



Title:

Large animal-vehicle collisions in the Central Canadian Rocky Mountains: patterns and characteristics

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Abstract:

The trends of increasing traffic volumes and road densities will only magnify the already adverse effects roads have on large mammals and other vertebrates. Development of practical highway mitigation will rely on an understanding of patterns and processes that result from highway accidents, which involve elk *Cervus elaphus* and other large animals. We specifically address three areas relating to the patterns and characteristics of large-animal vehicle collisions on different road-types in the Central Canadian Rocky Mountains. First, we investigate the spatial error associated with reported wildlife-vehicle collisions (WVCs). Second, we look at the demographic and temporal patterns of elk and wildlife-vehicle collisions on different road-types. Finally, we investigate the type of vehicles involved in WVCs and what conditions contribute to injury-related accidents. We found that the average reporting error from park wardens, highway maintenance contractors and from Royal Canadian Mounted Police (RCMP) data ranged from 300m-2000m. The sex ratio of elk-vehicle collisions (EVCs) was significantly different from that found in the population, and highly skewed towards greater male mortality during the 15-year period. The age ratio of EVCs was highly skewed towards greater subadult mortality. We found



no difference in marrow fat content between highway and railway killed elk, but both had higher fat content than predator-killed elk. EVCs were significantly higher on the Trans-Canada Highway (TCH) in the province which had the highest traffic volumes. The TCH in Banff National Park (BNP) had a significantly higher rate of EVCs than the secondary highway (93S) in Kootenay National Park. EVCs declined over time on the unmitigated section of TCH in BNP and on highway 93S, even though traffic volumes were increasing. We found that local elk abundance was decreasing and was the driving force in EVC rates; however, traffic volume determined the rate of EVCs on different road types. WVCs occur more often than expected at dusk and night periods and on weekends. Injury-related WVCs are more likely to occur in dry conditions than in slush, snow or icy conditions. Injury-related WVCs are more likely to occur with smaller vehicles than in larger vehicles. Further, larger vehicles were involved in more WVCs than expected on two of our road-types. In conclusion, spatial road-kill data can aid in determining location of mitigation measures, e.g., wildlife signage and crossing structures. Patterns of WVCs can be valuable in devising mitigation based on specific hour of day or season when collision frequencies are highest, and what individuals within a population are most susceptible to road-kills. Factors contributing to WVCs, such as traffic volumes and elk abundance, can help managers predict long-term viability of wildlife populations with incurring road mortality.



LARGE ANIMAL-VEHICLE COLLISIONS IN THE CENTRAL CANADIAN ROCKY MOUNTAINS: PATTERNS AND CHARACTERISTICS

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Abstract: The trends of increasing traffic volumes and road densities will only magnify the already adverse effects roads have on large mammals and other vertebrates. Development of practical highway mitigation will rely on an understanding of patterns and processes that result from highway accidents, which involve elk *Cervus elaphus* and other large animals. We specifically address three areas relating to the patterns and characteristics of large-animal vehicle collisions on different road-types in the Central Canadian Rocky Mountains. First, we investigate the spatial error associated with reported wildlife-vehicle collisions (WVCs). Second, we look at the demographic and temporal patterns of elk and wildlife-vehicle collisions on different road-types. Finally, we investigate the type of vehicles involved in WVCs and what conditions contribute to injury-related accidents. We found that the average reporting error from park wardens, highway maintenance contractors and from Royal Canadian Mounted Police (RCMP) data ranged from 300m-2000m. The sex ratio of elk-vehicle collisions (EVCs) was significantly different from that found in the population, and highly skewed towards greater male mortality during the 15-year period. The age ratio of EVCs was highly skewed towards greater subadult mortality. We found no difference in marrow fat content between highway and railway killed elk, but both had higher fat content than predator-killed elk. EVCs were significantly higher on the Trans-Canada Highway (TCH) in the province which had the highest traffic volumes. The TCH in Banff National Park (BNP) had a significantly higher rate of EVCs than the secondary highway (93S) in Kootenay National Park. EVCs declined over time on the unmitigated section of TCH in BNP and on highway 93S, even though traffic volumes were increasing. We found that local elk abundance was decreasing and was the driving force in EVC rates; however, traffic volume determined the rate of EVCs on different road types. WVCs occur more often than expected at dusk and night periods and on weekends. Injury-related WVCs are more likely to occur in dry conditions than in slush, snow or icy conditions. Injury-related WVCs are more likely to occur with smaller vehicles than in larger vehicles. Further, larger vehicles were involved in more WVCs than expected on two of our road-types. In conclusion, spatial road-kill data can aid in determining location of mitigation measures, e.g., wildlife signage and crossing structures. Patterns of WVCs can be valuable in devising mitigation based on specific hour of day or season when collision frequencies are highest, and what individuals within a population are most susceptible to road-kills. Factors contributing to WVCs, such as traffic volumes and elk abundance, can help managers predict long-term viability of wildlife populations with incurring road mortality.

Introduction

Within the last 30 years, roads with vehicles probably overtook hunting as the leading direct human cause of vertebrate mortality on land (Forman and Alexander 1998). Current estimates reveal that tens of millions of vertebrates are killed on roadways each year. Surveys of state transportation and natural resource agencies indicate that in the United States alone, approximately 0.5 to 1.5 million deer are killed on roadways annually (Cook and Dagget 1995, Romin and Bissonette 1996a, Conover 1997).

For years, collisions with wildlife have been a problem in the Central Canadian Rocky Mountain national parks and a cause for concern among park managers and transportation planners. The long-term trend and prospects are for increasing traffic volumes on the Trans-Canada Highway (TCH) and other primary roads in the parks. Development of practical highway mitigation will rely on an understanding of patterns and processes that result from highway accidents, which involve large animals.

The national and provincial parks collected information since the 1960s on wildlife-vehicle collisions in the Central Canadian Rocky Mountains (Flygare 1978, Damas and Smith 1982, Fraser and Pall 1982, Sanderson 1983). Inevitably, there will be a certain degree of error in describing the event and location, due to many people reporting road-killed wildlife and motor vehicle accidents. We are not aware of any information from the scientific literature or technical reports that attempt to measure the spatial error associated with each wildlife-vehicle collision (WVC) report. In our first analysis we devised a way to arrive at a road-kill reporting error estimate. This measure will be essential for analyses of site-specific features of WVCs, and under certain circumstances enable a larger amount of less-spatially accurate road-kill information to be utilized for study.

The construction and operation of roads across ungulate ranges is a concern to many wildlife managers (Romin and Bissonette 1996a, Cole *et al.* 1997, Putman 1997); however, most studies have focused on deer-vehicle collisions and the means of reducing them (Puglisi *et al.* 1974, Bashore *et al.* 1985, Feldhammer *et al.* 1986, Hubbard *et al.* 2000). Little attention has been given thus far to the characteristics of elk-vehicle collisions (EVCs) (Singer 1975, Ward *et al.* 1980, Boulanger 1999), despite elk *Cervus elaphus* being the dominant ungulate species in many western ecosystems.

We focused our second analysis on elk-vehicle collisions where we addressed demographic, seasonal mortality, and highway-related temporal and spatial patterns of accidents that might reveal ways in which EVCs may be reduced by mitigation. In our third analysis, we used wildlife-vehicle-collision data collected by the Royal Canadian Mounted Police (RCMP) to determine the effects of time of day, day of week, and type of vehicle on collisions. In addition, we looked at what road-related factors, such as road conditions, cause injury-related motor vehicle collisions in the Central Canadian Rocky Mountains.

Study Area

Our research was carried out in the Central Canadian Rocky Mountains approximately 150km west of Calgary, in southwestern Alberta and southeastern British Columbia (fig. 1). The area comprises mountain landscapes in Banff, Kootenay and Yoho national parks and adjacent Alberta provincial lands.

The TCH in Banff National Park (BNP) runs along the floor of the Bow Valley, sharing the valley bottom with the Bow River, the township of Banff (population 9,000); several high-volume-two-lane highways, numerous secondary roads; and the Canadian Pacific Railway. The highway is a major commercial motorway between Calgary and Vancouver. In 1998, annual average daily traffic (AADT) volume at the BNP East entrance was 14 600 vehicles per day, and summer annual traffic volume was 21,500 vehicles per day (Parks Canada Highway Service Centre, unpublished data). Other roads in the study area we investigated consisted of two-lane primary roads that served as arterial transportation routes. AADT volume on the primary roads Highway 93S and 40, were respectively 2,870 and 2,150 vehicles per day in 1998 (Parks Canada Highway Service Centre and Alberta Infrastructure, unpublished data). All highways in this study were two to four lanes and unmitigated (no fence or wildlife crossing structures).

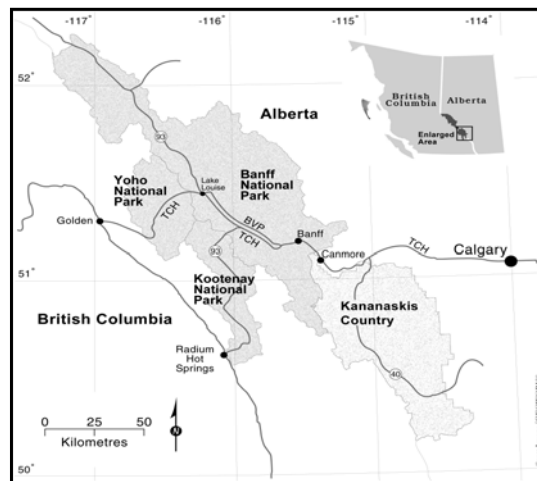


Fig. 1. Location of study area and highways used to examine patterns and characteristics of large mammal vehicle collisions in the Central Canadian Rocky Mountains.

Methods

Error Reporting

National parks and Alberta province

Since January 1999 we made an effort to maximize WVC reporting and its accuracy. In doing so, we contacted everyone responsible for collecting and reporting wildlife road-kills in Banff-Kootenay-Yoho national parks and the province of Alberta (Bow Valley and Kananaskis Country). Cooperators included national park wardens, provincial park rangers and the private highway maintenance contractor (Volker-Stevin).

We provided all cooperators with coloured pin-flags to be carried with them in their vehicles. After collecting road-killed wildlife they were advised to mark the site of the WVC by placing the pin-flag in the right-of-way and report back to us via telephone, fax or email. Most accidents and pin flagging were reported to us within 48 hours.

The reported location of WVCs was recorded by the collaborators by describing the location with reference to a nearby landmark (e.g., 0.3km east of park east gate). The true location of a WVC was acquired by visiting the reported accident site; recovering the pin-flag, and obtaining the actual location by measuring the odometer distance from the same reported nearby landmark to the pinflag. UTM location coordinates were also collected

using a differentially correctable global positioning system (GPS) unit (accuracy = ≤ 5 m). We calculated the reporting distance error for each WVC by subtracting the actual distance to the landmark from the reported distance to the same landmark. We calculated the average (\pm SD) reporting error for each collaborator and within the national parks for each method of reporting.

Royal Canadian Mounted Police

As a separate error analysis from the national parks and province, we obtained WVC data from the transportation section of Alberta Infrastructure, from 1991 to 2000 for BNP highways, and Alberta provincial highways. The WVCs were derived from vehicle accident forms completed by the Royal Canadian Mounted Police (RCMP) at the collision site. A WVC location is noted on the report form by giving a distance measurement in kilometres (or metres) to the closest street, highway, town, etc. This measurement is then converted into standard kilometre postings (to the nearest metre) by the transportation section of Alberta Infrastructure. Alberta Infrastructure provided us with the geographic location of each kilometre posting on highways in the study area.

We selected kilometre-posted accident locations from the RCMP records that corresponded to WVCs, from which we had acquired differentially corrected GPS locations from our pin-flagging and error reporting exercise (see above). We plotted both RCMP-reported WVC locations, and our accurate WVC locations (<3 m error) on a differentially corrected highway layer in a GIS. We measured the spatial error between each paired RCMP reported location and true WVC location. Distance measurements were calculated from the two corresponding WVC locations using Edit Tools Version 2.4 in ArcView GIS (ESRI 1999). An average distance error and standard deviation were calculated for the RCMP WVC data set.

Elk-Vehicle collisions

Data collection

Parks Canada (Banff, Yoho, Kootenay national parks) and Alberta Natural Resources Service recorded EVCs year-round. The site of each accident was visited and the date of the kill reported, along with information regarding the number of individuals, their sex and age. We analyzed data from all reported EVCs occurring on unmitigated sections of highway.

We obtained annual traffic volume data on national park roads from Parks Canada (Parks Canada Highway Service Centre, unpublished data) and on provincial roads from the province of Alberta (Alberta Infrastructure, unpublished data). Elk relative abundance data were obtained from Parks Canada and Alberta Natural Resources and used for the analysis of the relationship between relative abundance (as a measure of annual population trends) and rates of EVC. We used elk relative abundance estimates from annual classified ground counts in the national parks (KNP and BNP), conducted in spring and autumn between 1985 and 2001 (Woods 1990, Woods *et al.* 1996, Parks Canada, unpublished data).

Sex and age

To test whether there were more male or female, and adult or sub-adult EVCs in the overall study area, we examined the sex and age ratios in the road-kill database from 1986 to 2000. Sub-adults were defined as year of young or yearling elk. Chi-square analysis was used to test for a sex and age bias from an assumed 1:1 ratio.

To test whether there was a sex or age class bias in the EVCs with the TCH-park (BNP) elk population, sex and age ratios for the population were determined. A Chi-square analysis was used to compare these observed ratios with the expected ratios, calculated from the average of spring and fall elk counts on the TCH park (BNP), from 1986 to 2000.

Comparison of Elk Mortality Condition

We tested for differences in condition of elk killed on highways, railways and by predators in BNP. Park research, wardens and veterinary personnel confirmed predator-killed elk. Femur marrow was assayed to measure percent fat content (Neiland 1970); however, we used a dehydrator instead of an oven. Elk mortalities were cross-tabulated by mortality type (highway railway, predator) and condition (i.e., femur marrow fat percentage). We screened data for normality prior to analysis. We tested for independence among categories using ANOVA and Fisher's exact tests (Zar 1999).

Seasonality

To test whether there were seasonal peaks in accidents we assigned EVC records to a season of the year. We used a Kruskal-Wallis ANOVA to test the hypothesis that season had no effect on EVC frequencies. Tukey's HSD multiple range test was used to compare mean values between seasons.

Road Type, Traffic Volume and Elk Abundance

To determine the relative risk posed by each type of highway, elk road-kill frequency was standardized by road length to produce an EVC rate. We used a Kruskal-Wallis ANOVA to test for differences between elk road-kill rates among road types.

We used Spearman's rank correlations to test for a relationship between annual average traffic volume, standardized elk numbers (elk/km) and EVC rate on the TCH Park (BNP) and Highway 93S combined. To test the hypothesis that EVCs differed among these regions, we modeled the effects of relative elk abundance and traffic volume separately. We tested for these effects using two ANCOVAs, one for elk abundance and one for traffic volume. Road type [TCH-park (BNP) and Highway 93S] was included as the categorical predictor. As elk abundance and traffic volume were highly correlated on Highway 93S and TCH park (BNP) (Spearman's rank correlation, both $r > -0.80$, $p < 0.05$), we performed an additional test to tease apart the effect of these variables on EVC rate. We used an ANCOVA to test the effects of elk abundance on EVC rate on the TCH park (BNP) during a period where traffic volumes remained constant. Season (spring and fall) was included as a categorical variable.

Wildlife Vehicle-Collisions

Data Collection

We obtained information on WVCs from the transportation section of Alberta Infrastructure for BNP highways, from 1991 to 1999 and Alberta provincial highways from 1991 to 2000. These WVCs were derived from vehicle accident forms completed by the RCMP. The law requires that motor vehicle accidents with damages totaling more than CD \$1,000 (CD \$500 up until 1991) or resulting in human injury must be reported to the RCMP.

We chose to use WVC data from the RCMP reports rather than national park warden or provincial ranger reports, as the former were more accurate in reporting the actual time of WVCs. Furthermore, park and provincial WVC data did not include the type of vehicle involved in the collision or severity of the accident, unlike the RCMP reports. One limitation to the RCMP reports was missing information regarding the wildlife species involved in the WVC. For this reason our collision analysis is not species-specific but includes all large mammal wildlife species.

We obtained information on annual traffic volume and classification of vehicle types, on national park roads from Parks Canada (Parks Canada Highway Service Centre, unpublished data) and on provincial roads from the province of Alberta (Alberta Infrastructure, unpublished data).

Temporal Patterns

We used a Spearman's Rank correlation to determine whether WVCs were associated with traffic volumes for each highway from 1996 to 2000. We used traffic volume data from 1999, as they were highly correlated ($R = 0.99$) with traffic volumes from 1997 and 1998. WVCs were classified by the hour of occurrence from the RCMP reports as daylight, dawn, dusk, or darkness periods using sunrise, sunset and twilight time tables, calculated for day 15 of each month (as provided by the Herzberg Institute of Astrophysics, National Research Council of Canada). Dawn and dusk were each 1-hour long. We used a chi-square test to evaluate the null hypothesis that the frequency of WVCs during each time period occurred in proportion to the time available for each period. The significance of each time period was evaluated using Bailey's confidence intervals (Cherry 1996).

We assessed weekly patterns of WVCs by classifying the day of each WVC as weekdays (Monday, Tuesday, Wednesday, Thursday) and weekends (Friday, Saturday, and Sunday). Friday was included as part of the weekend because weekend travel generally begins on Friday. We used a chi-square test to assess the null hypothesis that WVCs occurred equally on weekdays and weekends. The observed values were the number of WVCs that fell within each period. We calculated expected values as the proportion of total observed WVCs relative to the length of each time period.

Mortality by Vehicle Type

We classified the type of vehicle involved in each WVC as a passenger vehicle or large vehicle, for the entire study area from 1991-2000. Passenger vehicles included passenger cars, vans and pick-ups, whereas large vehicles were large trucks (>4500kg), semi trucks, recreational vehicles and buses. We tested the null hypothesis that, WVCs occurred equally between both vehicle classes on Highway 93S and the TCH. We divided the TCH into two sections: TCH-west (west of Sunshine interchange to Yoho National Park west boundary) and TCH-east (east of Sunshine interchange to Highway 40 junction). Observed values were the WVC frequencies that fell within each vehicle class. We calculated the expected values, based on the proportion of each vehicle class on the corresponding road type as determined vehicle-classifying traffic counters (Parks Canada Highway Service Center, unpublished data).

Severity of Wildlife-Vehicle Collisions

We used a logistic regression (maximum likelihood estimates) to predict the probability of occurrence of injury-related motor vehicle accidents as a function of driver safety variables. We developed a motor vehicle collision (MVC) model, which included all types of motor vehicle accidents within the study area and a WVC model, which included only wildlife-related accidents. Five independent variables were included in the model: *darkness* (day vs. dark-dawn-dusk); *type of accident* (wildlife vs. other); *posted speed* (90km/h vs. 110km/h); *vehicle involved* (passenger car vs. large vehicle); and *surface condition* (dry vs. slush- snow-ice). RCMP officers classed accidents at three severity levels: fatal, injury related or property damage. Since fatal MVCs were relatively few ($n = 47$), they were included with injury-related accidents. Indicator or dummy variables were created for each categorical variable with one reference comparison variable.

We used the log-likelihood ratio test (Hosmer and Lemeshow 1989) to determine the overall significance of each model. We assessed the improvement of fitted models over null models according to the difference in (-2) log-likelihood ratios. Significance ($p \leq 0.05$) of explanatory variable coefficients was based on chi-square tests of Wald statistics (Hosmer and Lemeshow 1989). Standardized effect coefficients were not calculated; however, we multiplied logistic regression coefficients by the standard deviation of the respective variables within the model. We called this parameter the standardized estimate coefficient. Interpretation of logistic regression coefficients was made in terms of statements about odds ratios. We also included cross-validation classification accuracies for each model. Prior to performing the regression analysis we tested potential explanatory variables for multicollinearity (Menard 1995).

Data were analyzed for all analyses using Microsoft Excel, SPSS version 7.5 (SPSS 1996) and the Statistica™ kernel release 5.5 statistical package (Statsoft 2000). All analyses assume data are independent and drawn at random; however, we caution that the efficiency of accident reporting between seasons, years and geographical location may vary. We screened all data for outliers and normality prior to each analysis. Chi-square analyses assume that equal sampling effort was applied to each category. The sample size in each analysis was different because some vehicle collision records did not contain information for all variables. We assumed that the number of wildlife collision records collected and used for analysis provided a representative sample of the total wildlife collisions in the study area.

Results and Discussions

Error Reporting

National Parks and Alberta Province

The average reporting distance error between the national park and the provincial collaborators was significantly different ($t = 2.34, p < 0.05$). The average reporting error was almost twice as large in the national parks (mean = 618 ± 993 m) compared to the province (mean = 364 ± 371 m) (table 1). The standard deviation was highest for national park reporting (=993m) compared to provincial reporting (=371m). The overall average reporting error in the study area was 516 ± 808 m.

Table 1

Average distance reporting errors from all road-kill records from mountain national parks (Banff, Kootenay, Yoho) and the province of Alberta (1998-2001).

GROUP	N	Mean error (m)	Minimum (m)	Maximum (m)	\pm SD (m)
MOUNTAIN NATIONAL PARKS					
National Park Reporting (Occurrence reports and mortality cards)	138	618	0	6500	993
ALBERTA PROVINCE					
Alberta Province Reporting (Volker-Stevin and Alberta Natural Resources)	95	364	0	1700	371
TOTAL (National parks & province)	233	516	0	6500	808

It is difficult to compare the mean reporting errors between the mountain national parks and the Alberta province since their methods of reporting were different, and the degree of interaction between project personnel and reporters varied between parties. The high standard deviation associated with national park reporting can be explained by the quantity and churn of personnel within the national parks. Volker-Stevin had the same five or six collaborators reporting collisions, while the national parks had over 50 reporters who changed seasonally over the study period. Methods of reporting, degree of interaction between personnel and reporters, quantity of reporters, and attitude of reporters will all determine the success, and accuracy of this type of project.

Royal Canadian Mounted Police

The average distance reporting error of the RCMP WVC records was $2154 \pm 1620\text{m}$ ($n = 26$ paired records). This surprisingly large RCMP reporting error is likely to be a result of the method of reporting and eventual designation of road-kill location by Alberta Infrastructure. The transfer of data from the field-reported record, referenced to landmarks in the field, followed by their conversion into standard kilometre postings, undoubtedly results in greater error being added to the definitive road-kill location. Nonetheless, these data have been used in the past to identify WVC hot spots, other site-related characterizations of road-kill occurrences and/or planning mitigation signage locations (Kerr 1997; Seaby 1997, 1998). Caution should be taken before using these data, particularly if spatial analyses are carried out. The spatial error is sufficiently large that resulting analyses will not be robust, nor provide useful information for mitigation planning.

The data we collected on the true WVC locations and average reporting error, have allowed us to obtain site-specific information on WVCs to be used in future analyses of local-scale factors influencing wildlife-vehicle accidents. Information on the average reporting error will allow the use of the much larger BNP mortality database (1981-present) in coarse-scale analyses of factors influencing WVCs in the Banff-Bow Valley.

Elk-Vehicle Collisions

Sex and Age

Within the overall study area there were significantly higher numbers of female EVCs than male EVCs ($\chi^2_1 = 71.0$, $n = 586$, $p < 0.010$). More adult elk were involved in EVCs than sub-adults ($\chi^2_1 = 54.9$, $n = 569$, $p < 0.001$).

There were higher quantities of female EVCs compared to male EVCs on the TCH park (BNP) between 1986-2000. This female bias can be explained by there being fewer bulls in the Bow Valley population (Flook 1970).

The overall sex ratio of EVCs was significantly different from that found in the Bow Valley population, and highly skewed towards greater male mortality during the 15-year period ($\chi^2_1 = 62.1$, $n = 147$, $p < 0.001$). Different patterns of movement between female and male elk can explain the higher probability of male elk becoming involved in a vehicle collision. Woods (1991) showed more bulls migrate than females as a whole in the Bow Valley population. During the rutting season males then move back into the rutting grounds within the valley to access more mates (Woods 1991). Romin and Bissonette (1996b) and Joyce and Mahoney (2001) found a similar male-biased relationship with deer- and moose-vehicle collisions, respectively.

The number of EVCs involving sub adults on the TCH park (BNP) was comparable to the number of EVCs involving adults; whereas, the overall age ratio of EVCs was significantly different from that found in the population and highly skewed towards greater sub-adult mortality over the entire time period, 1986 to 2000 ($\chi^2_1 = 160.5$, $n = 224$, $p < 0.001$). This could be related to driver behaviour, as a driver will swerve to miss the adult cow only to hit her calf following close behind, as noted by Joyce and Mahoney (2001) with moose-vehicle collisions. Further, sub-adult elk do not have experience in crossing roads and probably cross the road less cautiously than adult cows. Dusek *et al.* (1989) also showed a greater proportion of yearling, male white-tailed deer involved in collisions than that found in the population.

Comparison of Elk Mortality Condition

Between 1990 and 1998, 397 elk carcasses were collected in BNP that were killed on highways ($n = 102$), railway ($n = 133$), and by predators ($n = 162$). There was a significant effect of elk condition on the three types of mortality (Kruskal-Wallis test, $F_{2,397} = 9.45$, $p < 0.0001$). Percent marrow fat content of highway- and railway-killed elk was not significantly different, but both had a significantly greater percentage fat content than predator-killed elk (Tukey's HSD test, $p < 0.05$). This suggests that motor vehicles on highways, and trains on railways, do not discriminate based on the condition of elk; however, predators apparently do by taking individuals in poorer-than-average condition. O'Gara and Harris (1988) found the opposite results of our study, i.e., predators such as cougars and coyotes killed prime-aged deer, and deer killed by automobiles were in poor condition.

Seasonality

Season had a significant effect on the number of EVCs (Kruskal-Wallis test, $F_{3,44} = 3.48$, $p = 0.025$) as displayed in figure 2. There were significantly more EVCs in fall compared to spring, summer, and winter (Tukey's HSD test, $p = 0.003$ and $p = 0.010$, respectively). This can be largely explained by the seasonal population trends for elk in the Rocky Mountains that occurred during the study period. Elk numbers on average increased more than two times from spring to fall during the study period (Parks Canada, unpubl. data). Previous studies have documented peak mortalities with ungulates in autumn (Hubbard et al. 2000; Puglisi et al. 1974; Romin and Bisonette 1996b; and Groot and Hazebroek 1996), which are associated with an increase in movements during the hunting and breeding periods.

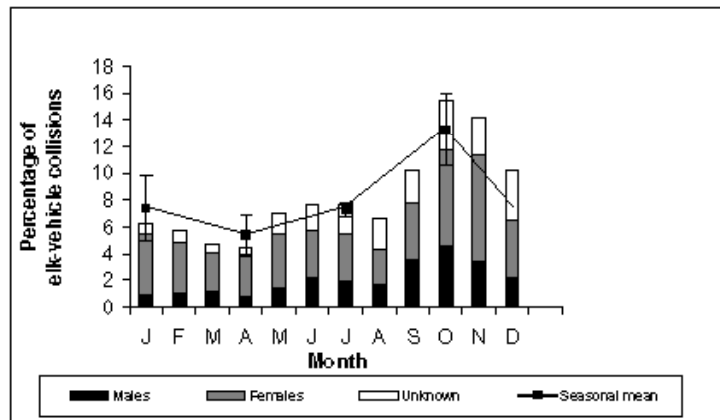


Fig. 2. The seasonal distribution of elk-vehicle collisions in the Canadian Rocky Mountains, 1985 to 2001 ($n = 770$). Seasonal means are shown as connected points; bars indicate \pm SE.

Road Type, Traffic Volume and Elk Abundance

EVC rates were significantly different between each road type (Kruskal-Wallis test, $F_{3,44} = 19.33$, $p < 0.0001$). They were significantly higher on the TCH province compared to TCH-park (BNP), TCH park (YNP) and Highway 93S (Tukey's HSD test, $p = 0.002$, $p < 0.0002$, and $p < 0.0001$, respectively). The TCH park (BNP) had a significantly higher rate of EVCs than Highway 93S ($p = 0.023$).

Figure 3 below shows the number of EVCs for each year, together with the average number of elk surveyed per kilometre and the annual average daily traffic volume for the TCH park (BNP) and Highway 93S. As traffic volume increases, the mean number of elk per kilometers and the number of EVCs decrease (Spearman's rank correlation, between all variables $r > 0.9$, $p < 0.0001$).

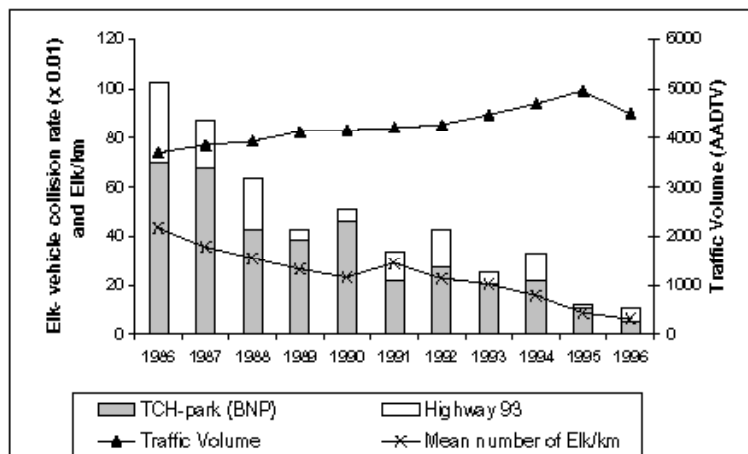


Fig. 3. Standardized number of elk-vehicle collisions annually, with annual average daily traffic volume and estimated standardized elk abundance along Highway 93 and the Trans-Canada Highway park in the Central Canadian Rocky Mountains, 1986-1997.

It is common knowledge that the incidence of wildlife-vehicle collisions is dependant on traffic volume and relative abundance of wildlife species (Fahrig *et al.* 1995, Boulanger 1999, Philcox *et al.* 1999, Romin and Bissonette 1996b). However, to understand how these variables interact to determine EVC rates on different road types is much more complicated. Elk collision rates differed between road types in our study, where those having the highest traffic volumes had the highest kill rates. Therefore, it was an interesting correlation to find that as traffic volume increased, the mean number of elk mortalities per kilometers decreased on highway 93S and the TCH park (BNP). The decline in elk population numbers throughout the 1980's drove this relationship. This relationship has also been documented by Fahrig *et al.* (2001) and Boulanger (1999), which suggested that highway mortality rates can be used as an indicator of population trends even when highway traffic volumes are changing.

The model describing the effect of standardized elk abundance on EVC rate on Highway 93S and TCH park (BNP) was significant (ANCOVA, $F_{3,18}=18.19$, $p < 0.0001$, $r^2 = 0.75$). There was a significant interaction between road type and elk abundance ($F_{2,18} = 15.5$, $p < 0.0001$). There was a positive relationship between EVC rate and elk abundance, which was more significant on the TCH park (BNP) than on Highway 93S.

The model describing the effect of traffic volume on EVC rate on Highway 93S and TCH-park (BNP) was significant (ANCOVA, $F_{3,18} = 27.04$, $p < 0.0001$, $r^2 = 0.82$). There was a significant main effect of road type ($F_{2,18} = 10.5$, $p < 0.01$), with the TCH having more EVCs than Highway 93S. There was also a significant interaction between traffic volume and road type ($F_{2,18} = 24.4$, $p < 0.0001$) indicating that the relationship between traffic volume and EVC rate depends on road type. The negative relationship between EVC rate and traffic volume, was more extreme on Highway 93S compared to TCH-park (BNP) where traffic volumes were significantly higher ($t = -26.62$, $n = 11$, $p < 0.0001$).

The model describing the effect of elk abundance on the EVC frequencies when traffic volume remained constant was significant (ANCOVA, $F_{3,18} = 28.70$, $p < 0.0001$, $r_s = 0.82$) indicating that elk abundance influences EVC rate independent of traffic volume. There was a significant interaction between season and elk abundance ($F_{2,18} = 24.19$, $p < 0.0001$), indicating that the relationship between the EVC frequencies and elk abundance differed between the two seasons. The rate of increase of EVCs with respect to elk abundance was greater during the fall season when elk abundance numbers were higher ($t = -2.09$, $n = 16$, $p = 0.045$).

The relationships between EVC rate, traffic volume and elk abundance were the same on both road types, but the degree of interaction differed between them. As traffic volumes increased throughout the study period the EVC rate decreased to a lesser degree on the TCH. Further, the positive relationship between EVC rate and abundance levels was more prominent for the TCH park (BNP). The sheer numbers of traffic on the TCH compared to Highway 93S increased the probability of elk-vehicle collisions on this highway. More research is needed to determine if at some point the increased traffic volumes will result in animals avoiding the road and thus reducing collision rates. Long-term trends in population abundance, traffic volumes and collision rates can help to tease apart this phenomenon.

When traffic volumes (spring vs. fall) and confounding variables associated with the study area were held constant, collision rates were significantly higher in the fall when population numbers increased due to the addition of the spring calf cohort. Romin and Bissonette (1996b) also report a seasonal decrease in deer mortality due to reduced population numbers after harsh conditions in winter. As noted above fall peaks have been documented in ungulate mortalities (Romin and Bissonette 1996b, Hubbard *et al.* 2000, Puglisi *et al.* 1974) due to an increase in movement patterns associated with the breeding season and hunting season. Elk-vehicle collision trends followed fluctuations in population abundance, independent of increasing or level traffic volumes, however behaviour associated with life history activities of elk, e.g. breeding, and migration, may have also influenced year-round road-kill levels and composition.

Wildlife-Vehicle Collisions

Temporal Patterns

The frequency of WVCs for each hour from 1991-2000, together with the average hourly traffic volume for 1999 is shown in figure 4. The frequency of hourly WVCs was not correlated ($R = -0.25$, $n = 24$, $p = 0.225$) with average hourly traffic volumes. This result suggests there must be another factor influencing the occurrence of WVCs during the 24-hour day.

We rejected the null hypothesis that WVCs occurred equally in all light categories ($\chi^2_3 = 258.10$, $n = 1706$, $p < 0.0001$). Light, dark and dusk categories had expected values that fell outside Bailey's 95 percent confidence intervals (Cherry 1996). Dark and dusk categories had significantly more accidents than expected, while light had significantly fewer accidents than expected. Fifty-nine percent of WVCs occurred during darkness

and dusk. Joyce and Mahoney (2001) have shown this same temporal pattern in moose-vehicle collisions in Newfoundland, with 75 percent of all accidents occurring between sunset and sunrise.

The U.S. National Highway Traffic Safety Administration reports that at night you can only see 160 feet ahead of your vehicle resulting in less time to avoid a crossing animal. In addition, humans lack the ability to distinguish similarly coloured objects at night, and glare from oncoming headlights bleach human visual receptors, temporarily blinding drivers (Hess *et al.* 1990), contributing to the likelihood of a wildlife collision at night.

We rejected the null hypothesis that MVCs occurred equally on weekdays and weekends ($\chi^2_1 = 23.07$, $n = 1805$, $p = 0.0001$). More accidents than expected occurred on weekends than weekdays. The most logical explanation for this result would be the increased traffic volumes evident on weekends (Parks Canada, unpublished data) as more people travel at this time. Alberta Transportation (2001) also reported Friday as being the most collision-prone day of the week, perhaps due to motorist behaviour, such as fatigue, which reduces reaction time to a dangerous situation.

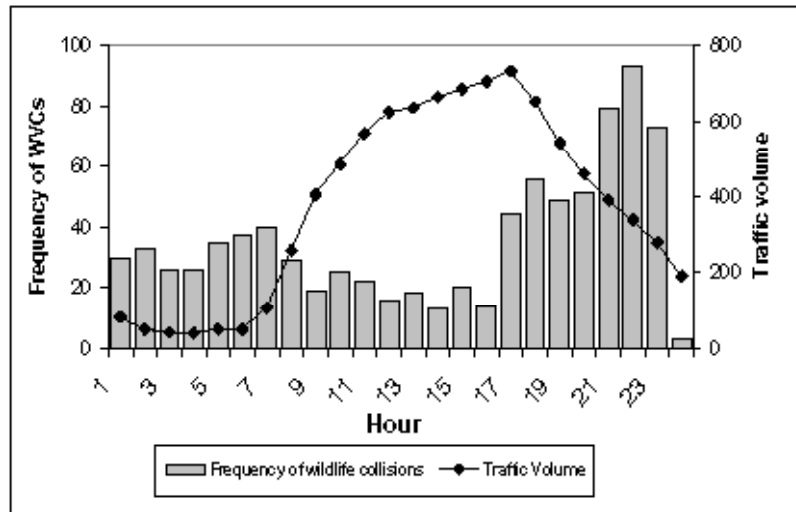


Fig. 4. Relationships between frequencies of hourly wildlife-vehicle collisions and average hourly traffic volume on the Trans-Canada Highway in Banff National Park and the province of Alberta and Highway 40 from 1991 to 2000.

Mortality by Vehicle Type

Passenger vehicles caused 8 percent of the WVCs; whereas, 14 percent involved large vehicles. We rejected the null hypothesis that WVCs occurred equally among vehicle classes on Highway 93S ($\chi^2_1 = 65.86$, $n = 187$, $p < 0.0001$) and the TCH-west section ($\chi^2_1 = 7.88$, $n = 42$, $p = 0.005$). On both highways there were more large vehicles causing WVCs than expected, and fewer WVC than expected were caused by passenger vehicles. WVCs occurred in proportion to what was expected on the TCH-east ($\chi^2_1 = 3.63$, $n = 546$, $p = 0.057$). Caution should be used when using these reported frequencies, as WVCs reported by passenger vehicles are much higher than those reported by large commercial vehicles, because the damage to a larger vehicle is minimal and therefore goes unreported. Nonetheless, more WVCs involving large vehicles than expected occurred on two sections of highway even though counts would have been conservative. Larger vehicles have a much longer stopping distance due to the weight of the vehicle (Alberta Transportation 2001), and it would be unsafe to swerve out of the way of a crossing animal.

Severity of Wildlife-Vehicle Collisions

We used 2,619 accident records in the MVC model, of which 506 were injury-related accidents and 41 were fatalities. There were 27 percent ($n = 719$) of accidents that were wildlife related, of which 57 were injury related and none was fatal.

The MVC and WVC model were both statistically significant with $p < 0.001$ and $p < 0.001$, respectively. The variance explained by the models and overall cross-validation accuracies were highest for the MVC model ($R^2 = 0.086$; 80.26%), followed by the WVC model ($R^2 = 0.062$; 93.05%). Accident type was most important

in explaining severity in MVCs. Injury-related accidents were 87 percent (odds ratio = 0.1257) less likely to occur in a wildlife collision relative to other types of collisions. Lo (2003) reports that only three percent of WVCs were injury related, while 0.05 percent were fatal in all wildlife-vehicle crashes on rural roads in Alberta in 2001. Human injury or fatality in a wildlife-vehicle collision may be low relative to other types of collisions; however, injury and fatality for the animal is almost certain, and the economic costs are extreme. Joyce and Mahoney (2001) report an annual economic loss of \$3,850,000 (CD) from moose collisions alone in Newfoundland.

Further, injury-related accidents were 69 percent (odds ratio = 0.3125) less likely to occur in slush, snow or ice conditions relative to dry conditions. Likewise, Alberta Transportation (2001) reports that the majority (70.9%) of all casualty collisions occurred when surface conditions were dry. This is probably due to motorist behaviour in different weather conditions. As road conditions improve drivers tend to speed, increasing the likelihood of being involved in a motor/wildlife-vehicle collision. Speeding is one of the most prevalent factors contributing to traffic crashes. Speeding reduces a driver's ability to steer away from objects in the roadway, and extends the distance necessary to stop a vehicle (as provided by the National Highway Traffic Safety Administration, U.S Department of Transportation).

The only significant factor in the WVC model was type of vehicle. Injury-related accidents are 3.65 times more likely to occur when driving a passenger vehicle relative to larger vehicles. Alberta Transportation (2001) also reports that passenger cars are involved in 76 percent of the total casualty collisions. Smaller vehicles have less structure and size to absorb crash energy, so injurious forces can easily harm the occupants in crashes.

Conclusions and Recommendations

The long-term trend and prospects are for increasing traffic volumes on the TCH and other primary roads in the parks. Our findings link increasing traffic volumes with a decreasing elk population, which underscore the need for more information on the factors contributing to ungulate-vehicle collisions before mitigation schemes are planned, designed or implemented. Mitigation implemented based on wildlife-vehicle collision data analyses should be rigorously monitored to determine how effective measures are at reducing road-kills.

Wildlife-vehicle collisions tend to occur more than expected, at night, on dry road conditions and by larger vehicles. The ability for a motorist to avoid a collision is reduced in all these situations due to reduced visibility and increased stopping distances. By decreasing the speed, the motorist can compensate for the increased probability of being involved in a collision. Wildlife managers should enforce current speed limits and consider decreasing night driving speeds for all vehicles.

Spatial road-kill data can aid in determining location of mitigation measures, e.g., wildlife signage and crossing structures. Patterns of WVCs can be valuable in devising mitigation based on specific hour of day or season when collision frequencies are highest. Determining what individuals within a population are most susceptible to road-kills can help assess the demographic impacts of wildlife collisions. The type of vehicle, such as passenger vehicles and trucks, involved in collisions can help target public awareness and education campaigns. Factors contributing to WVCs, such as traffic volumes and elk abundance, can help managers predict long-term viability of wildlife populations with incurring road mortality. In addition, WVC intensities on different road-types can help managers identify and prioritize road-types for mitigation.

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