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Tammy L. Joyce and Shane P. Mahoney

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Abstract In Newfoundland, 5,422 moose-vehicle collisions (MVCs) occurred between 1988 and 1994, resulting in 14 human and approximately 4,800 moose (*Alces alces*) fatalities. We examined daily, seasonal, and spatial distribution patterns of MVCs and used log-linear modeling to assess effects of darkness, posted speed limits, road condition, vehicle occupants, and road alignment on severity of human injury resulting from such collisions. Seventy-five percent of all MVCs occurred between dusk and dawn. We found no differences among diurnal patterns of MVCs involving moose of different sex and age groups. Seasonally, 70% of MVCs occurred between June and October and peak accident periods differed somewhat among moose age classes (calf, yearling, adult). However, we found no seasonal differences between males and females. Spatially, MVCs were dependent on moose densities and traffic volume, with greater probability of MVCs in areas of high or low (but not moderate) moose densities and high traffic flow. Risk of severe human injury was 2.0 times greater at highway speeds ranging from 80 to 100 km/hour and 2.1 times greater at night. Human injuries were more severe for MVCs occurring when road conditions were dry and when passengers were present. We found no relationship between road alignment and injury severity, although 79% of MVCs occurred on straight sections of highway. The predominant influence of darkness on MVCs may result from low light conditions and increased movement of moose at night. The high occurrence of MVCs under dry road conditions and on straight sections of road was surprising and may indicate inadequate driver attention to potential road hazards. We suggest that a long-term driver education program may be the only viable mitigation effort available to reduce number of MVCs.

Key words *Alces alces,* density, human injury, moose-vehicles collisions, Newfoundland, spatial, temporal, traffic volume

Moose-vehicle collisions (MVCs) are costly in terms of injury and death to humans and moose (*Alces alces*) and damage to vehicles. Therefore, reducing MVCs is an important management objective for many jurisdictions. In Newfoundland from 1983–1990, collisions between moose and motor vehicles averaged 2 human fatalities/year (Oosenbrug et al. 1991). Despite the lethal potential of MVCs, in Newfoundland most human injuries are minor. For example, Rattey and Turner (1991) reported for one year 133 injuries in 661 MVCs (20%), with 90% of these injury cases involving only superficial wounds. Björnstig et al. (1986) reported a lesser human injury rate of 11% in Sweden. However, costs of these accidents are substantial. For Newfoundland, Rattey and Turner (1991) determined that $188,500 (Canadian) was spent annually on initial health care for patients involved in

Authors' address: Ecosystem Research and Inventory Section, Inland Fish and Wildlife Division, Department of Tourism, Culture, and Recreation, P.O. Box 8700, St. John's, NF, A1B 4J6 Canada; e-mail for Joyce: tammyjoyce@mail.gov.nf.ca.

MVCs and this did not include costs for operative treatment or follow-up visits. Additionally, Oosenbrug et al. (1991) estimated annual losses of \$1,000,000 (Canadian) in vehicle damage; \$600,000 in moose meat; and approximately \$200,000 in wildlife outfitting, adventure tourism, and other local industries in Newfoundland.

Moose-vehicle collisions are not random events in either time or place. Peak accident periods have been identified for most areas where MVCs occur, although seasonal patterns are not consistent among regions. In Newfoundland, MVCs occur throughout the year with the most occurring during summer (Oosenbrug 1986). In southern Sweden (Lavsund and Sandegren 1991) and Maine (K. Morris, Maine Department of Inland Fisheries and Wildlife, personal communication) the greatest number of MVCs occurs during periods of seasonal transition (spring, fall), when animals are more vagile; Alaska (Del Frate and Spraker 1991), British Columbia (Child et al. 1991), and northern Sweden (Lavsund and Sandegren 1991) report most MVCs in winter. Despite this seasonal dissimilarity, diurnal patterns are consistent. Moose-vehicle collisions are more likely to occur during dusk and dawn and at night than during the day for all areas (Sweden [Almkvist et al. 1980, Lavsund and Sandegren 1991], Newfoundland [Oosenbrug 1986], British Columbia [Child et al. 1991]).

Moose-vehicle collisions are clustered spatially (Almkvist et al. 1980, Damas and Smith 1982, Poll 1989, Child et al. 1991). Sites of spatial aggregations have been targeted for a variety of mitigative measures, such as highway reflectors (Schafer and Penland 1985, Ingebrigtsen and Ludwig 1986, Waring et al. 1991), animal reflectors (Farrell et al. 1996), artificial lights (Pojar et al. 1975, Reed and Woodward 1981), fences (Falk et al. 1978, McDonald 1991, Brown and Ross 1994), and predator scents (Jolicoeur and LeMay 1993; W. Bradford, Parks Canada, personal communication; T. Joyce and S. Mahoney, Newfoundland and Labrador Department of Forest Resources and Agrifoods [NLFRA], unpublished data), but usually with little success and often without examining the possible factors contributing to these accidents. The only thorough published examinations of accident site characteristics were by Bashore et al. (1985) in Pennsylvania and Poll (1989) in Kootenay National Park, where they examined numerous habitat and highway variables thought to influence the occurrence of deer-vehicle collisions.

We describe the temporal and spatial clustering of MVCs in Newfoundland from 1988 to 1994 and relate the rate and severity of human injury to time of accident, road conditions, road alignment, vehicle speed (via posted speed limits), number of vehicle occupants, and the sex and age of moose struck. Our objective was to develop measures to reduce number of MVCs and severity of human injuries.

Study area

Our focus is Newfoundland, the island portion of the Canadian province known as Newfoundland and Labrador. Newfoundland (106,000 km^2) is a mosaic of boreal forest, bog-marshland, heath barren, rocky highlands, and abundant lakes and rivers. Generally, the climate is moderate with temperatures averaging from $-15°C$ in winter to $25°C$ in summer. Average annual precipitation exceeds 1,000 mm, with 75% as rain. During winter, snowfall is heavy for all of Newfoundland, reaching total accumulations of more than 300 cm in some locations. Weather conditions for winter and summer are more variable for the central and western portions of the island, and these areas receive greater accumulations of snow in the winter and warmer temperatures in the summer than the eastern portion. Fog is common for the eastern areas throughout the year and in the central portion of the island during the spring.

While Newfoundland's road systems cross all land types, the major route across the island is the Trans-Canada Highway (TCH), which mainly traverses areas of commercial timber and productive moose habitat (Figure 1) and has a posted speed limit of 90 to 100 km/hour. Secondary highways have a posted speed limit of 80 to 90 km/hour and <70km/hour for the other road systems. Spatial mapping of MVCs and traffic volume data were available only for the TCH; all other analyses were completed on accident reports from the TCH and secondary roads. In 1994, there were approximately 415,500 registered vehicles in Newfoundland (N. Campbell, Newfoundland and Labrador Department of Works, Services, and Transportation [NLWST], unpublished data).

Moose are found throughout Newfoundland at densities varying from 0.41 to >7.0 moose/km^2 (S. Mahoney, NLFRA, unpublished data). The island-wide population was estimated at approximately 150,000 animals during 1988-1992 (S. Mahoney, NLFRA, unpublished data). Having peaked in the

Figure 1. The route of the Trans-Canada Highway across Newfoundland in relation to areas of productive forest (gray).

late 1980s, the moose population was stable or declining in most regions; however, populations were increasing in some areas. In Newfoundland, the only natural predator of moose is the black bear (*Ursus americanus*), which preys on calves less than 2 months old (T. Porter and S. Mahoney, NLFRA, unpublished data); wolves (*Canis lupus*) have been extirpated since about 1922. Humans were the major source of mortality to moose in Newfoundland, with 20,000 animals removed annually through a regulated fall hunt.

Methods

Moose-vehicle collisions

We compiled MVC reports provided by Newfoundland and Labrador Wildlife Division Conservation Officers (COs) and the Royal Canadian Mounted Police (RCMP) from 1988 to 1994. Generally, a CO was contacted if a moose was injured or killed, and by law in Newfoundland, vehicle accidents with damage totaling more than $1,000 (Canadian, $500 prior to 1991) or resulting in human injury must be reported to the RCMP. Thus, both agencies might be contacted on a single accident. We compared reports from both agencies by date, time, location, and description and combined duplicates into a single record. While the number of accidents decreased from 1989 to 1994, the spatial and temporal trends highlighted in our analyses did not differ between years, thus years were pooled. For all analyses, $P \leq 0.05$ was used to test significance.

Temporal distribution of MVCs

We assessed diurnal patterns of MVCs by classifying occurrence time of each MVC as daylight, dawn, dusk, or darkness using sunrise, sunset, and twilight times calculated for day 15 of each month as provided by the Directorate of Time, United States Naval Observatory. Dawn and dusk were set at a length of 30 minutes each. We used log-likelihood goodness-of-fit test (G^2, SAS Institute Inc. 1995) to evaluate the null hypothesis that MVCs occurred at the same rate for all time intervals. The observed values were the number of MVCs that fell within each time period. We calculated expected values as the proportion of total observed MVCs relative to the length of each time interval.

We assessed seasonal patterns by dividing the calendar year into peak and nonpeak periods based on the average daily accident rate (ADMVC) for each month. We accounted for seasonal differences in traffic volume (TCH only) on MVC patterns using the average daily traffic volume (ADT), which we determined from temporary and permanent traffic counters placed along the TCH at various locations (N. Campbell, NLWST, unpublished data), and we calculated the actual risk of an MVC during peak versus nonpeak periods as $(ADMVC/ADT)_{peak}$ / $(ADMVC/ADT)_{non\text{-}peak}$. A risk factor of 1.0 implied that the probability of an MVC occurring was equal during peak and nonpeak periods; a risk factor of 2.0 means that an MVC was twice as likely to occur during the peak as the nonpeak period. For peak and nonpeak periods, we also compared the risk of any human injury and of minor versus severe injuries.

Spatial distribution of MVCs

For the TCH only, we tested the null hypothesis that the spatial locations of MVCs were independent of moose density and traffic volume through the main effects model, MVC=[moose density][traffic volume] (SAS Institute Inc. 1995). For 1989 to 1994, we plotted 1,690 MVCs that occurred on the TCH on 1:50,000-scale topographical maps and digitized using the desktop mapping system MapInfo® (MapInfo Corporation 1995). We divided the TCH, about 900 km in length, into 90 10-km sections. We categorized each section by annual average MVCs, <1.75 (low), 1.75-3.0 (medium), and >3.0 MVCs/

Table 1. Human injuries and deaths from moose–vehicle collision in Newfoundland, 1988–1994.

Year	Moose–vehicle collisions	Known injury status of vehicle occupants	Collisions with at least one injury	Total injuries	Human deaths
1988	842	360	61	84	2
1989	897	403	68	120	4
1990	867	405	54	89	4
1991	879	383	61	97	1
1992	664	294	53	82	1
1993	657	271	44	62	2
1994	616	221	41	75	0
Totals	5,422	2,337	419	609	14

10-km (high); moose density, <1.0 (low), 1.0–2.0 (medium), and >2.0 moose/km^2 (high); and traffic volume, low or high (N. Campbell, NLWST, unpublished data). Moose density for each highway section was taken to be equal to that of the surrounding management unit; if >2 management units adjoined the highway, we calculated their mean.

Moose-vehicle collisions and human injury

We used log-linear modeling to evaluate effects of 1) darkness ([D], day vs. dark-dawn-dusk); 2) road condition ([R], dry or wet-slick); 3) road alignment ([A], straight or curved); 4) vehicle occupants ([O], driver only or driver+passengers); and 5) posted speed limits ([S], highway (≥80 km/hr) or non-highway (<80 km/hr)), on severity of human injury [I] (Fingleton 1984, Agresti 1990). RCMP officers classed injuries as none, moderate (person treated and released without hospitalization), severe (required hospitalization and extended treatment), or fatal based upon visits to the accident scene or communication with medical treatment facilities. To focus our analysis on severe injuries and death, we combined injury categories: none with moderate and severe with death. We considered each MVC as a sample; if more than one injury occurred in an MVC, it was rated by the most severe one. We restricted our analyses to passenger (vs. commercial) vehicles, including motorcycles, as this group was involved in 89.5% of all collisions and involved the most serious injuries, including all human fatalities. Because weather was correlated with road condition, we excluded it from the analysis.

We determined the influence of each variable on human injury severity through forward model selection, by moving from the main effects model to the saturated model (SAS Institute Inc. 1995). For example, we first evaluated the main effects model ([I][D][S][O][R][A]), then used the log-likelihood value (G^2) as a baseline against which all other parameters were judged. Each 2-way interaction (i.e., [ID] or [IO]) was then added to the main effects model and tested. The deviance between the baseline value and the derived G^2 statistic measured importance of that parameter to the model. We excluded parameters with small deviance, determined at a 95% confidence level, as they did not significantly enhance the model.

Moose in MVCs

We classified moose involved in MVCs by sex and age (calf, yearling, adult) and examined effect of these variables on accident patterns and occurrence and severity of human injuries. We tested the null hypothesis that the ratio of cows and bulls involved in MVCs was consistent with their proportions in Newfoundland's moose populations. We calculated expected numbers of each sex using the ratio 1 bull to 1.97 cows, the average sex ratio estimated from helicopter surveys conducted throughout the province in 1994–1995 (13 surveys, 3,700 moose classified). The relationships between the diurnal pattern of MVCs and the sex or age of moose involved in them were assessed by log-likelihood goodness-of-fit tests (G^2).

We examined human injury versus moose age class by testing the null hypothesis that the probability of injuries resulting from an MVC was equal among moose age classes (H_O: $C_{inj} = Y_{inj} = A_{inj}$) against the alternative hypothesis, H_A: $C_{inj} < Y_{inj} < A_{inj}$ using the Cochrane Mantel-Haenszel chi-square statistic (CMH) for ordinal data (SAS Institute Inc. 1995).

Results

We reviewed 6,070 MVC reports from COs and RCMP for 1988 to 1994, eliminating 648 duplicates, totaling 5,422 reports (Table 1).

Severity of human injury was known in 2,337 cases and included 609 injuries in 419 MVCs, 14 fatalities in 13, and 1,905 MVCs without injuries. Overall, 17.9% of MVCs had at least one vehicle occupant injured. Total annual injury rate was 26.1% and the fatality rate was 0.6%, about 2 deaths/year. Highway collisions involving moose comprised 3.5% of accidents recorded by the

RCMP. For 1993 and 1994 MVCs, average vehicle damage was approximately $3,000 (Canadian), for a total annual estimate of $2,250,000. Due to RCMP reporting regulations, this figure only included accidents where vehicle damage costs exceeded $1,000 and therefore is an underestimate. Moose died or were destroyed in 89.0% of collisions for which COs recorded animal status (n=3,733); in the remainder, COs did not located the injured animals. In relation to weather, 73% of MVCs occurred during clear conditions, 22% during fog or rain, and 5% during snow.

Temporal distribution of MVCs

We rejected the null hypothesis that MVCs occurred equally in all light categories (G^2_3= 1,134.30, P=0.001). Seventy-five percent of MVCs occurred during darkness and 60% between sunset and midnight, although early morning accidents (0000-0600 hours) also were common, especially in June, July, and August (Figure 2). Only the daylight period had fewer accidents than expected.

Most accidents (70%) occurred from 1 June to 31 October (the "peak period") with an average incidence of 3.5 MVCs/day (range=2.9-4.8). During the remainder of the year, the rate was 1.1 MVCs/day (range = 0.4-2.0), for an overall mean daily accident rate of 2.1 MVCs/day. After accounting for traffic volume, the probability of being involved in an MVC was 2.8 times greater during the peak versus nonpeak accident period. However, we found no difference in the risk of injury (θ= 1.0) nor in the risk of severe injury or death (θ=1.1) between peak and nonpeak periods.

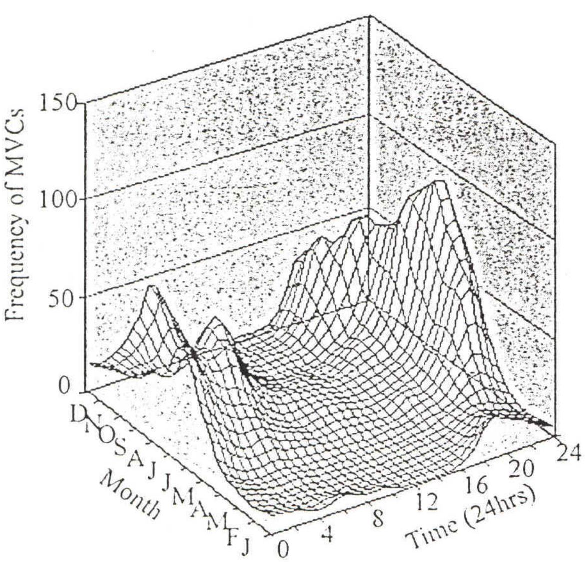

Figure 2. Frequency of moose-vehicle collisions by month and time of day (24-hour clock) for Newfoundland, 1988–1994 (n= 2,637). Accidents were low from January to April, then increased sharply to peak during July and August, and dropped slowly through the fall and early winter. Daily trends show an increase in accidents around sunset (throughout the year) and through to midnight.

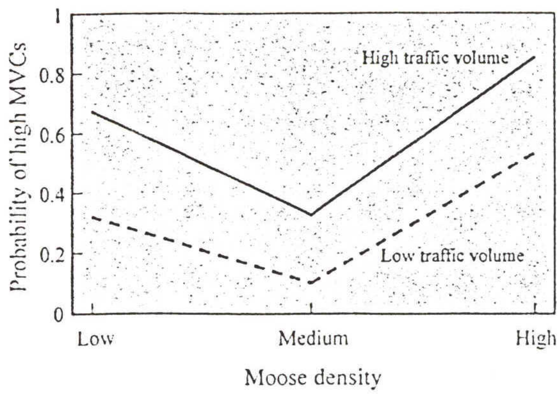

Figure 3. Probability of a high number of moose-vehicle collisions at low, medium, and high moose densities and low and high traffic volumes, Newfoundland, 1988–1994.

Spatial distribution of MVCs

The model relating spatial locations of MVCs to moose density and traffic volume fitted the observed data (G^2_4=3.37, P=0.497). Moose-vehicle collisions were not independent of moose density (G^2_4=10.15, P=0.039) or traffic volume (G^2_2=10.10, P=0.006). Areas of low (<1.0 moose/km^2) or high (>2.0 moose/km^2) moose densities experienced greater probabilities of MVCs than areas of moderate moose densities (Figure 3). The probability of highway sections being classed as high for MVCs was greater for areas of high traffic volume, regardless of moose density. Thirty-one of the 90 10-km sections were classed as areas of high risk for MVCs, with frequencies ranging from 3.1 to 8.6 MVCs/10-km (Figure 4).

Moose-vehicle collisions and human injury

Although 79% of accidents occurred on straight versus curved sections of road, we did not identify any significant relationship between road alignment and injury severity. Examination of the log-likelihood values indicated that 2 separate groups of variables fitted the data (Table 2). Model 1 ([ID][IS]) related human injury severity to lighting condition and posted speed limit (G^2_2=3.21, P<0.05); both

Table 2. Model selection to predict human injury severity from moose–vehicle collision based on darkness, posted speed, road condition, and presence of occupants, Newfoundland, 1988–1994.

Model parameters	G^2	df	Deviance	Significance of deviance
Model 1 Injury [I], Darkness [D], Speed [S]				
[I][D][S]	9.32	4	Main effects	
+[IS]	8.09	3	1.23	NS[a]
+[ID]	4.73	3	4.59	NS
+[ID][IS]	3.21	2	6.11	$P < 0.05$
Model 2 Injury [I], Road condition [R], Occupants [O]				
[I][R][O]	18.16	4	Main effects	
+[IO]	14.12	3	4.04	NS
+[RO]	9.15	3	9.01	$P < 0.05$
+[RO][IO]	3.06	2	15.10	$P < 0.05$

[a] NS = non-significant

statistics were mutually independent. Risk of severe injury was 2.1 times greater at night and 2.0 times greater at highway versus nonhighway speeds.

The second model ([OR][IO]) dealt with effects of road condition and vehicle occupants on injury severity. This model indicated that more accidents than expected occurred when passengers were in vehicles driving on dry roads ($G_2^2=3.06$, $P>0.05$, Table 2), but not in the 3 other cases where there were no passengers or wet roads. Risk of severe injury or death was twice as likely ($\theta=2.0$) with at least one passenger in the vehicle (as compared to driver only). In all MVCs (excluding motorcycles) involving death ($n=11$), at least one passenger was present, and in 9 cases the driver was the victim.

Fifty-three (9%) of 585 injured occupants for whom the status of seatbelt use was known were not wearing seatbelts when the MVC occurred. This group, which excludes motorcycle drivers and passengers, accounted for 4 human deaths, resulting in a risk of fatal injury 8 times greater than with occupants wearing seatbelts. Sixteen MVCs involved motorcycles, 2 of which resulted in human deaths. The probability of severe injury or death while traveling on a motorcycle was 12 times that for occupants of all other passenger vehicles combined.

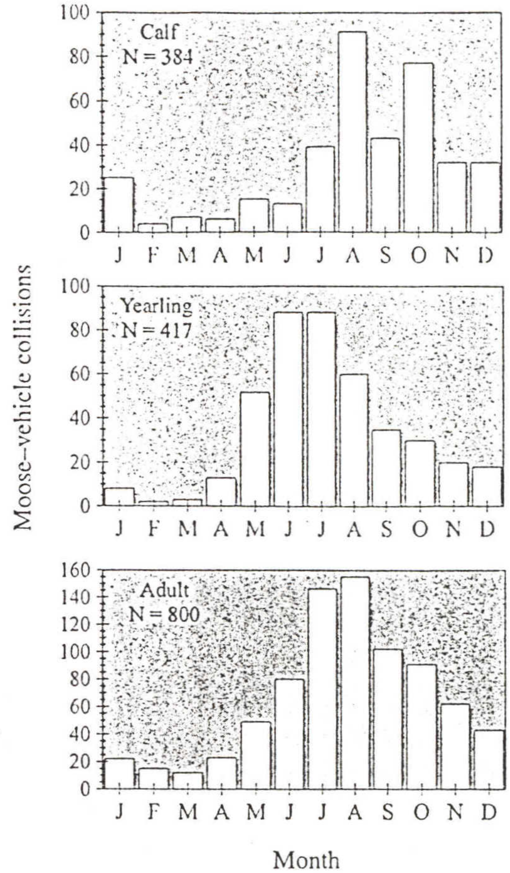

Figure 5. Monthly distribution of moose killed in moose–vehicle collisions by age classes—calf, yearling, and adult—Newfoundland, 1988–1994.

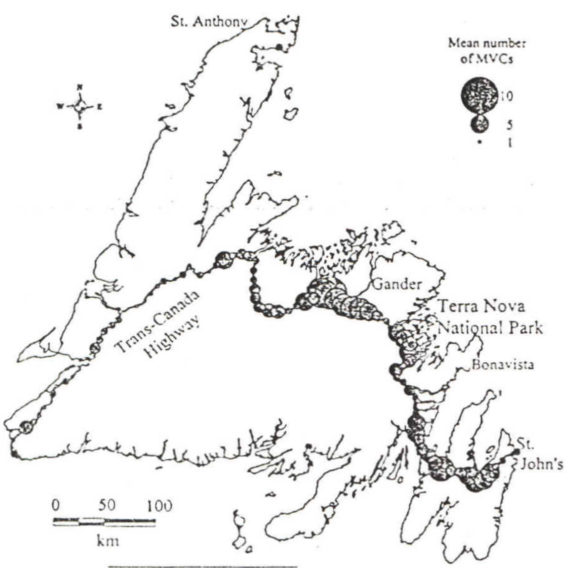

Figure 4. Spatial distribution of moose–vehicle collisions in Newfoundland along the Trans-Canada Highway. Graduated symbols represent the average annual number of accidents for 1989 to 1994.

Moose in MVCs

Seasonal patterns emerged regarding the age and sex of moose involved in MVCs. Moose calves were more likely to be involved in August and October, yearlings in June and July, and adults in July and August (Figure 5). More bull moose were involved in MVCs than expected ($G_1^2=69.52$, $P=0.01$). We found no significant relationships between diurnal patterns and sex ($G_3^2=0.15$, $P=0.985$) or age ($G_3^2=12.32$, $P=0.055$) of the moose involved in MVCs.

We rejected the null hypothesis that there was no difference in rates of injuries resulting from collisions involving 3 moose age classes ($CMH_1=31.37$, $P=0.001$). Rate of human injury increased progressively with age class of moose struck, such that injury was 6 times more likely in a collision with an adult versus a calf moose.

Discussion

In Newfoundland, MVCs declined from 879 in 1989 to 616 in 1994. Despite this decrease, average number of human fatalities (2/year) remained unchanged from earlier patterns (1983-1990, Oosenbrug et al. 1991). While the rate of human injury did not differ between 1988 and 1994, the mean rate calculated in this analysis was slightly greater than that reported by Rattey and Turner (1991). However, they used hospital records only and thus did not include vehicle occupants treated for minor injuries at the collision site. By combining reports from COs and RCMP, our study resulted in MVC numbers considerably greater than those reported elsewhere for Newfoundland (750 MVC/year vs. 500 MVC/year, Oosenbrug et al. 1991; 330 MVC/year, Rattey and Turner 1991), and thus the calculated vehicle damage costs also were greater. At 750 MVCs/year, we calculated the following annual losses: approximately $500,000 (Canadian) in initial health costs, $2,250,000 in vehicle damage, $800,000 in consumable moose meat, and $300,000 in losses to the outfitting and related industries. The cumulative cost of MVCs to the Newfoundland economy is therefore substantial.

We estimated annual mortality rate for moose involved in MVCs to be at least 89.0%, with 11.0% of the animals leaving the area with unknown injuries. This accounted for approximately 0.6% of the Newfoundland moose population. In comparison, Groot Bruinderink and Hazebroek (1996) reported 4,000, 1,500, and 150 MVCs/year for Sweden, Norway, and Finland, respectively, accounting for about 1.4% of their combined moose populations. In Newfoundland for the period of this study, MVCs are 3.0% of the annual allowable harvest ($\bar{x}$= 25,000), which is greater than Child (1999) reported for Manitoba (0.5%) but much less than for Maine (60.0%) and New Hampshire (196.0%).

Temporal distribution of MVCs

Collisions between vehicles and moose increase significantly at night, demonstrating the predominant influence of darkness on these accidents (Almkvist et al. 1980, Child et al. 1991, Groot Bruinderink and Hazebroek 1996). In Newfoundland, the rate of MVCs increased around sunset and 75% of all accidents occurred between sunset and sunrise. In addition, severe human injury or death was twice as likely for MVCs occurring after dark. In Sweden, MVCs were 8 times more likely to occur during dusk than daylight and 6 times more likely during dawn and darkness (Almkvist et al. 1980). This pattern is similar for British Columbia (Child et al. 1991) and Maine (Farrell et al. 1996), with most accidents occurring between sunset and sunrise.

Moose are more mobile at night and around sunrise and sunset (see Phillip et al. 1973, Best et al. 1978, van Ballenberge and Miquelle 1990, Groot Bruinderink and Hazebroek 1996), leading to increased probability of MVCs. In addition, many studies have shown that human perception experience may be an important factor.

Humans are unable to distinguish similarly colored objects at night (i.e., moose and a background of road or trees), and glare from oncoming headlights bleach human visual receptors, temporarily blinding drivers (Hess et al. 1990). Furthermore, in Sweden Johansson and Rumar (cited in Reed and Woodard 1981) concluded that motorists had difficulty estimating distances to moose on or near the highway if the animal was in silhouette, which is often the case at night. Boersema and Zwaga (1996) investigated the ability of drivers to detect important objects from the visual "noise" along roadways. It took practice and concentration by drivers for road signs to be noticed from even visually simple backgrounds during daylight hours. This may explain why hunters in Sweden were involved in proportionately fewer MVCs than nonhunters (Almkvist et al.1980). Perceptually, hunters would be more familiar with moose and thus recognize them more quickly than nonhunters, especially when the animals were emerging from roadside vegetation or ditches. Additionally, having observed moose in the wild, hunters also would be more cognizant of their behavior and movement patterns.

Finally, nighttime fatigue also may impair a driver's ability to respond to rapidly appearing obstructions.

Seasonal patterns of MVCs in Newfoundland, although different from other jurisdictions, appeared related to moose reproductive and behavioral patterns. Yearling moose were more likely to be involved in accidents during June and July, following possible abandonment by cows with new calves (Peterson 1955). Calves were struck most often in August, when cows accompanied by calves are reported to increase mobility (Peterson 1955, Phillip et al. 1973, Cederlund et al. 1987, Demarchi and Bunnell 1995), and in October, when calves may be more vulnerable because cows are involved in mating (Peterson 1955). Notably in several cases, drivers avoided the cow only to hit the accompanying calf. Finally, adult bulls were involved in more MVCs than expected, possibly due to their larger home range sizes (Lynch and Morgantini 1984, Cederlund and Sand 1994), although we found no difference between the sexes in seasonal MVC pattern.

Despite the apparent relationship between MVCs and moose behavior, our summer peak in MVCs was not consistent with many other regions (Child et al. 1991, Del Frate and Spraker 1991, Lavsund and Sandegren 1991, Child 1999). This seasonal inconsistency across the species' range indicates the complexities in the animal's behavior and its interactions with the external local environment. For example, in northern Sweden (Lavsund and Sandegren 1991) and British Columbia (Child et al. 1991, Child 1999), salt, used as a road de-icer, attracts moose and deep snow forces animals to travel along roads. This does not seem to be the case in Newfoundland. Despite significant snowfalls, particularly on the west coast of the island, relatively high moose densities compared to other jurisdictions, and the large quantity of salt used (N. Campbell, NLWST, unpublished data), there are a relatively small number of MVCs in winter. Furthermore, number of MVCs in Newfoundland does not peak in the spring during green-up, as found in Ontario (Fraser and Thomas 1982) or Maine and other northeastern states (K. Morris, Maine Department of Inland Fisheries and Wildlife, personal communication).

The increased risk of being involved in an MVC was not explained by the increased number of vehicles on the highway per se. Although we could not test it, the type of driver involved in MVCs may be different between peak and nonpeak accident periods. During summer, an increased number of naive drivers, residents and visitors, travel on Newfoundland's highways, many of them vacationing and traveling on unfamiliar roads. These drivers, especially vacationers, may be more easily distracted from the road and objects on it by activity inside and outside the vehicle.

Spatial distribution of MVCs

When examined temporally, increased traffic volume could not explain the greater risk of MVCs during summer. However, when examined spatially, traffic volume was an important factor influencing occurrence of MVCs. Sections of the TCH with high traffic volume had a greater probability of high MVC numbers, regardless of moose density (Figure 3). Moose density was important, however, and areas of high and low densities showed a greater probability of MVCs. Surprisingly, areas of moderate densities (1.0–2.0 moose/km^2) had the fewest number of MVCs (Figure 3). In Sweden, Almkvist et al. (1980) found a tendency toward a positive relationship between MVCs and high moose density (>1.5 moose/km^2), but not lesser moose densities (<1.5 moose/km^2). A major factor contributing to this relationship is likely the interaction of habitat availability and use patterns by moose (Peek 1999). Almkvist et al. (1980: 73) concluded "moose density is not a dependable measurement of the risk of [MVCs]", as "moose density covers comparatively large areas and does not, with certainty, represent the number of moose along the roads" or crossing the roads. It is important to note that simply managing for specific moose densities may not result in the desired decrease in MVCs. The relationship between moose density and MVCs found here must be examined in conjunction with habitat use and seasonal movements before being used in moose management.

Moose-vehicle collisions and human injury

A major concern regarding MVCs is the human injury and death they cause. We found that traveling at highway speeds increased the probability of vehicle occupants incurring severe injury or death by a factor of 2. Comparably, in Sweden, Lavsund and Sandegren (1991) reported a 3-fold increase in severity of injury for vehicles moving 70 to 90 km/hour as compared to lesser rates. Basically, as vehicle speed increases, so does the time needed to stop and therefore moose are struck while the vehicle is traveling at high speed, resulting in greater impact and thus more severe injuries.

Our analyses also revealed that more severe injuries than expected occurred in vehicles containing passengers. However, this relationship may not be a direct result of there being more people to sustain injury. In fact, regardless of number of occupants, the vehicle driver most often received the severest injury. Conversations with or the activities of passengers may serve as a distraction to drivers, leading to more frequent and severe MVCs. RCMP reports corroborate this, citing "driver inattention" as the second most common factor contributing to MVCs, behind "object on the road."

Other factors influencing the probability of human injury included use of seatbelts by vehicle occupants and age (calf, yearling, or adult) of moose involved. In recent years, effectiveness of seatbelts to reduce severe human injury and death in automobile accidents has been well documented, and seatbelt use became mandatory in Newfoundland in 1990. Our results further support use of seatbelts, as probability of being killed in an MVC was 8 times greater for occupants not wearing them. The relationship between moose age and human injury was expected. As moose mature they become not only heavier but also taller, such that most of their increased weight is located above the engine hood of the standard passenger car.

Although we found no relationship between road alignment (straight versus curved) and severity of human injury, 79% of MVCs occurred on straight sections of highway, where we might have thought that drivers would more easily see the animals. Similarly, in an examination of deer-vehicle collision sites, Bashore et al. (1985) found a positive relationship between speed limit, driver in-line visibility along the road, and number of collisions (see also Poll 1989). They suspected that when a driver could see a considerable distance (i.e., straight road sections), vehicle speed increased and deer emerging from blind spots, such as ditches, were more likely to be struck. With the increased speed, drivers had less time to respond to the suddenly appearing animal.

Management implications

The ultimate goal in analyzing trends in MVCs is to identify factors that increase MVCs and to reduce these accidents. Many products and procedures to keep moose and other ungulates off road systems have been deployed, with marginal or no success but with substantial financial and manpower costs (see reviews by Reed et al.1982, Bradford 1988, Brown and Ross 1994, Romin and Bissonette 1996). Vehicle speed could be adjusted to assist in reducing MVCs, but as Damas and Smith (1982) estimated, nighttime speed limits would have to be reduced to 60 km/hour or less under low-beam light to sufficiently expand stopping distances and prevent accidents. The enforcement effort required to ensure driver compliance with such regulations would be enormous (N. Campbell, NLWST, unpublished data). As with other jurisdictions, managers in Newfoundland are continually exploring and testing mechanisms to reduce MVCs, yet the most effective measure may lie with the vehicle drivers.

Early detection of moose through increased driver vigilance may be one of the most important means to reduce MVCs. Yet as we have identified, darkness, road condition, and passengers all affect a driver's ability to detect moose on or near the road. Because nighttime driving can cause fatigue or induce a semi-hypnotic state that further decreases driver awareness, time spent driving at night should be limited, or at least driving bouts should be reduced in length. Roadside signs help warn motorists of high-risk areas throughout Newfoundland; however, these high-risk areas can stretch distances >20 km. Seatbelt use also is extremely important, to avoid and reduce severity of human injury from MVCs.

These precautions must be communicated to the public, however, and we suggest that a driver awareness program be developed and implemented in Newfoundland. Generally, across many disciplines, such education programs are known for their limited success, particularly for hazards not encountered regularly (Organisation for Economic Co-operation and Development, 1994), yet with the high cost and low success of other measures, they may be the only viable option. Because of their low occurrence, even collisions or near collisions with moose may not correct poor driving practices. In a survey of risk awareness, Stout et al. (1993) collected information from drivers on their perception of being involved in a deer-vehicle collision. These researchers reported a sampling bias toward drivers who hit a deer (28%) or experienced near misses (49%). Despite this, most respondents believed the risk of a collision was low and thus few reported changing their driving habits.

A shortfall of many awareness programs, and probably the cause of their limited success, is their brief duration. Like the low occurrence of MVCs, an educational program of a few months and delivered sporadically is insufficient to instill corrective driving habits that reduce the risk of colliding with moose on roadways. Longer-term programs may be more effective, at least in developing a sustained, heightened awareness of the risk of MVCs, especially when used in conjunction with roadside signage. An example of this from Newfoundland is in Terra Nova National Park, which encompasses just 43 km of the TCH and has a low moose density, high traffic volume, and a medium number of MVCs. Despite these statistics, many Newfoundland drivers perceive Terra Nova National Park as one of the areas of greatest MVCs and of greatest risk of encountering moose. This perception is most likely due to the MVC awareness campaign within Terra Nova National Park, which has been ongoing for 12 years and involves use of moose silhouettes and a posting of the number of MVCs occurring each year (Hardy 1984; P. Deering, Parks Canada, personal communication). Similar increases in awareness have been shown with the "Give Moose a Brake" program in Alaska (T. Spraker, Alaska Department of Fish and Game, personal communication) and "Brake for Moose" program in New Hampshire (Child 1999).

To ensure the longevity of any MVC educational program, it would have to be low in cost. We suggest that for Newfoundland this could be accomplished by using local media groups, such as newspapers and radio stations, and sharing any program costs between agencies affected by MVCs, including various government departments (health, transportation, and natural resources) and car and health insurance companies. Finally, we recommend that awareness of MVCs be incorporated into all new driver training programs; currently, this is not the case in Newfoundland.

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Tammy L. Joyce (photo) is a wildlife biologist with the Inland Fish and Wildlife Division, Department of Forest Resources and Agrifoods, in Newfoundland and Labrador. She received her B.S. (Honors) in animal behavior at Memorial University of Newfoundland. She is currently working on population dynamics of snowshoe hares in Newfoundland for her M.S. (ecology) at University of British Colombia. Her interest lies in the ecological functioning of natural systems. *Shane P. Mahoney* is the chief of wildlife ecosystem research and inventory for the province of Newfoundland and Labrador. He holds a B.S. (Honors) and an M.S. from Memorial University of Newfoundland. His research has focused on the behavior and population ecology of seabirds, woodland caribou, and black bears. He is currently completing a synthesis of 50 years of research on Newfoundland's caribou populations.

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