FACTORS INFLUENCING THE TIMING AND FREQUENCY OF MOOSE-VEHICLE COLLISIONS AT URBAN-WILDLAND INTERFACES IN SUBARCTIC ALASKA

By

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Abstract

Wildlife-vehicle collisions concern road engineers, wildlife biologists, and the motoring public. In Alaska, moose-vehicle collisions (MVCs) are the most commonly reported type of wildlife-vehicle collisions. Each year an average of 101 MVCs were reported in the Fairbanks North Star Borough (FNSB), resulting in damages amounting to $3,000,000/yr. This thesis describes the spatial and temporal patterns of MVCs in the FNSB and uses these patterns to infer the interactions between human and moose behavior that cause them. The analytical approach used combined spatial and temporal records of MVCs collected by the Alaska Department of Transportation with spatially explicit data describing topography, land cover, traffic volume, and traffic speed. Multiple hypotheses about cause and effect were tested using computer-intensive, randomization procedures. MVCs occur most frequently during the first hours after sunset, particularly in autumn and winter. Roads in the vicinity of areas of recent wildland fires have a heightened risk of MVCs, particularly if there are moderate traffic volumes and speed limits of 90 km/h (55 mph). MVCs are also frequent on roads traversing land cover types where human population densities are low. Risk of MVCs in the FNSB is highest between 150 m and 200 m elevation. Based on these results, several mitigation measures to reduce MVCs in the FNSB are recommended, including seasonal warning signage and speed reductions in the hours after sunset. Roadside fencing designed to divert moose to designated road crossings in conjunction with infrared-triggered warning lights at these crossing points may be warranted in areas identified as hotspot locations for MVCs.
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INTRODUCTION

Interactions between moose (*Alces alces*) and humans frequently occur on Alaskan roads, sometimes with disastrous consequences. Many Alaskan drivers have encountered a moose at close range. Most such encounters do not involve collisions, and for tourists they are often the highlight of their visit to the North. On the other hand, some moose-vehicle encounters involve collisions (MVCs), sometimes with fatal results. Traffic collisions with moose usually result in the death or severe injury of the moose (Child, 1997). Vehicle damage usually also occurs, and injuries to vehicle occupants are frequent (Grenier, 1973; Joyce & Mahoney, 2001).

The average number of MVCs reported in the Fairbanks North Star Borough (FNSB) is 101/year over the period 2000-2012. Contrary to a general trend of increasing wildlife collisions throughout the USA and Europe (Groot Bruinderink & Hazebroek, 1996; Hughes, Saremi, & Paniati, 1996; Huijser, McGowen, & Fuller, 2008), the frequency of MVCs in the FNSB declined during this period. Nevertheless, Alaska-based newspapers regularly report dramatic collisions. For example, in the spring of 2015 two school bus accidents in the FNSB involved moose, both on the same road (Fairbanks Daily News-Miner, 2015).

Despite their frequent occurrence and the dramatic headlines, human fatalities in MVCs are rare. During the study period 2000-2012, two collisions out of a total of 1308 reported MVCs were fatal. That said, human injury in MVCs is a serious concern, with more than 15% of all reported MVCs between 2000 and 2012 resulting in at least minor injury to people. This injury rate is one of the main causes for the high monetary costs of MVCs. In North America as a whole, the average cost per MVC exceeds $30,000 per collision (Huijser, Duffield, & Clevenger, 2016).
This includes police dispatch, medical costs, vehicle damage, and the death of the moose. Based on these cost estimates, the damage resulting from MVCs in the FSNB exceeds three million dollars each year.

Interior Alaska, and the FNSB in particular, are interesting places to study animal-vehicle collisions for several reasons. The first reason is trauma to drivers and vehicle occupants. Second, the FNSB is representative of other urban-wildland interfaces in the circumboreal North. Patterns and processes involved in collisions described here may be applicable to other places in Subarctic regions. These patterns are increasingly important to understand as human populations in these regions continue to expand. The overall goal of the study is to better understand the places, times, and the factors contributing to MVCs in Interior Alaska in order to improve mitigation measures.
**Previous studies**

Research in Scandinavia and North America has identified a number of variables contributing to MVCs. Moose population density in an area is an important variable (Child, 1997; Seiler, 2004). Moose population densities vary locally in response to landscape features like elevation and land cover, and these landscape factors are thought to increase the risk of MVCs (Child, 1997; Finder, Roseberry, & Woolf, 1999; Rea, Johnson, & Emmons, 2014). In Maine and Sweden the frequency of MVCs has also been correlated with traffic parameters including traffic volume (vehicles per unit time) and posted speed limits (Danks & Porter, 2010; Seiler, 2005). MVC frequency and traffic parameters were found to be only weakly correlated in an analysis of deer collisions in Utah (Bissonette & Kassar, 2008). The seasonal timing of MVCs differs markedly in different regions (Steiner, Leisch, & Hackländer, 2014). For instance, in southern Alaska most MVCs occur in winter months (Garrett & Conway, 1999), while in Maine (Danks & Porter, 2010) and Finland (Niemi, Tiilikainen, & Nummi, 2013), most MVCs occur in summer.

**Study area**

The Fairbanks North Star Borough (FNSB) is located in hilly terrain bordering the Tanana River and has a total area of 19,250 km² (Fig. 1). Elevations range from 100 to 1700 meters above sea level (masl). Under the influence of extreme seasonal variation in solar radiation, the climate is subarctic and continental, with warm summers contrasting the cold winters when temperatures regularly drop to -40 °C. The mean annual temperature in the FNSB is -2 °C. Snow makes up 30% of the approximately 300 mm of precipitation per year (Wendler & Stuefer, 2016), and the maximum snow pack in late winter rarely exceeds 50 cm in depth.
Vegetation in the FNSB is a mosaic of forest communities whose spatial and temporal
distribution on the landscape is determined by interactions between aspect, elevation, the
presence of permafrost (perennially frozen ground), and time since the last wildland fire
(Kurkowski, Mann, & Rupp, 2008). Main deciduous trees species are birch (*Betula neoalaskana*)
and aspen (*Populus tremuloides*). Black spruce (*Picea mariana*) and white spruce (*Picea glauca*)
are the predominant conifer species. At high elevations and in areas undergoing secondary
succession after wildland fires, willow (*Salix* spp.) and alder (*Alnus* spp.) form extensive shrub
lands.

Moose range throughout the FNSB, from the most remote hinterlands to urban streets.
The Alaska Department of Fish and Game estimates moose population size every autumn in
Game Unit 20B, which includes the FNSB road system. Between 2000 and 2012, moose
numbers varied from 12,500 to 16,500 and showed a declining trend (Fig. 2). Moose activity
around the urban core of Fairbanks tends to increase in winter (Maier et al., 2005; Schneider &
Wasel, 2000), probably because urban areas provide food resources and shelter from predators
like wolves (*Canis lupus*) and grizzly bears (*Ursus arctos*).

Much of the FNSB is uninhabited and lacks road access, making the city of Fairbanks a
small, urban island in an otherwise largely natural, boreal landscape. The human population of
the FNSB increased steadily from 82,000 to 100,000 people between 2000 and 2012 (U.S.
Census Bureau, 2016). Most of this growth occurred within the city of Fairbanks. Two major
highways connect the FNSB with Anchorage and Valdez (Fig. 1), and the total length of the FNSB
road network is 3880 Km.
The Fairbanks North Star Borough is located in Interior Alaska. Human population numbers at approximately 100,000; moose population estimates at approximately 14,000. Between 2000 and 2012, the annual average of moose-vehicle collisions in the FNSB totaled at 101.
METHODS

Data sources

Locations of reported MVCs were obtained through the Alaska Department of Transportation and Public Facilities (ADOT&PF). This crash dataset describes MVC location, time, weather conditions, road conditions, and other details. ADOT&PF mandates the following disclaimer. The crash data provided by Alaska DOT&PF is compiled for highway safety planning purposes (23 U.S.C. § 148(h), 2015), and Federal law prohibits its discovery or admissibility in litigation against state, tribal or local government that involves a location or locations mentioned in the crash data (23 U.S.C. § 409, 2005; WALDEN v. DEPARTMENT OF TRANSPORTATION, 2001). This compilation is derived from crash reports completed by a responding law enforcement officer, or by a citizen, and maintained by DMV. ADOT&PF can make no representation about their accuracy.

This dataset contains 1307 reported MVCs. In 233 of these reports, spatial data was insufficient, and these MVCs were excluded from the analysis, totaling the analyzed number of MVCs at 1074. Elevation, aspect, and slope were defined for each site of a reported MVC using the National Elevation Dataset (NED) and entered into ArcGIS 10.3. NED data was also used to classify locations of simulated MVCs used in the randomization analysis (see below).

Land-cover characteristics were tabulated for each reported MVC within a 100-meter and a 2500-meter buffer zone around each collision site using the National Land Cover Database 2001 (NLCD). The NLCD provides a detailed (30m x 30m) description of land cover based on Landsat V and Landsat VII imagery (Homer, Huang, Yang, Wylie, & Coan, 2004). The same land-cover data was used to classify simulated MVCs in the randomization analysis.
Distances of observed and simulated MVCs to recently burned areas were estimated using the “near” tool in ArcGIS. Geospatial data on fire perimeters come from the US Bureau of Land Management Alaska Fire Service database (http://fire.ak.blm.gov/; accessed September 2016). Moose population densities tend to be high in the first 25 years after a wildland fire because early stages of secondary succession provide abundant forage (Peek, 1997). For this reason, a sliding window of 25 years was used when estimating distances between MVCs and perimeters of previous fires.

Geospatial data describing the FNSB road network was obtained from the Fairbanks North Star Borough and describes the road network as it was in 2012 (Kellen Spillman, personal communication, April 1, 2014). Road density was calculated using the “Line Density” tool in ArcGIS using a 1 km search radius. This procedure resulted in a 30m*30m raster with road density calculated for each individual pixel in terms of length (km / km²). In addition ADOT&PF provided posted speed limits and traffic volume as a GIS database layer.

Statistical analysis

To perform statistical analysis, a Monte Carlo approach was used utilizing computer-intensive methods to test for non-random associations between MVCs and environmental and temporal parameters. Because this approach is non-parametric, it does not require the assumption that sample data are normally distributed or that they were obtained through random sampling (Noreen, 1989; Manly, 2007). The latter assumption is particularly important here because it is likely that the MVC dataset is not a random sample of all MVCs (M.P. Huijser et al., 2008; Snow, Porter, & Williams, 2015). This is the case because MVCs involving either
significant property damage or human injuries are more likely to be reported than those with only minimal consequences. Other reasons for non-reporting include lack of cellphone reception; the atavistic attitudes of Alaskans towards authorities, rules, and regulations; and inclement weather conditions at the time of accident.

Testing hypotheses using a Monte Carlo approach involves comparing the frequency of actual events to the frequency of simulated ones. The percentage of all simulated events that equal or exceed the number of actual events is then used to estimate the likelihood that actual events are the result of random processes. A simple example helps clarify the rationale and the procedure behind this Monte Carlo approach.

Imagine ten MVCs occurred in one day, and that seven of these occurred between the hours of 1600 and 2000. What is the probability that this concentration of MVCs in the late afternoon and early evening is the result of chance? The null-hypothesis is that MVCs are randomly distributed throughout the course of a day. If that were true, what is the probability that the observed seven of the ten MVCs occurred as a result of chance between 1600 and 2000 hours?

The cumulative probability distribution of ten MVCs occurring can be simulated over the course of 10,000 hypothetical days. For each day, ten MVCs are randomly assigned an hour of occurrence and the results tallied. The number of simulated days when seven or more MVCs occurred between 1600 and 2000 hours are then divided by 10,000 to estimate the probability of encountering a day in which seven out of ten MVCs occur during those four hours.
It turns out that of 10,000 simulated, ten-MVC days, only six days have seven or more collisions between 1600 and 2000 hours. Following Davison and Hinkley (1997), the empirical $P$ value is estimated as $p = (r+1)/(n+1)$, where $n$ is the number of replicate samples that have been simulated and $r$ is the number of these replicates that produce a result greater than or equal to the actual data. The $(r+1)$ and $(n+1)$ terms are used rather than simply $(r/n)$ because this procedure utilizes ranks, and $(r+1)/(n+1)$ describes the proportion of all possible rankings of the realizations fulfilling this criterion (North, Curtis, & Sham, 2002). In this case, 7/10,001 yields an estimated $P = 0.0007$, indicating that the likelihood of obtaining seven MVCs in this four-hour period as the result of chance is exceedingly small. Consequently, the null hypothesis of randomness is confidently rejected.

Critical significance levels considered in randomization tests are similar to those used in other statistical approaches. Probability levels < 0.05 give a strong indication that observed patterns are not randomly distributed. The number of simulated trials depends on the desired significance level. For significance levels < 0.05, at least 1000 trials are desirable (Manly, 2007).

In the analyses, MVC statistics are calculated for each variable in each year of the study period (2000-2012). The mean number of MVCs reported between 2000 and 2012 is 100.6 per year, therefore 100 randomized collisions per year over 1000 simulated years were used in the Monte Carlo trials. Simulated collisions were randomly distributed over the road network of the FNSB, and the same statistics (altitude, land cover, etc.) were estimated as for observed MVCs.

Generalized boosting modeling (GBM) was used (Elith, Leathwick, & Hastie, 2008) to estimate the relative importance of different variables in contributing to the risk of an MVC occurring. GBM was performed using the R package “gbm” (R Core Team, 2015; Ridgeway,

GBM analysis depends on the “boosting” of regression trees (De’ath & Fabricius, 2000). Instead of one single tree, hundreds of regression trees are built, averaged, and then optimized. The output quantifies the relative importance of different variables and show important interactions between variables (Elith et al., 2008). In the analysis, tree complexity was set to 5; learning rate was set to 0.01; and “Bernoulli” was used as the error distribution of the response.

To perform the ranking analysis, a dataset was built with 1074 observed and 1489 simulated MVCs. The distance between observed MVC locations and randomized events was set to > 500 meters. Variables (elevation, traffic volume, distance to burn, etc.) were analyzed for both observed and random collisions.
RESULTS

Temporal trends

Moose vehicle collisions in the FNSB show a distinct decrease in frequency over the course of the study period (2000-2012). The average number of MVCs during the first six years (2000-2005) of the study period was 111 /year, while during the subsequent seven years (2006-2012), the average number declined to 88 /year. Between 2000 and 2012, the moose population in the FNSB is estimated to have varied between 12,500 and 16,500 animals (Fig. 2). Visual inspection of Figure 2 suggests a relation between MVCs and moose population, however, there is no statistically significant correlation (Spearman correlation <0.5).

Spring months (March, April, May) see the fewest MVCs (Fig. 3). Starting in June, MCV frequency starts to increase until January, which is generally the month with the highest number of MVCs (Fig. 3). In eight out of twelve years of the study period, January had the highest number of MVCs; September ranked second highest in four years of the study period. Seasonal changes in snow depth were analyzed as a potential factor affecting the temporal distribution of MVCs throughout the year, but no relation was found between snow depth and number of monthly MVCs.

MVCs display a distinct diurnal pattern: they tend to occur most often during the hours of twilight following sunset (Fig. 4). This pattern starts to appear in August (August 1 = day 213) and remains apparent until February (February 28 = day 59) (Fig. 4). During hours of darkness, MVCs occur most frequently before midnight. During summer, when Fairbanks experiences 24 hours of daylight, MVCs occur throughout the 24-hour cycle (Fig. 4).
Figure 2: MVCs and estimated moose population (2000-2012)

Number of MVCs in the FNSB (graph A) and estimated moose population size (graph B). The error bars in graph A reflect an estimated 15% under-reporting of MVCs (Garrett & Conway, 1999). The error bars in graph B reflect the minimum and maximum estimates of moose population. Each year, moose populations are estimated by ADF&G (Young, Donald (area biologist Alaska Department of Fish & Game) & Hollis, Tony (area biologist Alaska Department of Fish & Game), personal communication, August 5, 2016). Estimates for the moose population in 2002 and 2007 are not available.
Figure 3: Seasonal pattern

MVCs in the FNSB have a distinct seasonal pattern. MVCs are virtually absent during spring but increase during summer. The first peak of MVCs is visible during September. After a temporary dip in October, MVCs tend to increase until January.
Figure 4: Time of day

MVC occurrence at different times of day during different months. Each dot represents one MVC. MVCs occur more frequently in the hours after sunset.
MVCs and posted speed limits

Observed MVCs occur more often on roads with a speed limit of 55 mph compared to randomly distributed collisions (Fig. 5). Mean posted speed limits at observed MVC sites were 14.3% higher compared to the posted speed limits at the random locations of simulated collisions. Mean speed limit at observed locations was 51.8 mph (std. dev 1.3), while randomized collisions occurred at a mean speed limit of 44.4 mph (std. dev 1.5). Results are statistically significant at $p < 0.05$ for each year. At lower speed limits, observed MVCs occur less often compared to random, simulated collisions. At the highest possible speed limits (65 mph), MVCs are more frequent compared to random collisions, but results are not statistically significant.
Figure 5: MVCs in relation to posted speed limits

The percentage of MVCs occurring at different posted speed limits. Dark columns are observed MVCs, light columns are simulated MVCs. On roads where the posted speed limit is 55 mph, more MVCs occur than would be expected if they occurred randomly throughout the road system with no relation to speed limit. Fewer MVCs occurred on roads where posted speed limits are 30 mph or less than expected from random processes. Error bars reflect standard deviation for each category.
MVCs and traffic volume

MVCs are more frequent on roads where traffic volumes are high compared to randomly distributed, simulated collisions (observed mean: 4079 AADT [Annual Average Daily Traffic], randomized mean: 2674 AADT) (Fig. 6). In all years except 2003 and 2006, there is a statistically significant relationship between traffic volume and MVC frequency ($p < 0.05$), and there are large differences in MVC distribution between traffic volume categories. A detailed analysis of traffic volume reveals that MVCs occur more often on roads with medium traffic volume (3,000-10,000 AADT) than might be expected at random distributions (Fig. 6). At low traffic volumes (<2000 AADT), there are fewer MVCs compared to randomly distributed collisions, and these results are statistically significant ($p < 0.05$) for each year. At high traffic volumes (>10,000 AADT), MVCs tend to occur more often than expected, however this relationship is not statistically significant.
Figure 6: MVCs in relation to traffic volume

Distribution of MVCs in relation to traffic volume (percentage MVCs occurring per AADT category). Compared to random collisions observed MVCs occur more frequently at traffic volumes between 3000 and 5000 vehicles per day. Error bars reflect the standard deviation for each category.
MVCs and topography

In the hilly terrain of the FNSB, more MVCs occur at lower elevations than would be expected if they were randomly distributed (Fig. 7). The mean elevation of observed MVCs is 200 masl (7.7 m std. dev.), while randomized collisions generated in 1000 trials had a mean elevation of 244 masl (13.8 m std. dev). Although a large proportion (30%) of MVCs take place at elevations below 150 masl, this distribution is not statistically significant when compared to random collisions (33% below 150 masl). Moreover, observed MVCs are more frequent compared to random collisions between 150 masl and 200 masl (Fig 7). Randomized collisions occur more frequently above 350 masl (Fig. 7). Finally, no significant relation was found between slope orientation (aspect) and MVC occurrence.
Figure 7: MVCs in relation to elevation

Distribution of MVCs at different elevations in the FNSB. Compared to random collisions, observed MVCs occur more frequent between 150 masl and 200 masl. Randomized collisions occur more frequently above 350 masl. The majority of MVCs (+/- 64%) take place at elevations < 200 masl. Error bars reflect standard deviation for each category.
**MVCs and land cover**

Based on land-cover type present within a 100-meter buffer zones plotted around each MVC, observed MVCs tend to occur less frequently in “high” and “medium” developed areas compared to randomly distributed collisions (Table 1). Although not statistically significant, MVCs also seem to occur less frequently in forested areas compared to random collisions. MVCs tend to occur most often near “developed low-intensity” areas and “woody wetlands.” “Woody wetlands” are not a statistically significant variable when analyzed per year. However, when analyzed by season, “woody wetlands” show a distinct peak during the summer months. Results are less pronounced using 2500-m buffer zones around each MVC, which do not provide statistically significant results.
Table 1: Land cover surrounding MVC sites

Land cover characteristics based on a 100-m buffer zone surrounding each reported collision.

<table>
<thead>
<tr>
<th>Land cover</th>
<th>observed %</th>
<th>std.dev</th>
<th>randomized %</th>
<th>std. dev</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Developed Areas</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developed High intensity</td>
<td>0.13</td>
<td>0.10</td>
<td>0.64</td>
<td>0.38</td>
</tr>
<tr>
<td>Developed Medium Intensity</td>
<td>0.54</td>
<td>0.30</td>
<td>1.28</td>
<td>0.56</td>
</tr>
<tr>
<td>Developed Low Intensity</td>
<td>40.83</td>
<td>1.62</td>
<td>27.94</td>
<td>2.58</td>
</tr>
<tr>
<td>Developed Open Space</td>
<td>9.04</td>
<td>2.09</td>
<td>10.64</td>
<td>2.01</td>
</tr>
<tr>
<td><strong>Forest Areas</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Deciduous Forest</td>
<td>20.75</td>
<td>2.81</td>
<td>26.56</td>
<td>3.00</td>
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<tr>
<td>Evergreen Forest</td>
<td>8.78</td>
<td>1.71</td>
<td>14.29</td>
<td>2.34</td>
</tr>
<tr>
<td>Mixed Forest</td>
<td>4.34</td>
<td>1.19</td>
<td>5.57</td>
<td>1.22</td>
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<td><strong>Shrubland</strong></td>
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<tr>
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<td>0.02</td>
<td>0.07</td>
<td>0.10</td>
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<tr>
<td>Shrub/Scrub</td>
<td>1.67</td>
<td>0.71</td>
<td>2.65</td>
<td>1.02</td>
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<td><strong>Herbaceous</strong></td>
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<tr>
<td>Grassland</td>
<td>0.00</td>
<td>0</td>
<td>0.002</td>
<td>0.02</td>
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<tr>
<td>Sedge Herbaceous</td>
<td>0.02</td>
<td>0.06</td>
<td>0.04</td>
<td>0.08</td>
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<td><strong>Planted/ Cultivated</strong></td>
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<tr>
<td>Cultivated land</td>
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<td>0.27</td>
<td>0.32</td>
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<td>Pasture/Hay</td>
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<td>0.06</td>
<td>0.06</td>
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<td><strong>Wetlands</strong></td>
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<td>Woody Wetlands</td>
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<td>7.65</td>
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</tr>
<tr>
<td>Emergent herbaceous Wetlands</td>
<td>0.04</td>
<td>0.06</td>
<td>0.06</td>
<td>0.11</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open Water</td>
<td>0.89</td>
<td>0.62</td>
<td>0.89</td>
<td>0.45</td>
</tr>
<tr>
<td>Barren Land</td>
<td>2.33</td>
<td>0.80</td>
<td>1.38</td>
<td>0.67</td>
</tr>
</tbody>
</table>
MVCs and wildland fires

The spatial distribution of MVCs is strongly correlated with proximity to areas that burned sometime over the last 25 years (Fig. 8). The mean distance of all observed MVCs from the nearest burn area is 8.8 km (std. dev. 1.9 km), while the mean distance of randomized collisions from a recent burn is 3-4 times that distance (26.2 km, std. dev. 3.8 km).

Distinct patterns exist in the relationship between MVC frequency and distance from a recent burn. The difference between observed and randomized collisions does not appear at <1 km from a burn area; instead observed and randomized collisions are similarly distributed (Fig. 6), statistically significant results appear at distances > 1 km. The majority of observed MVCs take place at distances between 5 km to 15 km from recently burned areas. For distances of 10 to 15 kilometers from a burn, significant departure from randomness occur in 12 out of 13 years. Observed MVCs are virtually absent at distances > 20 km. This is in sharp contrast to the randomized collisions where after 1000 trials, 63% of all simulated MVCs took place at a distance larger than 20 kilometers from a recently burned area.

The same type of Monte Carlo randomization is performed at roads where posted speeds limits are 55 mph. Mean distance of randomized collisions on those roads is 7.6 km (std. dev. 0.8 km). These results are very similar to the pattern of the observed MVCs. Randomized and observed collisions follow the same type of distribution between 5 to 15 km distance of wildland fire perimeters. Moreover, randomized and observed collisions are virtually absent at distances > 20 km from a burn site.
Figure 8: MVCs distance to recent wildland fires

Distribution of MVCs in relation to distance from recent wildland fires (wildfires less than 25 years ago). At medium distances (5km - 15km) observed MVCs occur more frequently compared to random collisions. At larger distances (> 20km) MVCs are absent. MVCs show a similar pattern when compared to random collisions when these collisions are solely randomized on roads with 55 mph speed limits.
Risk factors in MVCs

Generalized boosting analysis provides a ranking of the relative importance of analyzed variables (topographic, landcover, traffic statistics, distance to wildland fires) in influencing the likelihood of an MVC occurring. Five variables account for > 82% of the explanatory power in the boosted regression tree analysis (Table 2). Distance to the nearest recently burned area has the highest relative importance, with an estimated contribution of 32%. The posted speed limit explains around 22% of variability in the location of MVCs in the FNSB. Traffic volume ranks third, with a relative contribution of 11.5%, while land-cover type (“developed areas”, using the 100 meter buffer) contributed 10.5%. Finally, elevation ranked fifth, with a relative contribution of 6.1%. All other factors ranked <5%. The other 18% is contributed by a combination of 11 other variables.
Table 2: Relative importance of different variables

Relative importance of different variables influencing the probability of a MVC occurring based on general boosting modeling.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Relative contribution (%)</th>
<th>observed mean</th>
<th>randomized mean</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to recent burn (km)</td>
<td>32.1</td>
<td>8840.8</td>
<td>26187.6</td>
<td>0.001</td>
</tr>
<tr>
<td>Posted Speed Limit (Mph)</td>
<td>22.0</td>
<td>51.8</td>
<td>44.4</td>
<td>0.999</td>
</tr>
<tr>
<td>Traffic Volume (AADT)</td>
<td>11.5</td>
<td>4078.6</td>
<td>2673.8</td>
<td>0.998</td>
</tr>
<tr>
<td>Land cover, developed low intensity (% in 100 meter buffer)</td>
<td>10.5</td>
<td>40.8</td>
<td>27.9</td>
<td>0.999</td>
</tr>
<tr>
<td>Elevation (meters above sea level)</td>
<td>6.1</td>
<td>199.9</td>
<td>244.5</td>
<td>0.001</td>
</tr>
<tr>
<td>Road density (km/km²)</td>
<td>4.9</td>
<td>5.3</td>
<td>5.5</td>
<td>0.329</td>
</tr>
<tr>
<td>Slope (degrees angle)</td>
<td>3.4</td>
<td>4.7</td>
<td>6.9</td>
<td>0.003</td>
</tr>
<tr>
<td>Land cover, developed open space (% in 100 meter buffer)</td>
<td>2.5</td>
<td>9.0</td>
<td>10.6</td>
<td>0.215</td>
</tr>
</tbody>
</table>
DISCUSSION

Diurnal and seasonal patterns

Moose vehicle collisions are not randomly distributed over the course of a day in the Fairbanks North Star Borough. One of the most striking features of MVCs is their concentration just after sunset in autumn, winter, and spring, which is similar to the situation in Finland (Haikonen & Summala, 2001). The cause for this crepuscular peak in collisions relates to an unfortunate intersection between the behaviors and sensory capabilities of moose and those of humans. Moose are typically most active just after sunset (Cederlund, 1989; Fliflet, 2012), and human vision is notoriously poor around the same time of day. During September, when daylight rapidly decreases and there is no reflectance from snow cover, moose standing against vegetation alongside the road are very difficult to see for drivers. In conjunction with the heightened activity of moose around dusk, this poor visibility is probably why MVCs occur most frequently in the first few hours after sunset.

Seasonal variation in MVC frequency shows no correlation with snow depth. This in contrast to the situation in other regions like the Kenai Peninsula in Alaska (Del Frate & Spraker, 1991) where winter snow packs typically reach greater depths than they do in the FNSB. The total depth of the snow pack in Interior Alaska rarely exceeds 70 cm, which in other areas is thought to be the threshold at which moose start using roads as travel corridors (Child, 1997).

Multi-year trends in MVCs

Unlike wildlife-vehicle collisions in many other parts of the world (Found & Boyce, 2011; Huijser et al., 2008; Groot Bruinderink & Hazebroek, 1996), MVC frequency in the FNSB has decreased since 2000 (Fig. 2). The decline of MVCs could be attributed to purposeful increase of
hunting pressure around the urban core of Fairbanks, regulated by ADF&G, aimed at reducing numbers of nuisance moose (Young, Donald (area biologist Alaska Department of Fish & Game) & Hollis, Tony (area biologist Alaska Department of Fish & Game), personal communication, August 5, 2016). Unfortunately, it is difficult to relate moose population to MVC frequency for two reasons. First, the accuracy of moose population estimates size is problematic. The Alaska Department of Fish and Game estimates moose numbers each fall (Young, Donald (area biologist Alaska Department of Fish & Game) & Hollis, Tony (area biologist Alaska Department of Fish & Game), personal communication, August 5, 2016), but the census area does not exactly overlap with the area of the FNSB. In addition, the estimate gives a total number, and does not provide insight into locations where large numbers of moose were counted, for example favorable moose habitat areas.

The second difficulty with comparing MVC numbers to moose numbers arises from the under-reporting of MVCs. The error bars in the MVC data in figure 2 show a 15% error margin based on estimates of underreporting in the Anchorage municipal area (Garrett & Conway, 1999). Estimates from other areas suggest even larger rates of under-reporting of wildlife collisions, ranging from 50% (Marcoux & Riley, 2010) and above (Child, Barry, & Aitken, 1991). More detailed data on both moose population size and concentration and MVC occurrence are needed to obtain better insights into their relationship.

**Spatial patterns**

The spatial distribution of MVCs in the FNSB is strongly influenced by five factors: distance to recently burned areas, posted speed limits, distribution of “low intensity developed
areas”, traffic volume, and elevation. These five variables account for > 80% of the contributions of all the spatial variables assessed.

One of the strongest determinants of MVC risk is the distance to a recent wildland fire. The mean distance of observed MVCs from an area that burned within the last 25 years is < 9 km, while most of the randomly simulated collisions occur at a distance > 26 km (Fig. 8). There is more to the story though because the correlation between MVCs and distance from a recent fire shows a similar distribution pattern on roads where posted speed limits are 55 mph. More research is necessary to determine which factor; speed or burn, is the most important one. The reason why MVC risk is greatest on roads near recent burns is probably that moose population numbers are higher in these areas. They contain the abundant forage moose prefer, including saplings of willow, aspen, poplar, and birch in addition to abundant herbaceous vegetation (Peek, 1997). The reason the proximity to a recent burn is only a significant risk factor if you are driving on a road with a high-speed limit is probably the simple consequence of reduced reaction time for drivers combined with more moose on the roadway.

**MVCs and traffic parameters**

The mean posted speed limit is more than 14% higher at observed MVC sites than it is at locations of simulated collisions. The majority (63%) of observed MVCs occur on roads with a speed limit of 55 mph (figure 5). Here, observed MVCs occur almost twice as much when compared to randomized collisions. There are several possible explanations for this pattern. First, most roads with speed limits of 55 mph are located outside the more intensely developed
areas: in places where moose are most abundant. Second, the faster the vehicle is moving, the shorter the time the driver has to react to the presence of an animal on the road.

In regard to speed limits and MVCs, it is interesting to compare traffic parameters in the FNSB with other parts of the world. Mean posted speed limits are 73 km/h in Edmonton, Alberta (Ng, Nielson, & Clair, 2008), 80 km/hr in Maine (Danks & Porter, 2010), and 90 km/hr in Sweden (Seiler, 2005). These findings show a similar relationship between speed limits and MVC distribution as found in the FNSB (88.5 Km/h).

Results show no statistical significance of MVC distribution at speed zones of 65 mph. At this speed limit, percentage of observed collisions is close to the percentage of randomized collisions. This low statistical significance at 65 mph roads could be explained by the barrier effect (Danks & Porter, 2010; Seiler, 2005): increased vehicle noise and in some cases heavier traffic volume deter moose from crossing the road.

The analysis also indicates that higher traffic volume does not necessarily increase the number of MVCs (Fig. 6). This may be because high traffic volume causes a barrier effect similar to that of higher speed limits (Grilo, Ferreira, & Revilla, 2015; Huijser et al., 2008; Seiler, 2004).

MVCs rarely occur on roads that have low posted speed limits (<= 35 mph). Out of 1074 collisions, only 24 took place at roads with a posted speed limit of 35 mph or less. Low speed limits probably allow drivers to notice moose on the road and provides more time for evasive action by both moose and driver. Furthermore, most of these low-speed roads are located in highly developed areas, which contain less suitable moose habitat, more domestic dogs, and are therefore overall less attractive to moose.
Landscape characteristics and MVCs

Landscape characteristics like land-cover types play a surprisingly minor role in the distribution of MVCs within the FNSB. Occurrence of MVCs in forested areas is much lower for observed collisions when compared to randomized trials. This is a surprising finding because forested areas may contain areas of preferred moose habitat. Interestingly, similar findings are reported for deer collisions in Minnesota (Nielsen, Anderson, & Grund, 2003).

Another low contributing landscape characteristic are low-intensity developed areas. Developed low-intensity areas are characterized by a mixture of cleared, open spaces and forested areas, which provides a favorable habitat to moose. Fairbanks is a sprawling urban area (Lopez, 2014) that contains large areas of low-intensity, developed areas surrounding a fairly small, more intensely developed, urban core.

High and medium developed areas in the FNSB have very few MVCs compared to randomized collisions. These high and medium developed areas are located in the urban core of Fairbanks. Moose usually tend to avoid this urban core, which is similar to other findings of wildlife-vehicle collisions in other urban areas (Found & Boyce, 2011; Ng et al., 2008; Nielsen et al., 2003).

The virtual absence of MVCs in the urban core of the FNSB also becomes obvious when comparing MVC frequency to road density. As road densities increase over 16 km/km², MVCs become less frequent. These findings parallel observations in Edmonton, Alberta, where vehicle-deer collisions are most frequent in areas with low road densities (Found & Boyce, 2011; Ng et al., 2008).
The absence of MVCs in the urban core of Fairbanks is also noticeable when looking at elevation. The number MVCs tends to be higher at moderate elevations (150 masl to 250 masl) (Fig. 7). These higher elevations are largely located outside the urban core of Fairbanks, in places where development intensity is usually lower.

**Mitigating MVCs in the FNSB**

Based on the spatial and temporal patterns of MVCs in the FNSB, several steps can be taken to reduce their occurrence. Reducing speed limits to 40 mph during hours of darkness in winter would significantly reduce the incidence of MVCs (Joyce & Mahoney, 2001). Implementation of such a step faces obvious challenges in terms of driver cooperation and law enforcement.

Another mitigation technique could be the implementation of dynamic seasonal signage (DSS). DSS are lighted warning signs that turn on at sunset or during particularly high-risky time of the year (Dussault, Poulin, Courtois, & Ouellet, 2006). The risk of MVCs is clearly highest during three months (September, December and January) just after sunset. Moose-warning signs with flashing LED lights that illuminate shortly after sunset will get motorists’ attention much more effectively than year-round signage (Hammond & Wade, 2004). Placement of DSS in the FNSB could be based on the MVC-hotspot map (Appendix 1). During summer, DDS might be activated near high-risk wetland areas or near recently burned areas that show peak collision-risk in summer.

Furthermore, fencing and wildlife-crossing structures should be considered at MVC hotspots. In other parts of the world where large ungulate–vehicle collisions are a problem, such fencing has proven to be a reliable option for reducing wildlife-vehicle collisions (Huijser et
al., 2008; McDonald, 1991; Seiler, 2005). Crossing structures would consist of road-parallel fencing with occasional openings in designated crossing spots. Crossing gaps would have warning lights triggered by heat-sensitive sensors activated when moose approach. Wildlife overpasses/underpasses, which have proven utility in other countries (Huijser et al., 2009) are probably too expensive to consider in the FNSB.

Additionally, improved urban planning, specifically roadway planning, can significantly reduce MVCs (Barnes, Morgan, Roberge, & Lowe, 2001). Concentrating development near the urban core reduces urban sprawl, resulting in less traffic volume in low intensity developed areas. Reduction of the urban sprawl could reduce the urban wildlife interface where moose and other wildlife encounter people in vehicles.

Finally, reducing the moose population in the FNSB can decrease MVC occurrence. Moose culling can be accomplished by lengthening the hunting season, easing restrictions on the sex and age of the animals killed, and broadening the variety of weapons hunters are allowed to use.
REFERENCES CITED


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Appendix 1: MVC hotspot map of the FNSB