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Temporal variation of moose–vehicle collisions in Alaska

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Abstract: Collisions between vehicles and wildlife have long been recognized to pose threats to motorists and wildlife populations. In addition to the risk of injury or mortality faced by the motorists involved in wildlife-vehicle collisions (WVCs), other drivers are also put at risk due to road obstructions and traffic congestions associated with WVCs. Most WVCs in Alaska involve moose (*Alces alces*), an animal that is sufficiently large to pose a threat to property and human life when involved in collisions. We analyzed the temporal variation in the number of moose–vehicle collisions (MVCs) reported in the 4 most populous boroughs of Alaska, USA from 2000–2012. We examined daily and annual trends in MVC rates and compared them to moose and human behavioral patterns to better understand possible mitigation strategies. The distribution of MVCs was skewed toward winter and hours of the day with less visibility. Fifty percent of the MVCs reported from 2000–2012 occurred where the commuter rush hours overlapped with dusk and dawn in winter. Knowledge of these temporal patterns can provide managers with practical mitigation options, such as the use of seasonal speed reduction, improved lighting strategies, dynamic signage, or partnerships with mobile mapping services.

Key words: Alaska, *Alces alces*, deer–vehicle collision, human–wildlife conflict, mitigation, moose, moose–vehicle collision, ungulate, urbanization, wildlife–vehicle collision

Wildlife–vehicle collisions (WVCs) are a consequence of human population growth and urbanization. Although WVCs have occurred since the introduction of motorized vehicles, the WVC rate has increased geometrically with increasing traffic volumes and speeds (Conover et al. 1995). Contemporary WVCs place motorists and wildlife at increased risk of mortalities and injuries. If WVCs are not sufficiently mitigated, we should expect the risks to motorists to increase as urbanization continues. These increased risks subsequently reduce the cultural carrying capacity of the wildlife population (Kilpatrick and LaBonte 2003, Siemer et al. 2013).

Studies in Canada and the northeastern United States have documented seasonal variation in WVCs involving moose (*Alces alces*; Joyce and Mahoney 2001, Danks and Porter 2010). In Norway and Canada, the seasonal change in snow depth and temperature predicted fluctuations in moose–train collision (MTC) and moose–vehicle collision (MVC) patterns (Gunderson and Andreassen 1998, Dussault et al. 2006, Rolandsen et al. 2011). Krauze-Gryz et al. (2017) and Niemi et al. (2013) linked the life-cycle strategies of moose to the seasonal variation in MTCs in Poland and MVCs in Finland.

Temporal patterns of MVC reports likely reflect the seasonal constriction of the distribution of moose to areas where roads are more common, but little empirical evidence of such a trend exists to support this assumption in Alaska, USA. For example, in Alaska, more MVCs occur between November and February than in all other months combined (Del Frate and Spraker 1991). In south-central Alaska, moose typically cluster at lower elevations during the winter months as the snow depth in the mountains increases, thereby increasing moose population density in valleys (Ballard and Whitman 1988, Prichard et al. 2013). Because valleys are also areas of urban sprawl, this seasonal variation in moose population density near roads should be reflected in the pattern of MVCs throughout the year (U.S. Census Bureau 2010). In a 31-year study in Norway, Rolandsen et al. (2011) found

Figure 1. Female moose (*Alces alces*) staring at oncoming traffic after successfully crossing Palmer-Fishhook Road with her calf on September 30, 2016 near Fishhook, Alaska, USA.

the density of moose populations to be the most important factor explaining the variation in MVCs, and Dussault et al. (2006) and Seiler (2005) used moose population density to explain the variation in MVCs in Canada and Sweden.

Both traffic flow and moose activity peak daily in a bimodal crepuscular pattern, so the daily pattern of MVCs should reflect this difference, especially during the darkest months of the year (Steiner et al. 2014). Dussault et al. (2006) found that probability of MVCs in Canada increased 2–3 times higher at night. Similarly, Gunderson and Andreassen (1998) in Norway and Joyce and Mahoney (2001) in Newfoundland reported MTC and MVC frequency to be highest between dusk and dawn.

Based on Alaska Department of Transportation and Public Facilities (ADOTPF) unpublished data, moose are the most common species involved in reported WVCs in Alaska (Figure 1). Between 2000 and 2012, ADOTPF documented 9,949 MVCs in the state (ADOTPF, unpublished data). These MVCs resulted in 23 human fatalities, 118 incapacitating injuries, and approximately 1,400 minor injuries (ADOTPF, unpublished data). The ADOTPF estimated that $33,000 is lost every time an MVC occurs in the state.

The objective of our research was to delineate temporal trends in MVCs across Alaska to assist managers in developing potential MVC mitigation strategies. We expected past MVC reports to be clustered at times of the day or year when moose were expected to be more active (i.e., during dusk and dawn) or be in closer proximity to roads (i.e., winter) and vehicular traffic was expected to be high (i.e., during commuter rush hours and during summer). Due to the overlap of commuter traffic intensity and crepuscular moose activity during winter, we expected MVC reports to be temporally clustered in the mornings and evenings of winter.

Study area

We conducted our study within 4 Alaskan boroughs: the Municipality of Anchorage (ANC), the Fairbanks-North Star Borough (FNB), the Kenai Peninsula Borough (KPB), and the Matanuska-Susitna Borough (MSB). The ANC, KPB, and MSB are situated within south-central Alaska within 58.6-63.5°N latitude and 146.4-154.7°W longitude. Topography within the ANC, KPB, and MSB ranges from sea level to a respective peak of 2,441, 3,480, and 4,443 m above sea level. The FNB is situated within interior Alaska between 64.2-65.5°N latitude and 143.8-148.7°W longitude and encompasses a range of elevations between 83 and 1788 m above sea level.

Between 2000 and 2012, the mean annual temperature was 3°C in south-central Alaska where the temperature oscillated from -26°C in winter to 24°C in summer (National Oceanic and Atmospheric Administration [NOAA] 2012). Mean annual precipitation ranged from 32–55 cm between 2000 and 2012, while mean annual snowfall ranged from 93–342 cm. The mean annual temperature was -2°C in interior Alaska where the temperature ranged from -42°C in winter to 24°C in summer (NOAA 2012). Mean annual precipitation ranged from 21–35 cm between 2000 and 2012, while mean annual snowfall ranged from 63–197 cm.

These boroughs were chosen because they represent the majority of the human population (82%) and the majority of the MVCs (88%) reported in Alaska during the study period between 2000 and 2012. As of the 2010 census, the most populous area of the state was the ANC, which accounted for 41% of the 700,000 residents of Alaska. In the FNB, KPB, and MSB, the human populations were

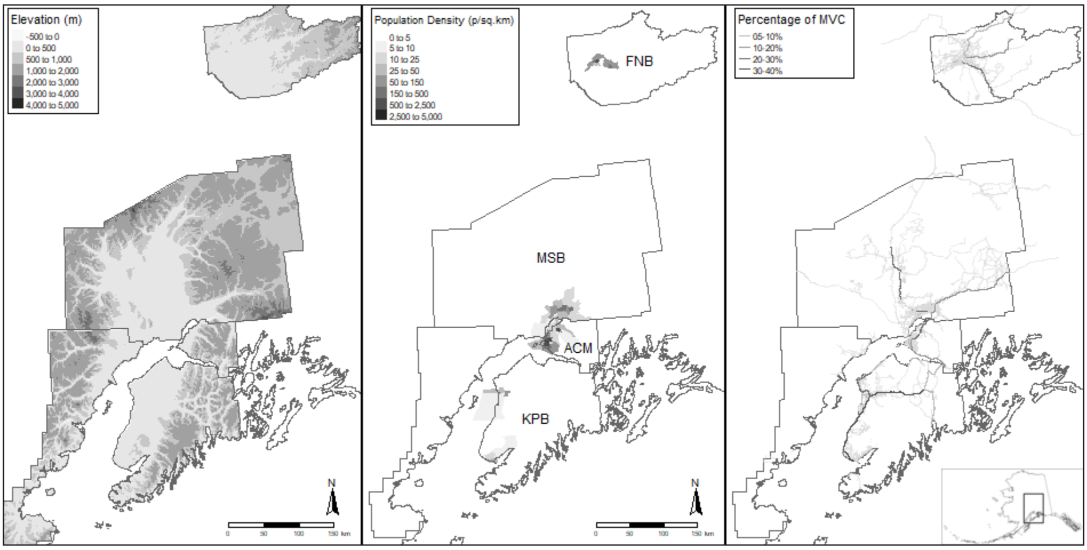

Figure 2. Map of study areas including elevation, population density, and percent of moose–vehicle collisions (*Alces alces*; MVC) on the road system within 4 Alaskan boroughs: the Municipality of Anchorage (ANC), the Fairbanks-North Star Borough (FNB), the Kenai Peninsula Borough (KPB), and the Matanuska-Susitna Borough (MSB), Alaska, USA, 2000–2012.

Figure 3. A patchwork of houses and mixed coniferous-deciduous wooded areas, which is a typical view from above in semi-urban areas of the Matanuska-Susitna borough. Photograph taken on July 9, 2016 from a biplane above the Fishhook community near Palmer, Alaska, USA.

highly concentrated into a small portion of their respective borough (Figures 2 and 3). The proportion of human population, change in population between the 2000 and 2010 census, area of the borough, reported moose density, and average artificial light reflectance on the road system are listed alongside the proportion of MVCs reported for each borough in Table 1. Within each borough, a large share of the reported MVCs in each borough occurred on a state highway, and only 6 local roads accounted for >5% of the MVCs in a given borough (Figure 2). Because the boroughs accounted for large areas of the state, ambient light conditions could differ among boroughs depending upon the time of year. The KPB is at much lower latitude than the FNB, so the hours of sunlight per day differ by as much as 2 hours in the winter.

Methods

Each time an MVC was reported by a driver within the state of Alaska, a law enforcement officer filed a report on the incident, which included information on the date, time, and location, by referencing the nearest intersection, as well as descriptive variables such as the number and type of injuries, number of animals, and number of vehicles involved. To facilitate this research, we accessed the statewide database of MVC reports compiled

Table 1. Summary table comparing the population, area, moose (*Alces alces*) density, artificial light reflectance on the road system, and daily vehicle miles traveled (DVMT) on the interstate highways in 4 Alaskan boroughs: the Municipality of Anchorage (ANC), the Fairbanks-North Star Borough (FNB), the Kenai Peninsula Borough (KPB), and the Matanuska-Susitna Borough (MSB), Alaska, USA, 2000–2012.

Borough	Proportion of Alaskan population (%)	Change in population between 2000 and 2010 (%)	Area (km^2)	Moose density (moose/km^2)	Artificial light reflectance on road system[6] (%)	DVMT (in thousands)	Proportion of reported MVCs (%)
ANC	41	+0.12	5,083	0.35±0.00 [1,2]	62.4	2,082	21
FNB	14	+0.18	19,280	0.53±0.07 [3]	15.5	550	14
KPB	13	+0.19	64,107	0.34±0.08 [4]	4.4	898	27
MSB	13	+0.50	65,418	0.62±0.08 [5]	4.4	481	27

[1] This estimate was reported throughout the time frame of this study. Deviation reflects change in upper and lower bounds of estimated moose density between management reports.
[2] Game Management Unit (GMU) 14C (Alaska Department of Fish and Game [ADFG] 2002–2014)
[3] GMU 20C (ADFG 2002–2014)
[4] GMU 15 (ADFG 2002–2014)
[5] GMU 14A/14B (ADFG 2002–2014)
[6] Extracted from 2012 VIIRS image to geospatial dataset representing the Alaskan road system and averaged based on borough (Elvidge et al. 2017)

from 2000 to 2012 by ADOTPF (2012). We filtered the MVC report data using Program R (R Core Team 2018), with the package Tidyverse (Wickham 2017), to only include the ANC, FNB, KPB, and MSB observations without missing accident date/time information and removed variables that were not relevant to the analysis. The resulting data table consisted of 8,794 observations described by accident date/time and borough.

Using the accident date/time variable, we created variables classifying each observation by the hour of the day, day of the week, ordinal day of the year, year, and a seasonal factor representing a period of the annual life cycle outlined for moose by Ballard and Whitman (1988). We also used the accident date/time and the centroid of each borough to classify each observation with the approximate sunrise, sunset, and sun altitude, the position of the sun in relation to the horizon, using Program R with the package Suncalc (Agafonkin and Thieurmel 2018).

Because moose activity was expected to increase during dusk and dawn, we used the sun altitude variable to categorize each observation as night, dawn, day, or dusk. Based on the astronomical definition of twilight, we defined night as a sun altitude below -18 degrees and day as a sun altitude above zero degrees. We defined dusk and dawn as a sun altitude between -18 and zero degrees and separated dawn and dusk based on the hour of the day. To evaluate whether the mean frequency of MVCs per hour was greater during dawn and dusk than day and night and whether the seasonal difference in lighting affects these differences, we performed Welch 2-sample *t*-tests on 8 subsets of the data. We filtered the observations to only include dusk or dawn, night or day, and winter or summer observations and compared the mean frequency of MVCs per hour between the 2 pairs of time groupings (e.g., winter, dusk > day or summer, dusk > day).

Finally, we used the accident date/time variable from the original 8,794 observations to create a time of the day variable standardized by hour (i.e., 0830 would be 8.5). This hour of the day variable was then plotted against the day of the year following the same procedure typically used to compute a kernel density surface of spatial data using Program R, with the package Ks (Krauze-Gryz et al. 2017, Duong 2018). We computed contours representing the smallest area that represented each quantile of the data to quantify the temporal clustering of reported MVCs in each borough. By plotting these contours, we were able to visualize the intersection between peaks in MVCs per day and peaks in MVCs per hour throughout the year and compare them to the life cycle periods of moose in Alaska (Ballard and Whitman 1988).

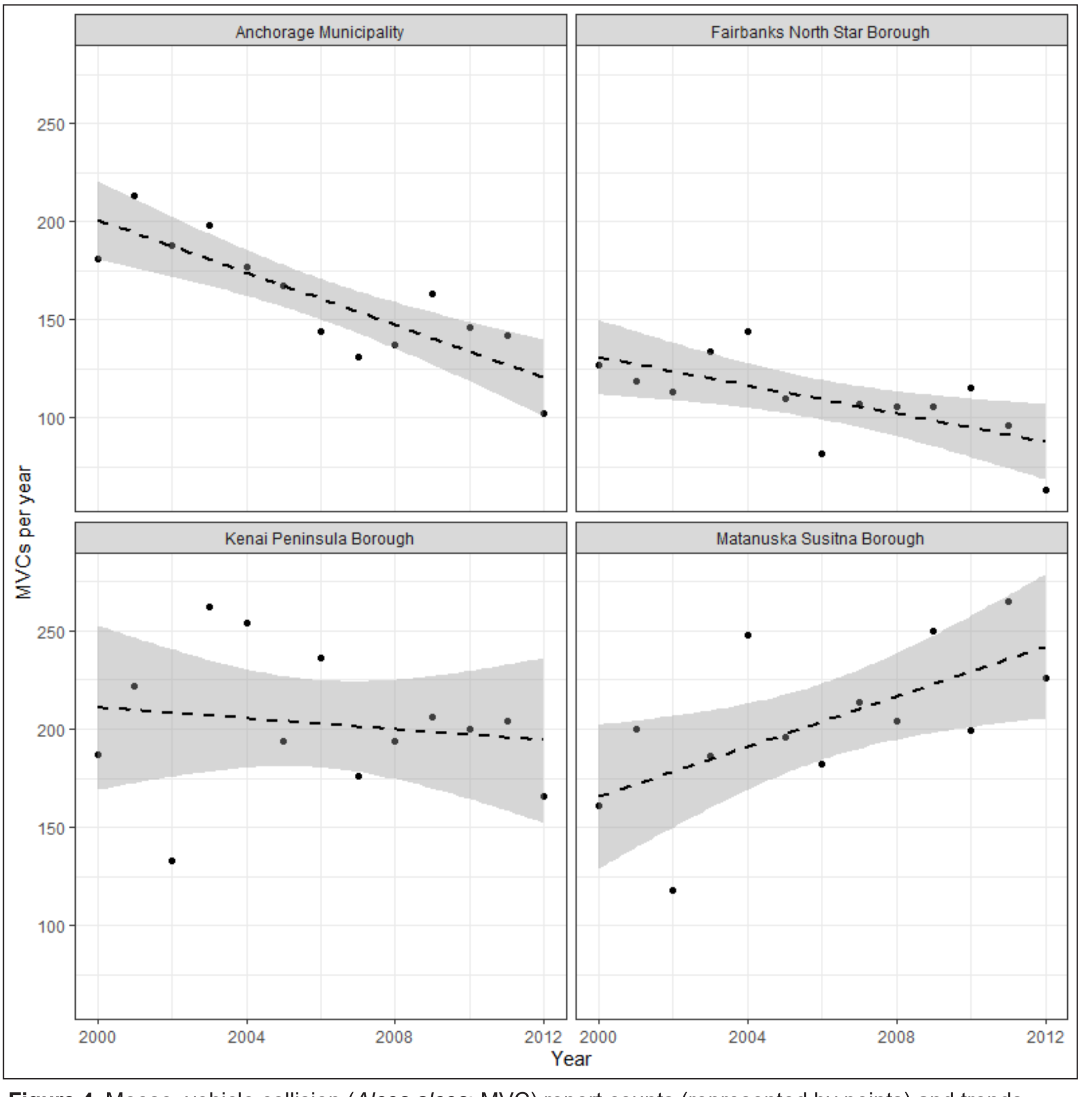

Figure 4. Moose–vehicle collision (*Alces alces*; MVC) report counts (represented by points) and trends (represented by dotted lines) between 2000 and 2012 in the 4 most populated areas of Alaska, USA. The shaded area indicates a 95% confidence interval.

Results

Within our study areas, 48.2% of MVCs were reported when moose were expected to be in their winter range, and 58.1% of MVCs were reported between 1700 hours and midnight. Further, only 30% of MVCs were reported on weekends or holidays, and only 19% of MVCs were reported during daylight hours. The KPB and MSB accounted for most of the reported MVCs in the state, followed by the ANC and FNB (Table 1). Between 2000 and 2012, annual MVC counts trended downward in the ANC and FNB while trending upward in the MSB, but counts of MVCs were highly variable among years in the KPB (Figure 4). The distribution of MVCs throughout the day skewed away from noon, and half of all MVCs in the state occurred between the hours of 1700 and midnight (Figure 5). Daily reports of MVCs were highest during fall and winter in the KPB and MSB, while the number of daily MVC reports in the ANC and FNB were nearly the same year-round (Figure 6).

During winter, the mean frequency of MVCs per hour was greater at dusk than at day (t = 8.020, df = 104.1, P < 0.001) and at night (t =

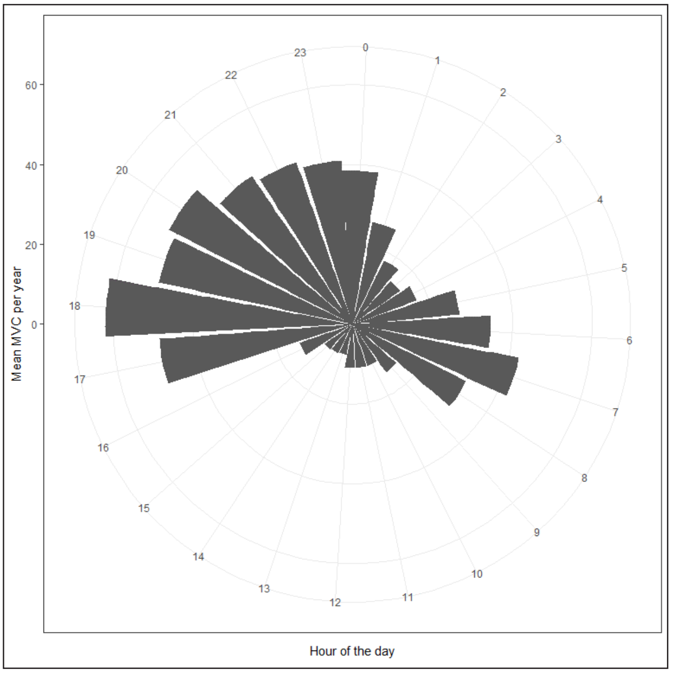

Figure 5. The distribution of moose–vehicle collisions (*Alces alces*; MVC) reported between 2000 and 2012 in 4 boroughs of Alaska, USA. The MVC frequency is categorized by the hour of the day from midnight (0) to 2300 hours (23), the year, and the average count of MVC per hour is presented.

2.097, df = 121.9, $P = 0.019$) and greater at dawn than at day ($t = 6.677$, df = 89.6, $P < 0.001$), but the mean frequency of MVCs per hour was less at dawn than at night ($t = -2.480$, df = 129.63, $P = 0.007$). During summer, the mean frequency of MVCs per hour was greater at dusk than at day ($t = 8.245$, df = 41.9, $P < 0.001$) and at night ($t = 10.080$, df = 41.7, $P < 0.001$), and greater at dawn than at day ($t = 7.388$, df = 117.8, $P < 0.001$) and at night ($t = 11.363$, df =112.2, $P < 0.001$).

Using kernel density estimation, we were able to quantify the intersection between daily and annual peaks in MVC frequency using a point pattern of time of the day plotted against day of the year for each observation. Fifty percent of all MVC observations were isolated to 20.3% of the temporal density surface within the ANC, 17.8% of the temporal density surface in the FNB, 13.3% of the temporal density surface in the KPB, and 13.6% of the temporal density surface in the MSB (Figure 7). These concentrations are represented by contours that demonstrated that MVC observations were densely clustered near dawn and dusk during fall and winter (Figure 8).

Discussion

The temporal distribution of MVCs in our study areas reflected daily and seasonal fluctuations in expected moose behavior and traffic flow. As moose migrated to lower elevations in winter, they became more likely to encounter highly trafficked roads. The concentration of wintering moose corresponded with decreased visibility due to increasingly dark days, especially during the commuter rush hours near dusk and dawn. Krauze-Gryz et al. (2017) reported similar seasonal peaks in wildlife–train collisions near dusk and dawn, which is a commonly reported phenomenon among animal–vehicle collision studies (Haikonen and Summala 2001, Smith and Dodd 2003, Danks and Porter 2010, Chen and Wu 2014, Bartonicka et al. 2018). Delineating the specific corridors used for this seasonal movement will be crucial to further the study of MVCs in these areas of Alaska.

During the winter solstice in Alaska, sunrise is between 1000 and 1100 hours and sunset is between 1500 and 1600 hours, depending upon the latitude, yet sunlight is available past midnight during the summer solstice. These changing light conditions throughout the year cause dusk and dawn to overlap the morning and evening commuter rush hours during winter, but keep the commuter rush hours during summer completely lit by ambient light. Concurrently, these populations of moose are expected to constrict their range to lower elevations, increasing the likelihood that motorists come into contact with moose during the winter (Ballard and Whitman 1988, McDonald 1991). During winter, the rate of MVCs per hour was greater at dusk than at night, but the rate of MVCs per hour was less at dawn than at night. In a study focused on the general timing of traffic accidents, Akerstedt et al. (2001) reported that late afternoon and nighttime accidents have a more pronounced peak than early morning accidents due to a variety of factors including visibility, intoxication, impatience that leads to speeding, and drowsiness. Additionally, the

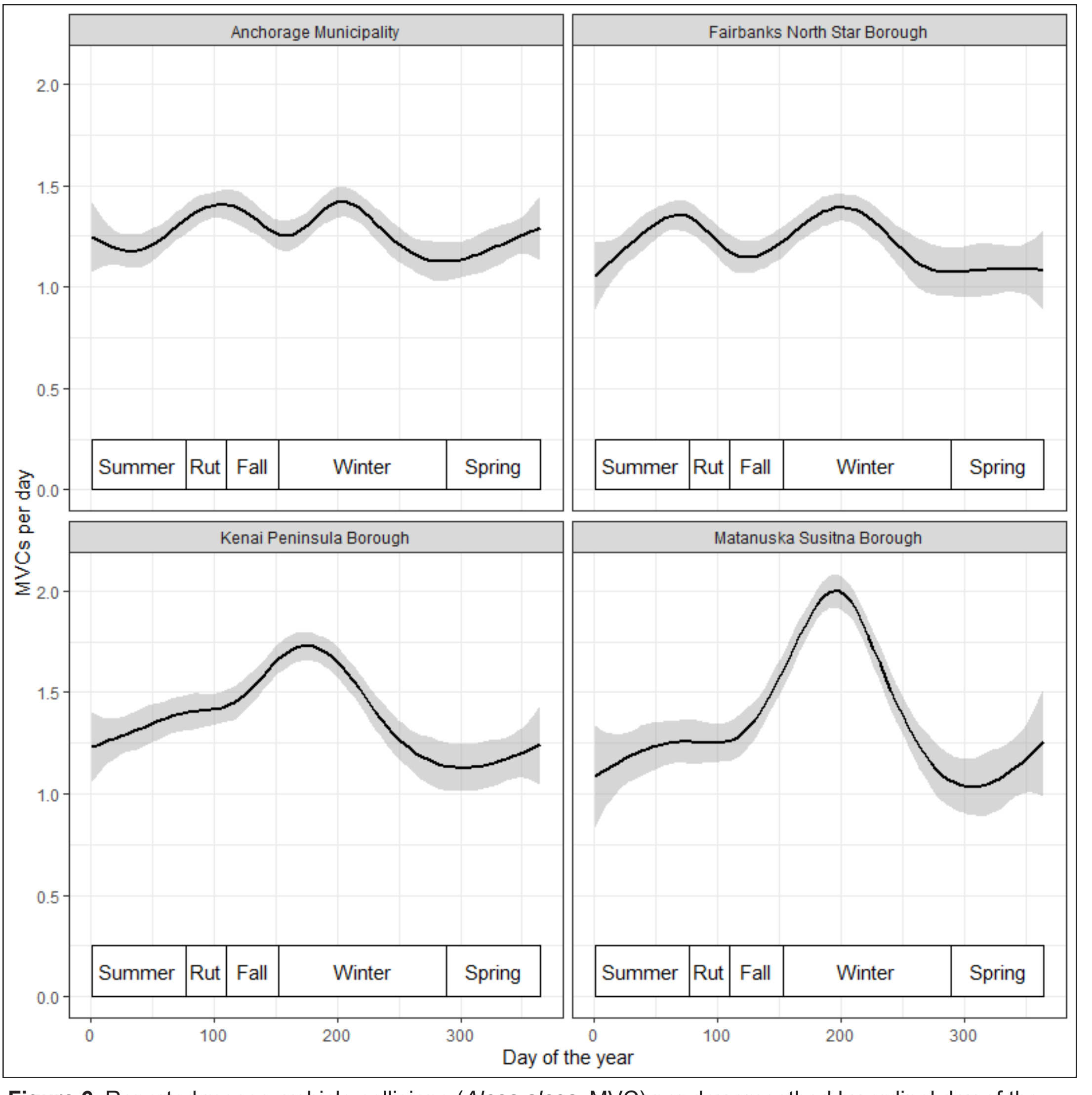

Figure 6. Reported moose–vehicle collisions (*Alces alces*; MVC) per day smoothed by ordinal day of the year, Alaska, USA, 2000–2012. The x-axis is scaled to start the year at July 1 to emphasize the winter peak in MVC rates. The moose life history periods documented by Ballard and Whitman (1988) are labeled below each trend line. The shaded area indicates a 95% confidence interval.

increased prevalence of high-intensity halogen headlights may lead to lower visibility when traffic flow is high and ambient light is low. As nighttime in winter is especially hazardous due to weather and light conditions, the increase in moose activity at dawn may be overshadowed by the lack of visibility at night. The greater rate of MVCs per hour at dawn as opposed to at night in the summer may be more attributed to increased moose activity at dawn than visibility.

As seen from the kernel density contours (Figure 8), half of all reported MVCs in each borough occurred during the winter either just before sunrise or just after sunset. This temporal clustering may be attributed to artificial lighting. The ANC, being the most populous area, had the most artificial light reflectance measured on its road system, and simultaneously had the lowest MVC rate as a function of traffic among the 4 boroughs in this study. The FNB, which had the second highest amount of artificial light on its road system, was equal in population to the KPB and MSB, yet had far fewer MVCs as a function of traffic.

The relationship between the proportional size and the proportion of observations within each kernel density contour also reflects this difference (Figure 7). The contours of ANC

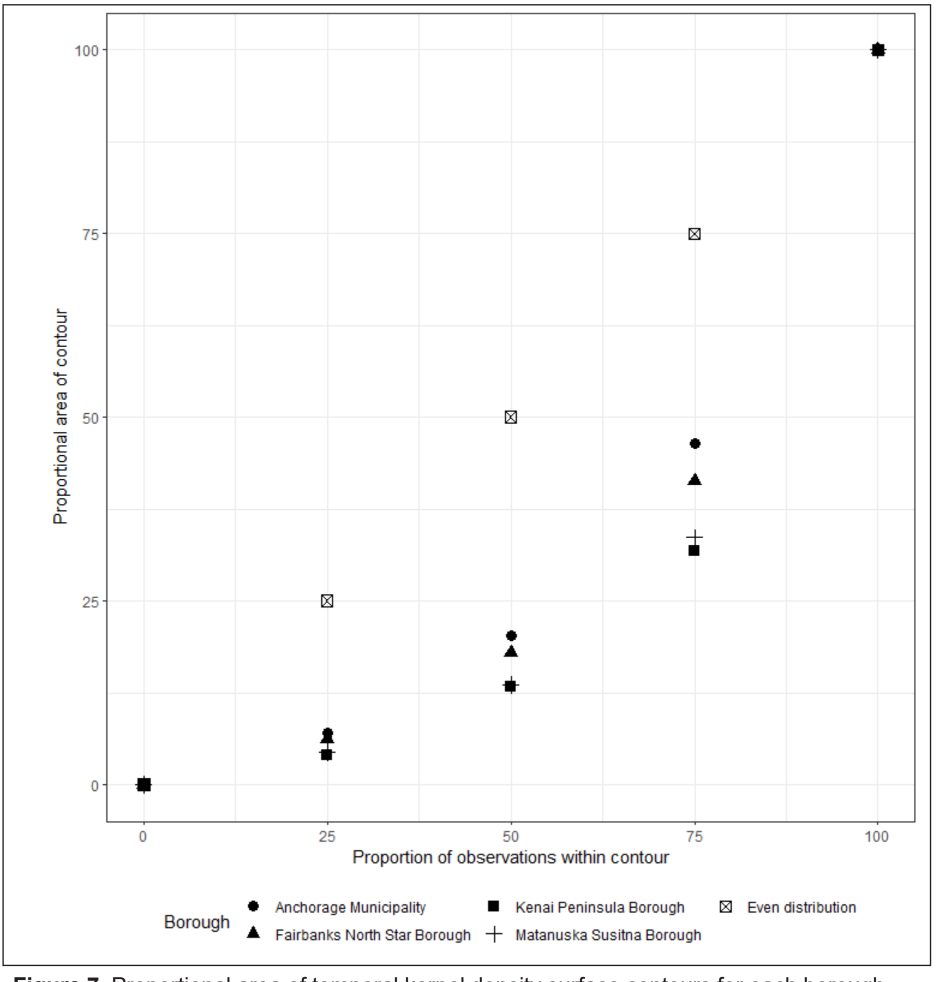

Figure 7. Proportional area of temporal kernel density surface contours for each borough at various levels compared to the expected proportional area of an evenly distributed surface. As the proportional area of the observations diverges from the proportion of observations associated with the contour, the observations within the kernel density surface are more clustered. The associated temporal density surfaces represent the intersection of the reported day of the year and time of day of moose–vehicle (*Alces alces*) collisions in Alaska, USA, 2000–2012.

and FNB show slightly less winter clustering than those constructed from the KPB and MSB observations. Conflicting results have been reported regarding the effects of artificial lighting on mitigating WVCs. Reed and Woodard (1981) found no evidence to support using artificial lighting to reduce deer–vehicle collisions in Colorado, USA, but McDonald (1991) found that artificial lighting led to a 65% decrease in MVCs on Alaska Highway 1. As a way to reduce overall light pollution and save costs, lighting structures can be strategically placed within areas of concentrated MVC risk and lit only during the winter rush hour when traffic levels and moose activity peak (Rolandsen et al. 2011, Gaston et al. 2014).

Permanent "safety corridors," designated lengths of the road system with reduced speed limits and higher safety fines, have reduced serious motor vehicle accidents within highly trafficked areas by 46% since their introduction to Alaska in 2006 (Kramer et al. 2017). The use of seasonal dynamic signage and seasonally reduced speed limits could provide a similar mitigation option for MVC hotspots throughout the state. Mastro et al. (2010) reported that motorists could not see deer decoys standing at the edge of the road until they were within 50 m of them. When driving >75 kph, this would be an inadequate braking time. The Alaska state highway system, on which 38% of the reported MVCs occurred, has speed limits

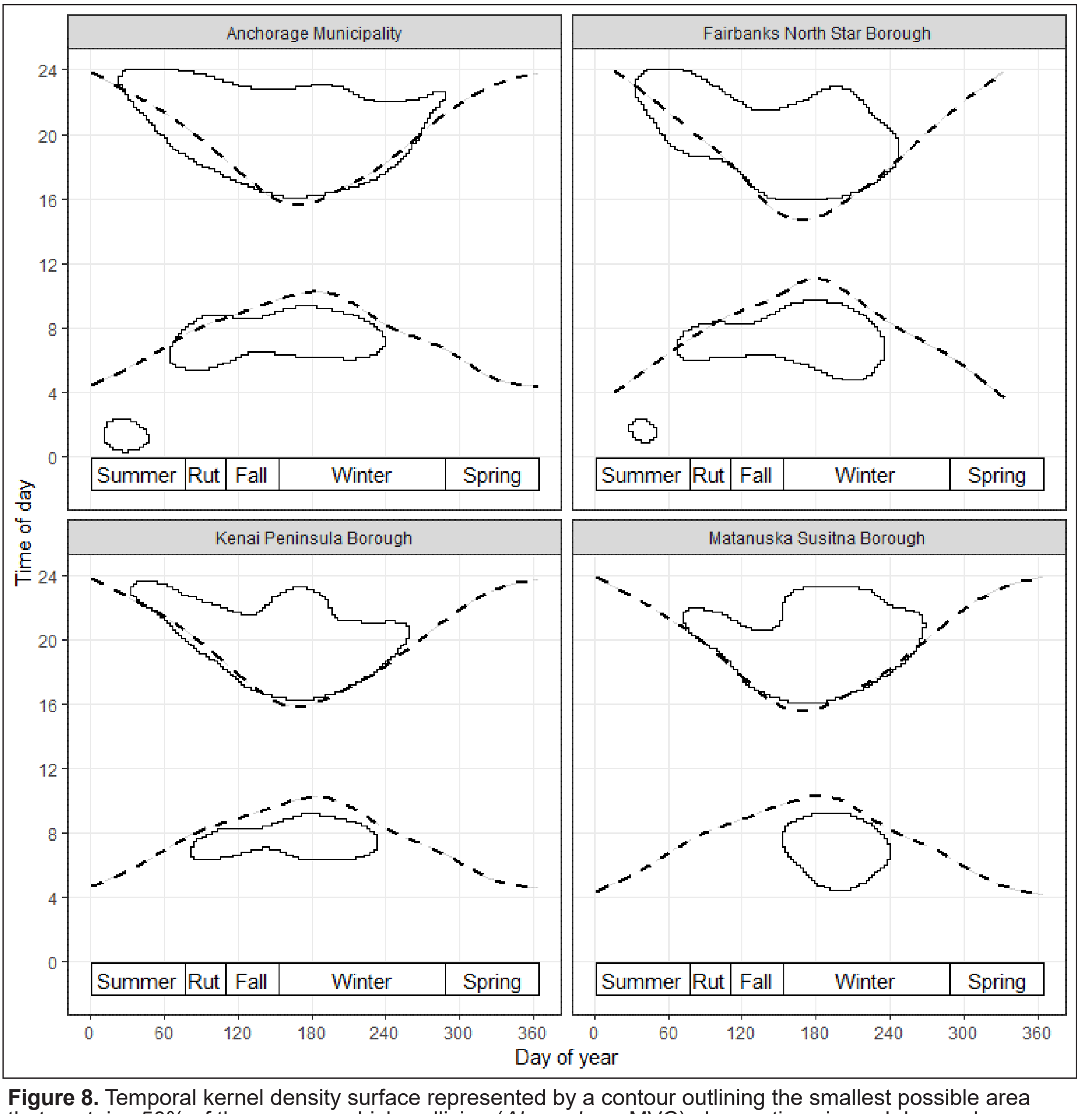

Figure 8. Temporal kernel density surface represented by a contour outlining the smallest possible area that contains 50% of the moose–vehicle collision (*Alces alces*; MVC) observations in each borough, Alaska, USA, 2000–2012. Sunrise and sunset times are demarcated with dashed lines to represent the changing day length and the timing of dusk and dawn.

that range from approximately 80–105 kph. Speeding fatalities accounted for 35–46% of all motor vehicle fatalities between 2005 and 2011, and 66% of surveyed drivers admitted to occasionally driving faster than 113 kph in a 106-kph speed zone (Kramer et al. 2012). A reduction of the speed limit to <75 kph during periods of high MVC threat could increase driver visibility and reduce braking time.

Sullivan et al. (2004) reported a 51% reduction in deer mortality when drivers, influenced by a seasonal signage treatment, followed the speed limit. Within the KPB and the MSB, dynamic signage, which is updated each month to show the number of MVCs that have occurred since July 1, has been implemented in the KPB and the MSB since the 1990s as part of a public awareness program to reduce MVCs (Del Frate and Spraker 1991). The use of strategically placed warning signs can keep drivers alert to the threat of MVCs, but drivers easily habituate to stationary signage (Figure 9). If new signage is implemented, it should include dynamic messaging or should be removed seasonally based on MVC threat to decrease habituation, and it should be paired with increased enforcement of speed limits (Sullivan et al. 2004, Hardy et al. 2006).

Figure 9. Stationary warning signage indicating moose (*Alces alces*) crossings southbound on the Parks Highway in the Matanuska-Susitna borough. Photograph taken while the authors were investigating a moose–vehicle collision site on October 11, 2018 near Houston, Alaska, USA.

As we have entered the information age, modernized alert systems could be implemented in mobile mapping services, such as Google or Apple maps, with the partnership of local government agencies. If these government agencies were to provide the mapping service with spatial and temporal MVC hotspots, an alert could be sent to drivers using the map application before they enter an area of high MVC probability, similar to the way map services warn drivers about upcoming traffic congestion. Further study is required to isolate the spatial extent of MVC hotspots within the state, but this mitigation option could be a promising alternative as more people adopt smartphones.

Our research provides insight into temporal patterns in MVC rates in Alaska that can be used to inform mitigation efforts. However, it is likely that many other factors influence MVC rates through both space and time. For example, differences in latitude and elevation gradients may lead to different behavioral adaptations than those documented by Ballard and Whitman (1988) for moose in south-central Alaska, especially in the moose population near FNB. Currently, in south-central Alaska, weather data is difficult to obtain due to the low number of working weather stations in the area. In future studies, weather patterns, especially snow depth patterns, should be explored as an index of moose population density, but this may require investment into increasing the number of weather stations in the area. In conjunction with artificial lighting, factors such as road geography, vegetation height, vegetation type, and weather may influence the driver's visibility as well as the moose's affinity for crossing at the site. Further study of Alaskan MVCs should focus on site-specific factors that lead to spatial and temporal hotspots.

Management implications

We were able to delineate the temporal distribution of MVCs within the state of Alaska and explain the daily and seasonal fluctuations using expected moose behavioral trends and traffic flow. This analysis could be replicated for any management unit that needs a preliminary assessment of possible WVC mitigation. Within the state of Alaska, the winter peaks in MVCs could be mitigated with dynamic or seasonal signage, seasonally decreasing speed limits, or with improved lighting strategies during the winter rush hour. Partnerships with mobile mapping services could become a promising alternative to seasonal mitigation practices.

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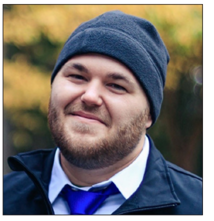

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