-enter level of $P \leq 0.1$.

Results

Temporal distribution of MVAs

There was a total of 754 MVAs in the Laurentides Wildlife Reserve during 1990-2002, with a significant

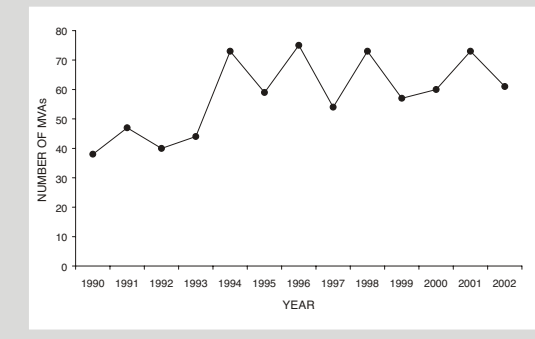


Figure 2. Annual number of MVAs in the Laurentides Wildlife Reserve during 1990-2002.

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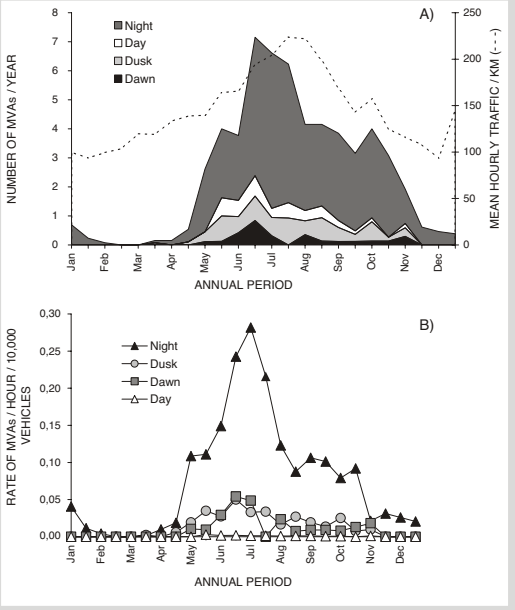


Figure 3. Mean number of MVAs per year (A) and mean rate of MVAs corrected for traffic level and daily period length (B) in the Laurentides Wildlife Reserve by semi-monthly period and time of day. Data were averaged over a 13-year period (1990-2002).

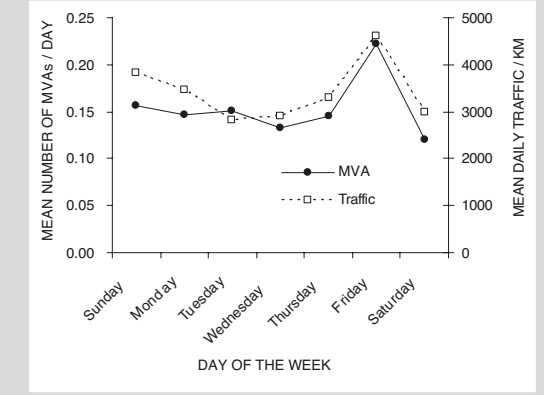


Figure 4. Daily number of MVAs and mean road traffic volume in the Laurentides Wildlife Reserve by day of the week during 1990-2002.

yearly variation ($\chi^2 = 35.1$, df = 12, $P < 0.001$). Annual numbers of accidents were 40-50 before 1994 but then increased to and stabilised at 50-70 thereafter (Fig. 2).

Number of MVAs varied between semi-monthly periods ($\chi^2 = 532.2$, df = 21, $P < 0.001$) and the pattern did not differ between years ($\chi^2 = 265.5$, df = 252, $P = 0.268$). Accidents were not frequent from mid-November to mid-April (Fig. 3A). The period with the highest number of accidents was the second half of June, but the number of accidents remained relatively high from mid-May to late August.

Visual examination of Figure 3A showed that variations in numbers of MVAs between semi-monthly periods were not simply related to changes in road traffic levels, especially during early summer. Indeed, the period during which traffic volume was highest (early August) did not correspond to the period when MVAs occurred most. From early August until late November, however, the reduction in MVAs closely followed the reduction in mean traffic volume.

MVAs were also not uniformly distributed among the different times of day ($\chi^2 = 571.2$, df = 3, $P < 0.001$). The number of MVAs was highest at night, followed by dusk, dawn and day (see Fig. 3A) and this trend did not change throughout the year ($\chi^2 = 42.6$, df = 60, $P = 0.957$). The risk for individual drivers appeared to be even higher at night after the hourly accident rate was corrected for road traffic volume (see Fig. 3B). The risk of accident by vehicle appeared at least 2-3 times higher at night than during any other time of the day, as it can be demonstrated using a response variable corrected for traffic level and daily period length (hourly accident rate by 10,000 vehicles; see Fig. 3B). In addition, MVAs were >42% more frequent on Fridays when road traffic levels were highest ($\chi^2 = 27.3$, df = 6, $P < 0.001$; Fig. 4).

The logistic regression also showed variations in accident rate between years, semi-monthly periods and days of the week (Table 2). Also, maximum daily temperature and minimum daily atmospheric pressure significantly influenced the probability of MVAs to occur on a given day. On average, the probability of an MVA increased when both air temperature and atmospheric pressure were high (Fig. 5). The ROC value of the final logistic regression model was 0.81 which can be considered an excellent fit (Hosmer & Lemeshow 2000).

Table 2. Results of logistic regression testing the effect of year, semi-monthly period, day of the week and weather variables on the probability of MVAs occurring on a given day in the Laurentides Wildlife Reserve during 1990-2002.

Variable	df	Wald χ^2	P
Year	12	31.41	0.002
Semi-monthly period	23	102.47	<0.001
Day of the week	3	17.65	<0.001
Maximum daily temperature	1	17.28	<0.001
Minimum daily atmospheric pressure	2	11.34	0.004

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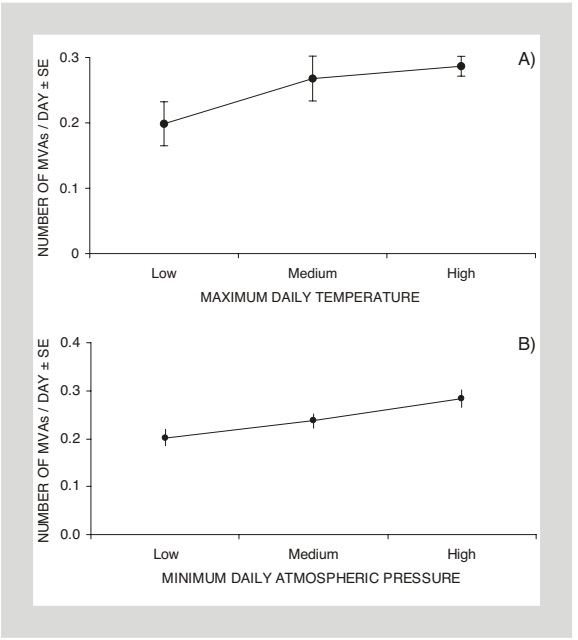


Figure 5. Relationship between mean number of MVAs by day and maximum daily temperature during June-August (A) or minimum daily atmospheric pressure during June-October (B).

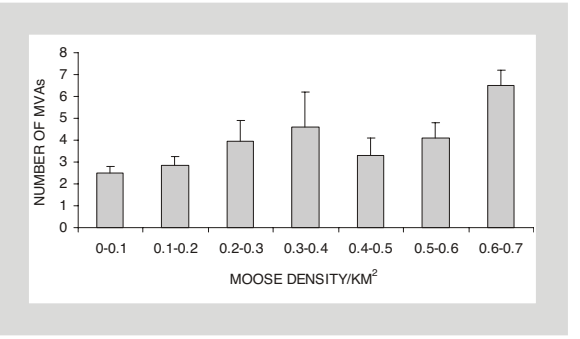


Figure 6. Relationship between number of MVAs along each 1-km road segment and moose density. MVA data were collected over the 1990-2002 period, and moose density was estimated by aerial survey in 1994.

Spatial distribution of MVAs

The stepwise multiple regression identified moose density as having the highest influence on spatial distribution of MVAs (Table 3), with MVA rate increasing with moose density (Fig. 6). The relationship between number of MVAs and number of brackish pools was not linear. MVAs were more numerous along 1-km road segments as soon as one brackish pool was present, but MVAs did not continue to increase with additional brackish pools. Number of MVAs increased by 80% on road segments where at least one brackish pool was present and by 120% in the presence of a valley crossing the road. Finally, frequency of MVAs increased as the mean slope of the terrain surrounding the roadway increased. These four variables explained 23% of the spatial variation in MVAs along 1-km road segments. Variables found not to affect frequencies of MVAs included distance to high food availability or water, altitude, range in slope of surrounding terrain and twisting and undulation of the roadway.

Table 3. Results of multiple regression model testing the effect of habitat-related variables on the number of MVAs occurring along 1-km road segments in the Laurentides Wildlife Reserve during 1990-2002.

Variable	B	df	F	P
Moose density/km^2	1.569	207	26.0	<0.001
Presence of a brackish pool	-	207	18.3	<0.001
Presence of a potential travel corridor	-	207	12.0	0.001
Mean slope of surrounding terrain	0.092	207	3.2	0.075

Discussion

Temporal distribution of MVAs

The noticeable difference in MVA numbers before and after 1994 is likely attributable to changes in data collection methods when the Quebec Ministry of Transportation (QMT) relieved the Quebec Ministry of Environment and Wildlife in 1994. Records of MVAs were higher because QMT also used accident reports of the provincial police as a complementary source of information. MVAs in the Laurentides Wildlife Reserve mostly occurred between mid-May and late November and peaked between mid-June and mid-July. This temporal distribution of accidents is similar to that reported by Grenier (1974) and Jolicoeur (1985) in the same area during the 1970s and 1980s and by other researchers in Ontario (Fraser 1979), Newfoundland (Joyce & Mahoney 2001) and southern Sweden (Skolving 1987, Lavsund & Sandegren 1991). According to Grenier (1974) and Jolicoeur (1985), the peak in the Laurentides Wildlife Reserve is the result of moose seeking sodium sources in early summer. The temporal distribution that we observed, however, differed from that in British Columbia (Child et al. 1991), Alaska (Del Frate & Spraker 1991, McDonald 1991, Modafferi 1991), Norway (Andersen et al. 1991, Gundersen & Andreassen 1998), Finland (Haikonen & Summala 2001) and northern Sweden (Lavsund & Sandegren 1991) where the peak occurs in mid-November or mid-winter when moose are seeking feeding sites with little snow accumulation which are often

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found in valleys along roads. Regional variations thus exist in the distribution of MVAs throughout the year. Peak accident rates are usually associated with major activity periods of cervids fulfilling particular requirements such as feeding, reproduction, seasonal migration or even dispersal of juveniles (Romin & Bissonette 1996b, Gundersen et al. 1998). The findings that males are more likely to be implicated in an accident during the rut and that juveniles are more vulnerable soon after separation from their mothers support this hypothesis (Groot-Bruinderink & Hazebroek 1996, Putman 1997).

As we observed in our study, the relationship between number of accidents and road traffic levels is not always straightforward (Groot-Bruinderink & Hazebroek 1996). Sometimes a relationship does not exist (Reilley & Green 1974, Del Frate & Spraker 1991, Madsen et al. 2002, Mysterud 2004) whereas at other times the relationship is linear (Grenier 1974) or logarithmic (Berthoud 1987, Skolving 1987, Seiler 2005). The daily peak in accidents occurs from dusk to dawn (Grenier 1974, Allen & McCullough 1976, Jolicoeur 1985, Berthoud 1987, Skolving 1987, Tunkkari 1987, Child et al. 1991, Lavsund & Sandegren 1991, Putman 1997, Gundersen & Andreassen 1998, Joyce & Mahoney 2001, Haikonen & Summala 2001) whereas traffic volume is generally highest during the day. According to Groot-Bruinderink & Hazebroek (1996), this high vulnerability of moose during the night is attributable to an increase in activity rate. Dussault (2002), however, found moose to be more active during the day than during the night throughout the year, indicating that this may not be the only explanation. Reduced drivers' visibility at night may be an important factor amplifying the problem. In our study, accident rates were similar at dawn and dusk which differs from the results of Haikonen & Summala (2001) who observed a daily peak of collisions with moose and white-tailed deer occurring one hour after sunset in Finland.

Accidents with moose were more frequent on Fridays, the day during which traffic level was highest. Friday coincides with the last day of work of the week and drivers could be less vigilant. Drivers leaving for the weekend period are also likely to quit at the end of the day during risky periods of low light conditions.

Contrary to Gundersen & Andreassen (1998) in Norway, we observed a higher probability of MVAs during hot days and when atmospheric pressure was relatively high. A potential explanation could be that moose reduce their activity rate during warm summer days and compensate by increased nocturnal activity (Dussault et al. 2004). High activity of moose at night, a time when drivers' visibility is limited, could induce a high probability of MVAs. Some researchers have suggested that moose seek open areas such as rights-of-way to escape harassment from biting insects (Kelsall & Simpson 1987). Hot summer periods likely correspond to peak abundances of some biting insects, such as Tabanids, that are known to harass moose (Renecker & Hudson 1990). The influence of high atmospheric pressure on animal behaviour is, however, more difficult to interpret. High atmospheric pressure can also lead to the formation of fog (R. Gagné, Québec Ministry of Environment, pers. comm.), which would obviously reduce drivers' visibility. High atmospheric pressure might also trigger moose activity year-round. However, this relationship remains to be shown.

To our knowledge, no other study has tested the effect of weather conditions on probability of MVAs or DVAs on a day-to-day basis (see Gundersen & Andreassen 1998 and Gundersen et al. 1998 for collisions with trains). Andersen et al. (1991) found an effect of air temperature on the frequency of MVAs throughout the year and concluded that accidents were frequent during cold periods, i.e. winter. Carbaugh et al. (1975) and Groot-Bruinderink & Hazebroek (1996) did not report any effect of weather conditions on the use of roadways by ungulates.

Spatial distribution of MVAs

The spatial distribution of MVAs in the Laurentides Wildlife Reserve was primarily determined by moose density, with accidents being frequent in sectors with high animal abundance. This confirms findings from other studies of MVAs (Modafferi 1991, Oosenbrug et al. 1991, Joyce & Mahoney 2001, Seiler 2004, 2005). Malo et al. (2004) found that collisions with animals at the landscape scale in Spain mostly occurred in areas with a high diversity of habitat types. Habitat suitability certainly was also a factor in our study area since areas of high moose density also offered the most suitable habitats (St-Onge et al. 1995). However, the variance in accident rate that could have been explained by habitat suitability was accounted for by density. The presence of a brackish pool was another habitat-related variable that had an influence on MVAs. Accidents were more frequent along road segments with at least one brackish pool than along segments where such pools were absent. The difference, an 80% increase, was not as high as that reported by Grenier (1973) in the same area in the early 1970s (200%), but Grenier (1974) did not use the same criteria to identify brackish pools as we did. It is likely that sodium, a rare but important element to mammals (Belovsky & Jordan 1981), attracts moose to these pools (Fraser et al. 1982, Jolicoeur & Crête 1994, Bechtold 1996). We are currently assessing the frequency of moose

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visits to brackish pools along roadways as part of another research project in the Laurentides Wildlife Reserve. Our preliminary results indicate that peak moose attendance at brackish pools occurs at night between early June and early August which corresponds directly to our peaks in MVAs, both for time of day and time of year. The problem of ungulate association with brackish pools was also reported for moose in Ontario (Fraser 1980) and for red deer *Cervus elaphus* in Finland (Nieminen & Leppaluoto 1985 cited in Tunkkari 1987).

Among the topographical variables, only the presence of a valley on either side of the road and mean slope of the terrain surrounding the roadway influenced spatial distribution of MVAs. Although no study to our knowledge has specifically studied moose movements relative to topography, moose could use the relatively flat corridors to carry out large- and medium-scale movements (e.g. dispersal). Gundersen et al. (1998), Finder et al. (1999), and Clevenger et al. (2001) also identified movement corridors as a factor associated with ungulate-vehicle collisions. Our results also indicated that accidents were frequent along road segments where mean slope of the surrounding terrain was high. Although these two results might appear to be contradictory, we believe they can be interpreted the same way. Accidents were more frequent in the presence of a movement corridor forming an angle with the roadway but also along route segments surrounded by elevated slopes. In the latter, the roadway itself likely was in a valley that might have been used by moose as a travel corridor. Our results are in agreement with the findings of Bellis & Graves (1971) who reported a high number of accidents in areas where slopes on either side of the road were steep, therefore confining animals to travel along the road. Feldhamer et al. (1986), on the contrary, did not report any influence of topography on DVAs in Pennsylvania. The presence of a ravine along the road could also force animals to circulate on the roadway (Finder et al. 1999) and increase the likelihood of accidents.

Management implications

The variables tested in our study explained < 25% of the spatial variation in accidents, which indicates that this phenomenon is far from predictable and that other variables or stochastic events must influence MVAs. However, we have demonstrated the effect of spatial variables on MVAs in the Laurentides Wildlife Reserve, and also showed that probability of MVA is not uniform throughout the year and day. Our results should be used to understand why some road segments and time periods are especially problematic and to help in the elaboration of mitigation measures at the local scale.

Essentially, an effective management plan should aim to warn motorists during the riskiest periods of the year and to reduce occurrence of moose on the roadway. Dynamic signage (Farrell et al. 2002, Gordon & Anderson 2002, Huijser & McGowen 2003) should be used mostly during summer months, when MVAs are likely to occur, where moose density is high and especially in areas with brackish pools or where the surrounding topography is broken with valleys facilitating moose movements across the landscape. Since the accident rate was high between dusk and dawn, a public awareness program should encourage drivers to reduce speed at night. In particularly problematic areas, accident frequency could be reduced by lighting the roadway (McDonald 1991).

For habitat management, we identified the presence of brackish pools and valleys crossing the roadway as variables likely increasing the occurrence of MVAs. A management programme that aims to eliminate brackish pools along the roadway is underway in the Laurentides Wildlife Reserve and its efficacy is under investigation. The relationship between the number of MVAs and the number of salty pools was not linear. These results support a recommendation to eliminate all salty pools. We also observed high accident frequencies where there was a valley on either side of the road. Security in such sectors could potentially be increased with the use of fences and infrared-activated signage (Taskula 1997, Huijser & McGowen 2003). More detailed information is necessary to fully understand moose behaviour with respect to topography.

In our study, we investigated MVAs at a medium scale (i.e. 1-km resolution). In the future we should attempt to identify the spatial factors acting at the collision site (Malo et al. 2004). No variable involving road design was found to be related to MVAs in our study. This may be related to the fact that roads in our study area were relatively straight. But we recognise that our scale of analysis was probably not fine enough to detect the influence of such variables. Alternatively, vehicle speed could also influence occurrence of MVAs as reported in Sweden (Seiler 2005). A finer scale analysis should allow us to explore new variables such as the presence of vegetation or small ravines that may reduce driver visibility and that are not currently found on GIS layers.

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References

Allen, R.E. & McCullough, D.R. 1976: Deer-car accidents in southern Michigan. - Journal of Wildlife Management 40: 317-325.

Andersen, R., Wiseth, B., Pedersen, P.H. & Jaren, V. 1991: Moose-train collisions: effects of environmental conditions. - Alces 27: 79-84.

Bechtold, J-P. 1996: Chemical characterisation of natural mineral springs in northern British Columbia, Canada. - Wildlife Society Bulletin 24: 649-654.

Bellis, E.D. & Graves, H.B. 1971: Deer mortality on a Pennsylvania interstate highway. - Journal of Wildlife Management 35: 232-237.

Belovsky, G.E. & Jordan, P.A. 1981: Sodium dynamics and adaptations of a moose population. - Journal of Mammalogy 62: 613-621.

Berthoud, G. 1987: Impact d'une route sur une population de chevreuils. - In: Bernard, J.M., Lansiart, M., Kempf, C. & Tille, M. (Eds.); Routes et faune sauvage. Proceedings of a SETRA Symposium, Strasbourg, France, pp. 167-169.

Carbaugh, B., Vaughan, J.P., Bellis, E.D. & Graves, H.B. 1975: Distribution and activity of white-tailed deer along an interstate highway. - Journal of Wildlife Management 39: 570-581.

Child, K.N., Barry, S.P. & Aitken, D.A. 1991: Moose mortality on highways and railways in British Columbia. - Alces 27: 41-49.

Clevenger, A.P., Chruszcz, B. & Gunson, K. 2001: Highway mitigation fencing reduces wildlife-vehicle collisions. - Wildlife Society Bulletin 29: 646-653.

Conover, M.R. 1997: Monetary and intangible valuation of deer in the United States. - Wildlife Society Bulletin 25: 298-305.

Courtois, R., Leblanc, Y., Maltais, J. & Crépeau, H. 1994: Québec moose aerial surveys: methods to estimate population characteristics and improved sampling strategies. - Alces 30: 159-171.

Del Frate, G.G. & Spraker, T.H. 1991: Moose-vehicle interactions and an associated public awareness program on the Kenai Peninsula, Alaska. - Alces 27: 1-7.

Dussault, C. 2002: Influence des contraintes environnementales sur la sélection de l'habitat de l'orignal (Alces alces). - PhD thesis, Université Laval, Québec, 141 pp.

Dussault, C., Courtois, R., Huot, J. & Ouellet, J-P. 2001: The use of forest maps for the description of wildlife habitats: limits and recommendations. - Canadian Journal of Forest Research 31: 1227-1234.

Dussault, C., Ouellet, J-P., Courtois, R., Huot, J., Breton, L. & Larochelle, J. 2004: Behavioural responses of moose to thermal conditions in the boreal forest. - Ecoscience 11: 321-328.

ESRI Inc. 1996: ArcView GIS. The geographic system for everyone. - Environmental Systems Research Institute Incorporated, Redlands, CA, 340 pp.

Farrell, J.E., Irby, L.R. & McGowen, P.T. 2002: Strategies for ungulate-vehicle collision mitigation. - Intermountain Journal of Sciences 8: 1-18.

Feldhamer, G.A., Gates, J.E., Harman, D.M., Loranger, A.J. & Dixon, K.R. 1986: Effects of interstate highway fencing on white-tailed deer activity. - Journal of Wildlife Management 50: 497-503.

Finder, R.A., Roseberry, J.L. & Woolf, A. 1999: Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois. - Landscape and Urban Planning 44: 77-85.

Fraser, D. 1979: Sightings of moose, deer, and bears on roads in northern Ontario. - Wildlife Society Bulletin 7: 181-184.

Fraser, D. 1980: Moose and salt: a review of recent research in Ontario. - Proceedings of the North American Moose Conference and Workshop 16: 51-68.

Fraser, D., Thompson, B.K. & Arthur, D. 1982: Aquatic feeding by moose: seasonal variation in relation to plant chemical composition and use of mineral licks. - Canadian Journal of Zoology 60: 3121-3126.

Gordon, K.M. & Anderson, S.H. 2002: Motorist response to a deer-sensing warning system in western Wyoming. - In: 2001 Proceedings of the International Conference on Ecology and Transportation, pp. 549-558.

Grenier, P. 1973: Moose killed on the highway in the Laurentides Park Québec, 1962 to 1972. - In: Addison, R.B. (Ed.); Proceedings of the North American Moose Conference and Workshop 9: 155-193.

Grenier, P. 1974: Orignaux tués sur la route dans le parc des Laurentides, Québec, de 1962 à 1972. - Naturaliste Canadien 101: 737-754. (In French).

Groot-Bruinderink, G.W.T.A. & Hazebroek, E. 1996: Ungulate traffic collisions in Europe. - Conservation Biology 4: 1059-1067.

Gundersen, H. & Andreassen, H.P. 1998. The risk of moose Alces alces collisions: A predictive logistic model for moose-train accidents. - Wildlife Biology 4: 103-110.

Gundersen, H., Andreassen, H.P. & Storaas, T. 1998: Spatial and temporal correlated to Norwegian moose-train collisions. - Alces 34: 385-394.

Haikonen, H. & Summala, H. 2001: Deer-vehicle crashes - Extensive peak at 1 hour after sunset. - American Journal of Preventive Medicine 21: 209-213.

Hosmer, D.W. & Lemeshow, S. 2000: Applied Logistic Regression. 2nd edition. - Wiley, New York, 373 pp.

Huijser, M.P. & McGowen, P.T. 2003: Overview of animal detection and animal warning systems in North America and Europe. - In: Irwin, C.L., Garrett, P. & McDermot, K.P. (Eds.); 2003 Proceedings of the International Conference on Ecology and Transportation, pp. 368-382.

Jolicoeur, H. 1985: Les mares saumâtres: leur rôle dans les accidents routiers impliquant des orignaux et essai d'un moyen pour les éliminer. - Ministère du loisir, de la chasse et de la pêche, 42 pp. (In French).

Jolicoeur, H. & Crête, M. 1994: Failure to reduce moose-vehi-

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cle accidents after a partial drainage of roadside salt pools in Québec. - Alces 30: 81-89.
Joyce, T.L. & Mahoney, S.P. 2001: Spatial and temporal distributions of moose-vehicle collisions in Newfoundland. - Wildlife Society Bulletin 29: 281-91.
Kelsall, J.P. & Simpson, K. 1987: The impacts of highways on ungulates; a review and selected bibliography. - Prepared for Ministry of Environment and Parks, Kamloos, BC, 105 pp.
Lavsund, S. & Sandegren, F. 1991: Moose-vehicle relations in Sweden: a review. - Alces 27: 118-126.
Madsen, A.B., Strandgaard, H. & Prang, A. 2002: Factors causing traffic killings of roe deer Capreolus capreolus in Denmark. - Wildlife Biology 8: 55-61.
Malo. J.E., Suárez, F. & Díez, A. 2004: Can we mitigate animal-vehicle accidents using predictive models? - Journal of Applied Ecology 41: 701-710.
McDonald, M.G. 1991: Moose movement and mortality associated with the Glenn Highway expansion, Anchorage Alaska. - Alces 27: 208-219.
Modafferi, R.D. 1991: Train moose-kill in Alaska: characteristics and relationship with snowpack depth and moose distribution in lower Susitna valley. - Alces 27: 193-207.
Mysterud, A. 2004: Temporal variation in the number of car-killed red deer Cervus elaphus in Norway. - Wildlife Biology 10: 203-211.
Oosenbrug, S.M., Mercer, E.W. & Ferguson, S.H. 1991: Moose-vehicle collisions in Newfoundland - Management considerations for the 1990's. - Alces 27: 220-225.
Putman, R.J. 1997: Deer and road traffic accidents: options for management. - Journal of Environmental Management 51: 43-57.
Rea, R.V. 2003: Modifying roadside vegetation management practices to reduce vehicular collisions with moose Alces alces. - Wildlife Biology 9: 81-91.
Reed, D.F. 1981: Effectiveness of highway lighting in reducing deer-vehicle accidents. - Journal of Wildlife Management 45: 721-726.
Reilley, R.E. & Green, H.E. 1974: Deer mortality on a Michigan interstate highway. - Journal of Wildlife Management 38: 16-19.
Renecker, L.A. & Hudson, R.J. 1990: Behavioral and thermoregulatory responses of moose to high ambient temperatures and insect harassment in aspen-dominated forests. - Alces 26: 66-72.
Robbins, C.T. 1993: Wildlife Feeding and Nutrition. 2nd edition. - Academic Press, San Diego, CA, 352 pp.
Romin, L.A. & Bissonette, J.A. 1996a: Deer-vehicle collisions: Status of state monitoring activities and mitigation efforts. - Wildlife Society Bulletin 24: 276-83.
Romin, L.A. & Bissonette, J.A. 1996b: Temporal and spatial distribution of highway mortality of mule deer on newly constructed roads at Jordanelle reservoir, Utah. - Great Basin Naturalist 56: 1-11.
SAS Institute Inc. 2000: The SAS System for Windows, version 8. - SAS Institute Inc., Cary, North Carolina, 1675 pp.
Sebbane, A. & Courtois, R. 2000: Restructuration du système d'information de la grande faune. - Société de la faune et des parcs du Québec, Direction de la recherche sur la faune, 36 pp. (In French).
Seiler, A. 2004: Trends and spatial patterns in ungulate-vehicle collisions in Sweden. - Wildlife Biology 10: 301-313.
Seiler, A. 2005: Predicting locations of moose-vehicle collisions in Sweden. - Journal of Applied Ecology 42: 371-382.
Skolving, H. 1987: Traffic accidents with moose and roe deer in Sweden. Report of research, development and measures. - In: Bernard, J.M., Lansiart, M., Kempf, C. & Tille, M. (Eds.); Routes et faune sauvage. Proceedings of a SETRA Symposium, Strasbourg, France, pp. 317-324.
St-Onge, S., Courtois, R. & Banville, D. 1995: Inventaires aériens de l'orignal dans les réserves fauniques du Québec. - Ministère de l'Environnement et de la Faune, Direction de la Faune et des Habitats, Québec, 109 pp. (In French).
Sullivan, T.L. & Messmer, T.A. 2003: Perceptions of deer-vehicle collision management by state wildlife agency and department of transportation administrators. - Wildlife Society Bulletin 31: 163-173.
Taskula, T. 1997: The moose ahead. - Traffic Technology International 42: 170-173.
Tunkkari, P.S. 1987: Moose and deer in traffic accidents in Finland: a review. - In: Bernard, J.M., Lansiart, M., Kempf, C. & Tille, M. (Eds.); Routes et faune sauvage. Proceedings of a SETRA Symposium, Strasbourg, France, pp. 151-154.

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