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Behaviours of moose at roadside mineral licks in British Columbia: Implications for moose-vehicle collisions

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ABSTRACT

Moose (*Alces americanus*) visit roadside mineral licks (RMLs; areas of roadside ditches where de-icing salts accumulate in spring) to obtain minerals that may be otherwise lacking in their diet. When moose use road corridors to access salts, they become hazards to motorists. Moose use of RMLs is dependent on season and time of day, but specific patterns of use and associated behaviours that may influence moose-vehicle collision risk are unknown. We used video-enabled camera traps, analysis of variance, and generalized additive mixed models to record, review, interpret, classify, and analyze the behaviours of adult moose between July 2012—July 2020 at five RMLs in north-central British Columbia. Monthly visitation rates to RMLs peaked in mid-summer which corresponds with the summer peak in moose-vehicle collisions in the study area. Bi-hourly visitation rates peaked at night. Vigilance and licking were the most common of many behaviours recorded. Cows with young spent the most time at RMLs, followed by bulls, then solitary cows. Proportion of time spent being vigilant peaked in May, licking peaked in June. Time spent licking was highest for bulls, followed by cows with young, then solitary cows. Research into complex and interacting factors such as traffic volume and flow, driver visibility and awareness of moose, and various methods for de-icing roads is further required to determine robust means of mitigating the risk of moose-vehicle collisions associated with RMLs.

1. Introduction

Moose (*Alces americanus*) are known to visit mineral licks throughout much of their distribution in North America (Fraser and Hristienko, 1981; Rea et al., 2004). These unique physiographic features are areas of high solute concentration and may be rare in some parts of the range (Fraser, 1980; BCMECCS, 2019) but can be vitally important as a mineral source for ungulates. Moose are thought to be attracted to mineral licks mostly due to the relatively high concentrations of sodium found in licks (Jordan et al., 1973; Fraser and Reardon, 1980), an element required for a suite of physiological processes including homeostasis, digestion (Chalyshev, 1998), reproduction and lactation (Timmermann and McNicol, 1988), and the growth and maintenance of antlers (Moen and Pastor, 1998).

Due to low concentrations of minerals in the winter diets of moose, a sodium hunger in the spring results in increased use of mineral licks during this time (Jordan et al., 1973; Fraser and Hristienko, 1981; Brochez et al., 2020). High concentrations of other essential nutrients such as iron, calcium, magnesium (Rea et al., 2013), and carbonates (Ayotte et al., 2006) are also likely to attract moose to mineral licks. Mineral supplementation can improve rumen function, which further enhances digestive ability, nutrient absorption, and overall body condition (Kreulen, 1985). Good body condition is important for overwintering survival and especially for cows during reproduction and lactation, and for bulls during the rut.

During winter, available browse items tend to be low in quality and high in fibre, providing a poor supply of minerals and resulting in dry feces (Ayotte et al., 2006). In spring, the annual leaf flush provides more abundant, higher quality browse that is lower in fibre (Ayotte et al., 2006), resulting in watery feces, which may not allow moose to effectively retain minerals (especially sodium). This appears to be connected to a drive by moose to seek out mineral licks (Jordan et al., 1973; Fraser, 1980). In later summer, moose incorporate aquatic vegetation into their diet that is relatively high in sodium. This results in a decreased need to use licks as summer progresses (Fraser and Hristienko, 1981).

Although mineral licks can form naturally and others are man-made to attract or divert the attention of animals (Abraham et al., 2023), licks can also be created from the incidental runoff and accumulation of road

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de-icing salts, such as sodium chloride (NaCl), applied to roads in winter (Fraser and Thomas, 1982; Hill et al., 2021; Rea et al., 2021). These types of licks, referred to here as roadside mineral licks (RMLs), form in slow-draining ditches alongside highways, where NaCl accumulates following spring runoff, making these areas highly attractive to moose (Fig. 1; Fraser and Thomas, 1982; Rea et al., 2021). Consequently, moose activity in and near RMLs can pose a serious threat to traffic along highways (Child et al., 1991; Leblond et al., 2007). Hundreds of moose-vehicle collisions (MVCs) occur annually in northern BC (O'Keefe and Rea, 2012), often where RMLs are found (Rea et al., 2014). These collisions result in both injuries and mortalities for motorists and moose, and in significant economic and societal costs (FWHA, 2008; Huijster et al., 2009; Danks and Porter, 2010).

Behaviours of moose may be the least well understood of all cervids in North America (Couturier and Barrette, 1988). Further, the specific behaviours exhibited by moose at RMLs have not been sufficiently explored (Filus, 2002; Silverberg et al., 2003), leaving a knowledge gap regarding how behaviours of moose in road corridors might influence the risk of MVCs. Most literature regarding moose behaviours around roads and RMLs are focused on activity patterns, rather than specific behaviours moose exhibit while visiting RMLs (Silverberg et al., 2002; Laurian et al., 2008a, b; Grosman et al., 2011; Eldegard et al., 2012; Laliberté and St-Laurent, 2020; Borowik et al., 2021). Understanding both the activity and specific behaviours of moose at RMLs will improve our understanding of what moose do while at RMLs, the implications of their behavior for road safety (Laliberté and St-Laurent, 2020), and in the development of MVC countermeasures (Laurian et al., 2008b).

Our goal was to record (with video-enabled camera traps), identify, describe, and classify the behaviours of adult moose at RMLs in north-central British Columbia (BC). We also investigated, by demographic class, daily and seasonal variations in visitation rates at RMLs, visit duration, and proportions of time spent in the most common behaviours with an aim at understanding how such behaviours may influence the risk of MVCs and how such risk might be mitigated.

2. Methods

2.1. Study area

We used camera traps to monitor five RML sites in north-central BC, Canada from July 2012–July 2020 (Supplementary Material 1; Fig. 2). The dominant biogeoclimatic zone in this area is the Sub-Boreal Spruce Zone (Meidinger and Pojar, 1991), with much of the landscape in this area impacted by commercial logging activities, wildfires, and outbreaks of mountain pine beetle (*Dendroctonus ponderosae*) over the past several decades (Kuzyk, 2016; Burton and Boulanger, 2018). Predominant overstory tree species include hybrid white spruce *(Picea engelmannii* x *glauca*) and subalpine fir (*Abies lasiocarpa*) in more mature sites, and lodgepole pine (*Pinus contorta* var. *latifolia*) and trembling aspen (*Populus tremuloides*) in younger sites (Meidinger and Pojar, 1991; Rea et al., 2021). The climate of the region has been described as humid continental, relatively wet and cool, with precipitation evenly distributed throughout the year (Meidinger and Pojar, 1991; Rea et al., 2021). The average daily temperature (most recent available data; 1981–2010) was 4.3°C, ranging from –7.9°C in January to 15.8°C in July (Government of Canada, 2016). Average annual precipitation was 595 mm, with the wettest months being June, October, and July. During the spring and summer months (May–August) when moose activity at RMLs is expected to be highest, the average daily temperature was 13.7°C and the average monthly precipitation was 57.0 mm (Government of Canada, 2016). The estimated density of moose in north-central BC ranges from 0.47–0.83 moose/km^2 (Scheideman and Anderson, 2021).

All cameras were set up at RMLs situated along primary and secondary highways where road de-icing salts are commonly used (Fig. 2). At the time of the study, these highways were undivided, rural, and had up to three lanes at a maximum speed of 100 km/h. Traffic volumes on the highways in our study area tend to peak between May and August (BC MoTI, 2012). The industrial de-icing agent used on highways in winter was raw, granular NaCl that is separated in rock form during the mining of potash. We described the terrain along highways in our study as level or rolling, with short mountainous stretches. Ditches that intercept road salt runoff where RMLs were located were generally 0.5–3.0 m deep, depending on terrain. RMLs were selected by driving highways and identifying muddy, trampled areas with upturned mineral soils and game trails (some transecting the highway) radiating away from the RML. These features were always situated in roadside areas where the roadside ditches were lower than surrounding lengths of ditches and where culverts contributed outflows from both sides of the highway. Features in this study varied in size of the exposed muddy areas used by moose from ~100–1000 m^2. RMLs remain wetted with standing water most of the year but can become dry in years with reduced precipitation. The vegetation surrounding the licks varied by site and biogeoclimatic zone but can be characterized generally as brushy due to vegetation management that occurs on a regular basis to

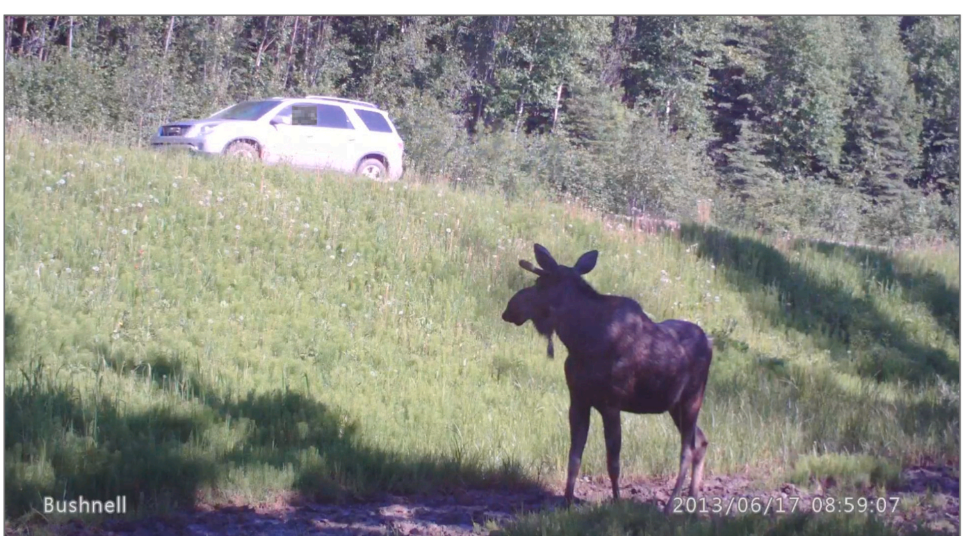

Fig. 1. Bull moose displaying vigilance at the Kennedy Siding roadside mineral lick in north-central BC. The exposed soil in which the moose is standing is the substrate that mixes with road salt runoff to create the roadside mineral lick.

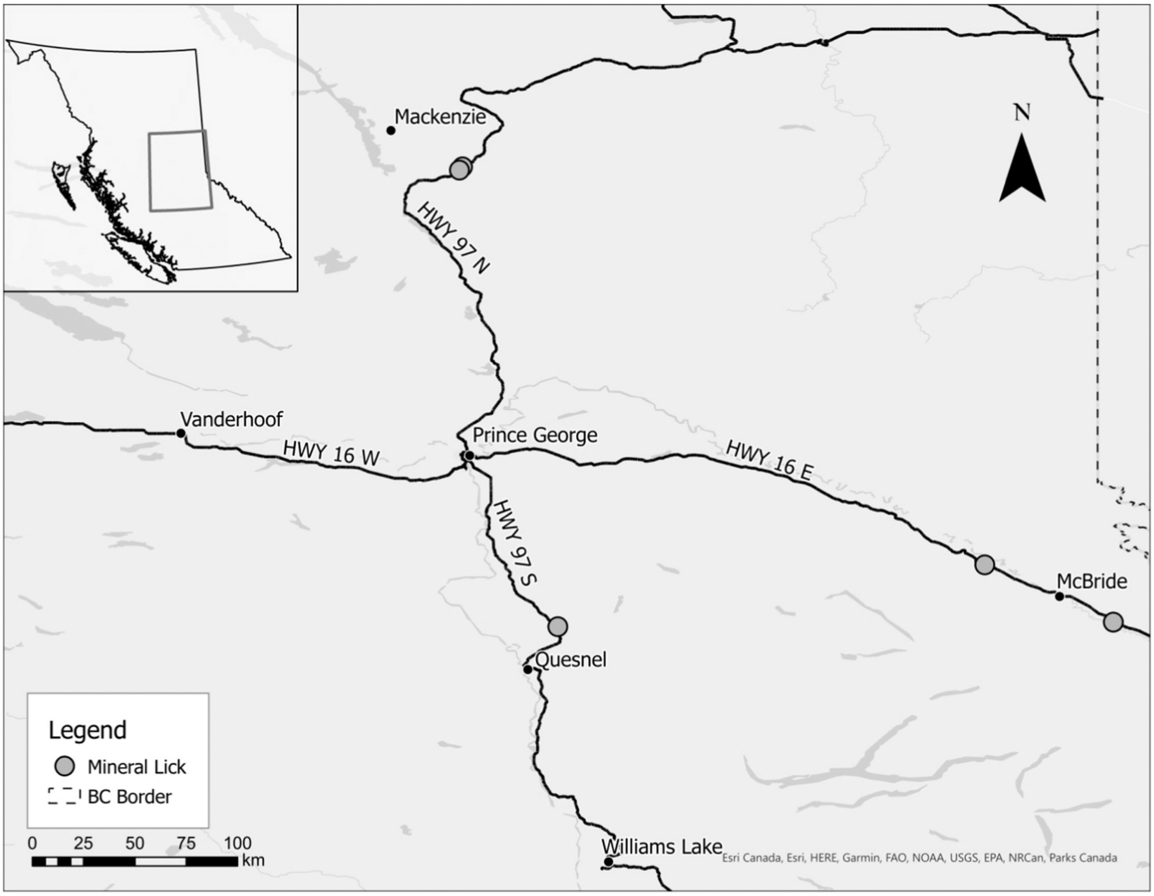

Fig. 2. General locations of roadside mineral licks (n = 5) equipped with video-enabled camera traps from July 2012–July 2020 to record behaviours of moose in north-central British Columbia.

maintain the vegetation in transportation corridors at an early seral stage and a low growing height to improve sight lines and driver visibility.

2.2. Data collection

We deployed camera traps at various times throughout the study period and they mostly operated continuously from their respective dates of deployment beginning in July 2012 (camera brands and dates of operation; Supplementary Material 1). We installed each camera trap on a tree at 1–2 m in height to overlook the RML (particularly the most trampled portion of it where use appeared to be concentrated) and maximize the chance of detecting moose and recording behaviours at the RML, while also keeping the camera out of view of passing motorists (which in the past has led to some cameras being stolen). We set the cameras to record videos of 20, 30, or 60 seconds in length with a 10-second delay between video captures. From May to August of each year, when moose activity at licks is expected to be highest (Risenhoover and Peterson, 1986; Brochez et al., 2020), we serviced the camera traps (i.e., batteries and memory cards replaced, obstructions removed, camera data downloaded) approximately once every four weeks. We chose this interval to prevent data loss that could result from batteries failing, memory cards reaching capacity, or disturbance from animals, although such events sometimes occurred, possibly leaving some visits unrecorded. In autumn and winter, we checked the camera traps approximately once every 8–10 weeks as there were fewer animal visits and the possibilities of vegetation growing in front of and interfering with the camera function was reduced. These maintenance checks were done by one individual throughout the study to ensure consistent methods were used. From the video records, we compiled dates and times of day for each visit and recorded associated moose behaviours.

2.3. Data interpretation

Geist (1963) provides descriptions of many behaviours observed in moose, applicable to a variety of contexts. We created and defined categories of major (frequent) and minor (infrequent) behaviours as we observed them, based on similar descriptions/terminology following Geist (1963), and entered these behaviours into an ethogram (Supplementary Material 2). For each video, we recorded the number of seconds that moose spent engaged in each behaviour in relation to the total number of seconds in which the moose was visible in the video.

Moose often visited mineral licks for extended periods, spanning multiple video captures. Quantifying the length of these visits required the definition of an “independent visit.” Adapted from Leblond et al. (2007), we noted the time of the first video occurrence of an individual moose, and any videos of the same individual captured within 60 minutes of any video in the series were considered part of the same independent visit. For example, if a bull moose was captured by video on a given day at 18:03 h, again at 18:44 h, and once more at 19:05 h, all three sightings would be considered individual parts of one independent visit. If a bull moose was then seen at 20:15 h, this was considered as a second independent visit. Two moose that differed in demographic class (described below) visiting the lick within 60 minutes were considered two independent visits, and two separate moose in the same demographic class visiting the lick in successive videos within the 60-minute time window were considered the same individual. For each independent visit, we summed the amounts of time from multiple videos spent on specific behaviours. We also included monthly visitation rate as a behaviour, which we defined as the number of independent visits per month for each year of the study, pooled across all sites. We did the same for time-of-day visitation rates, which was the number of visits every 2 h (Supplementary Material 2).

We classified moose into four demographic classes: bull, solitary cow, cow with young, and unknown. We defined solitary cows as cows without young <1 year of age. We note that solitary cows may have had a successful reproductive season with young at heel, but during a visit, the young may have remained outside the field of view of the camera trap and were thus classified as solitary cows. Unknown moose were visible enough to be definitively identified as moose, but not visible enough to accurately determine demographic class. Videos of unknown moose may have been captured in low light, or only captured one part of the animal's body, such as a leg, snout, or an ear.

Because the behaviours of young may be highly influenced by the presence of their mothers and are likely not independent from them (Altmann, 1958), we omitted young moose <1 year of age (any young moose detected on or after May 1st in the year of its birth and up to and including April 30th of the following year) and their behaviours from all analyses. However, we used the demographic class "cow with young" to assess if the behaviours of cows with young varied from behaviours of solitary cows. When multiple moose were present in the lick at the same time, aside from cows with young, we recorded their behaviours independently from one another. We omitted moose of unknown demographic class from statistical/behavioural analyses, because if the demographic class of the animal could not be determined in the video, most often the behaviour was not clear either. The exact age of young moose older than one year was often difficult to distinguish, therefore we considered all moose older than one year to be either bulls or cows.

2.4. *Statistical analysis*

We conducted all analyses with Microsoft Excel (v.2404) and RStudio (v.2023.12.0, R Core Team, 2023). We used one-way analyses of variance (ANOVAs) and Tukey's *post hoc* tests to assess if visitation rates varied by month and time of day within demographic classes. We also used this method to determine differences in visit length among classes. Two-way ANOVAs and Tukey's tests were used to assess differences in visitation rates among demographic classes in which demographic class and month (or time-of-day) were the two independent variables. We used generalized additive mixed models (GAMMs), a variation of the generalized additive model (Hastie and Tibshirani, 1986) with the *mgcv* package (Wood, 2011) to compare the proportions of time spent being vigilant and licking to time of year (month) for each demographic class. We found slight variation in the two dependent variables (vigilance and licking) attributable to site and year, therefore we added site and year into the models as random effects to control for this variation. We used an alpha of 0.05 as the threshold for statistical significance in all analyses.

3. Results

3.1. *Visitation*

Across all sites from July 2012–July 2020, we analyzed a total of 5033 videos of moose, comprising 1111 independent visits (Supplementary Material 3). 77.0% of these visits occurred at two of the five RMLs; the cameras at these sites operated the longest (Supplementary Material 1). There were 460 visits of bulls, 461 visits of solitary cows, 133 visits of cows with young, and 57 visits of unknown moose. Forty-nine of the videos we recorded showed moose visits with more than one adult moose: 22 were bulls/solitary cows; 10 were solitary cows/solitary cows; eight were bulls/bulls; eight were one moose with another of unknown demographic class; and one was a bull/young moose pair. With moose of unknown demographic class excluded, 1054 visits were considered for analyses.

Across every month of the study with sites pooled, bulls averaged 4.74 visits/month (± SE 0.42), solitary cows averaged 4.75 visits/month (± SE 0.42), and cows with young averaged 1.37 visits/month (± SE 0.28). Visitation varied significantly by month for bulls ($F = 10.83$, $df = 11$, $p < 0.0001$), solitary cows ($F = 7.46$, $df = 11$, $p < 0.0001$), and cows with young ($F = 3.16$, $df = 11$, $p = 0.0012$). Most visits occurred between May and July: 87.0% of bull, 68.3% of solitary cow, and 62.4% of cow with young visits occurred during these months. For all classes, visitation rates dropped off beginning in August with very few visits occurring between September and March. May had the highest average monthly visitation for bulls ($\bar{x} = 18.6 \pm$ SE 2.65 visits); solitary cows peaked in July ($\bar{x} = 12.9 \pm$ SE 2.65 visits), and cows with young peaked in June ($\bar{x} = 4.6 \pm$ SE 1.03 visits). Monthly visitation rates varied significantly between bulls and cows with young ($p < 0.0001$), and solitary cows and cows with young ($p < 0.0001$), but not between bulls and solitary cows ($p = 1.00$) (Fig. 3). Combining all years, sites, and demographic classes, June had the highest number of visits overall ($n = 280$; 26.6% of all visits), followed by May ($n = 260$; 24.7% of all visits) and July ($n = 258$; 24.5% of all visits).

Across all sites and seasons, visitation for all moose peaked at night, with relatively few visits occurring during mid-day. Occurrences of bulls and solitary cows peaked between 20:00–21:59 h and remained relatively high until about 04:00 h. Visitation by cows with young was less variable than that of bulls and solitary cows but peaked at a similar time, between 22:00–23:59 h. 58.3% of visits by bulls, 64.2% of visits by solitary cows, and 62.4% of visits by cows with young occurred between 18:00–03:59. Bi-hourly visitation rates varied significantly for bulls ($F = 3.11$, $df = 11$, $p = 0.001$), solitary cows ($F = 3.96$, $df = 11$, $p < 0.0001$), and cows with young ($F = 2.74$, $df = 11$, $p = 0.004$). Similar to the monthly visitation pattern, bi-hourly visitation rates varied between bulls and cows with young ($p = < 0.0001$), solitary cows and cows with young ($p < 0.0001$), but not between bulls and solitary cows ($p = 1.00$) (Fig. 4). On average, cows with young spent the most time at RMLs ($\bar{x} = 22.5 \pm$ SE 3.31 min), followed by bulls ($\bar{x} = 16.5 \pm$ SE 1.27 min), and finally solitary cows ($\bar{x} = 14.4 \pm$ SE 0.76 min). These differences were significant between bulls and solitary cows ($p = 0.001$), solitary cows and cows with young ($p < 0.0001$), and bulls and cows with young ($p = 0.04$).

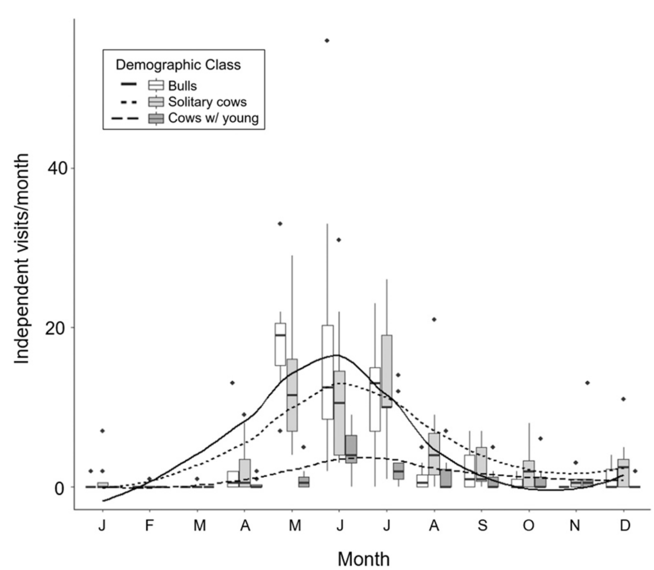

Fig. 3. Boxplots showing median (line), upper and lower 25th percentiles (boxes), and 90th percentile inclusion (whiskers) of independent visits per month of adult moose ($n = 1054$) by demographic class at roadside mineral licks ($n = 5$) as captured by video-enabled camera traps in north-central British Columbia from July 2012–July 2020. Distributions of each box represent the variation in monthly visitation among years. Data from sites are pooled.

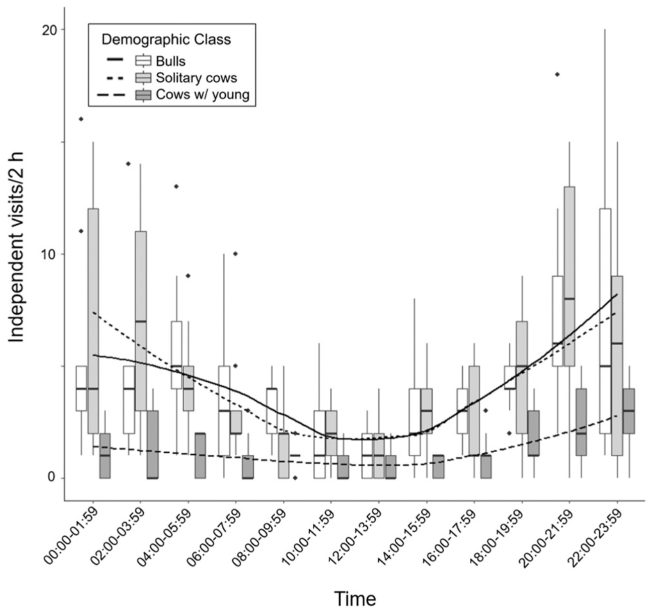

Fig. 4. Boxplots showing median (line), upper and lower 25th percentiles (boxes), and 90th percentile inclusion (whiskers) of bi-hourly independent visits of adult moose (n = 1054) by demographic class at roadside mineral licks (n = 5) as captured by video-enabled camera traps in north-central British Columbia from July 2012–July 2020. Distributions of each box represent the variation in bi-hourly visitation among years. Data from sites are pooled.

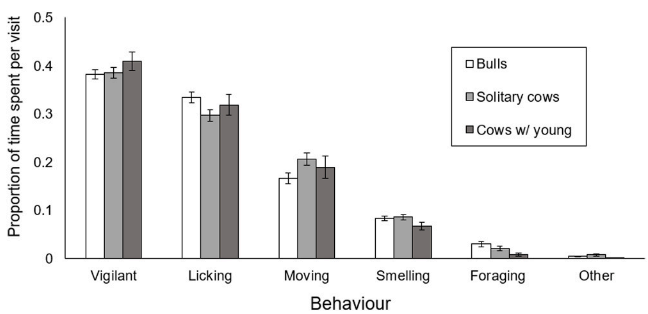

Fig. 5. Mean proportion of time ($\bar{x}$ ± SE) spent per independent visit on various behaviours by adult moose of various demographic classes at roadside mineral licks (n = 5) as captured by video-enabled camera traps in north-central British Columbia from July 2012–July 2020. Behaviours classified as "Other" included grooming, urinating, lying, nursing, aggression, and scratching (Supplementary Material 2).

3.2. Classifying behaviours during visits

Moose spent most of their time at RMLs engaged in at least one of five major behaviours: vigilance, licking, moving, smelling, and foraging (Supplementary Material 2). Of these behaviours, moose of all demographic classes spent the most time being vigilant and licking (Fig. 5). During licking, moose were only observed drinking water from the soils, and did not lick the bare ground or directly ingest soils. On average, only small proportions of time during each visit were spent foraging. Moose spent even less time engaged in the minor behaviours of grooming, urinating, lying, nursing, aggression, and scratching (Fig. 5).

On average, bulls spent 38.3% (± SE 0.95%) of their time being vigilant and 33.4% (± SE 1.09%) of their time licking. Solitary cows spent an average of 38.6% of their time being vigilant (± SE 1.08%) and 29.7% (± SE 1.17%) of their time licking. Cows with young averaged 41.0% (± SE 1.91%) of their time being vigilant and 31.9% (± SE 2.11%) of their time licking (Fig. 5).

3.3. Licking and vigilance

Bulls spent a higher proportion of time licking during a visit than solitary cows ($p = 0.03$) but not more than cows with young ($p = 0.54$) (Table 1). There was no difference in proportions of time spent licking between solitary cows and cows with young ($p = 0.26$). Proportions of time spent licking during a visit varied significantly by month; the smoothed term was statistically significant in the model ($F = 14.87$, $df = 4.42$, $p < 0.01$, adjusted $R^2 = 0.05$) (Table 1), and examination of the smoothed term showed a higher proportion of time spent licking for all moose from May to October and peaking in June (Fig. 6).

Proportions of time spent being vigilant by bulls during a visit did not differ from that of solitary cows ($p = 0.37$) nor cows with young ($p = 0.07$). Solitary cows and cows with young did not differ in time spent vigilant during visits ($p = 0.31$) (Table 1). For all classes of moose, proportions of time spent vigilant was less variable across months than was time spent licking, but the smoothed term was still significant ($F = 4.46$, $df = 2.29$, $p = 0.01$, adjusted $R^2 = 0.01$), with a slight peak in April that declined through the autumn months (Table 1; Fig. 6).

4. Discussion

4.1. Visitation

Increased visitation by moose to mineral licks, including RMLs, in spring and summer has been recorded (Fraser and Reardon, 1980; Brochez et al., 2020). Rea et al. (2013) reported smaller peaks of moose use of naturally-occurring mineral licks in winter, but we did not observe this. The seasonal use of licks is likely correlated with dietary shifts in moose during spring leaf flush (Dalke et al., 1965; Fraser and

Table 1
Statistical outputs ($\alpha = 0.05$) of the fits of generalized additive mixed models of proportions of time adult moose of various demographic classes spent being vigilant and licking per visit at roadside mineral licks in north-central British Columbia from July 2012–July 2020. Data are pooled across sites and years. To control for any variance due to site and year, these variables were entered as random effects in the model. Significant effects ($p < 0.05$) are bolded.

Model	Statistic				
Vigilance	p	df		F	R^2
Vigilance (Month)	**0.01**	2.29		4.46	0.01
Demographic Class					
Bulls vs. Solitary cows	0.37				
Bulls vs. Cows w/ young	0.07				
Solitary cows vs. Cows w/ young	0.31				
Licking					
Licking (Month)	**<0.01**		4.42	14.87	0.05
Demographic Class					
Bulls vs. Solitary cows	**0.03**				
Bulls vs. Cows w/ young	0.54				
Solitary cows vs. Cows w/ young	0.26				

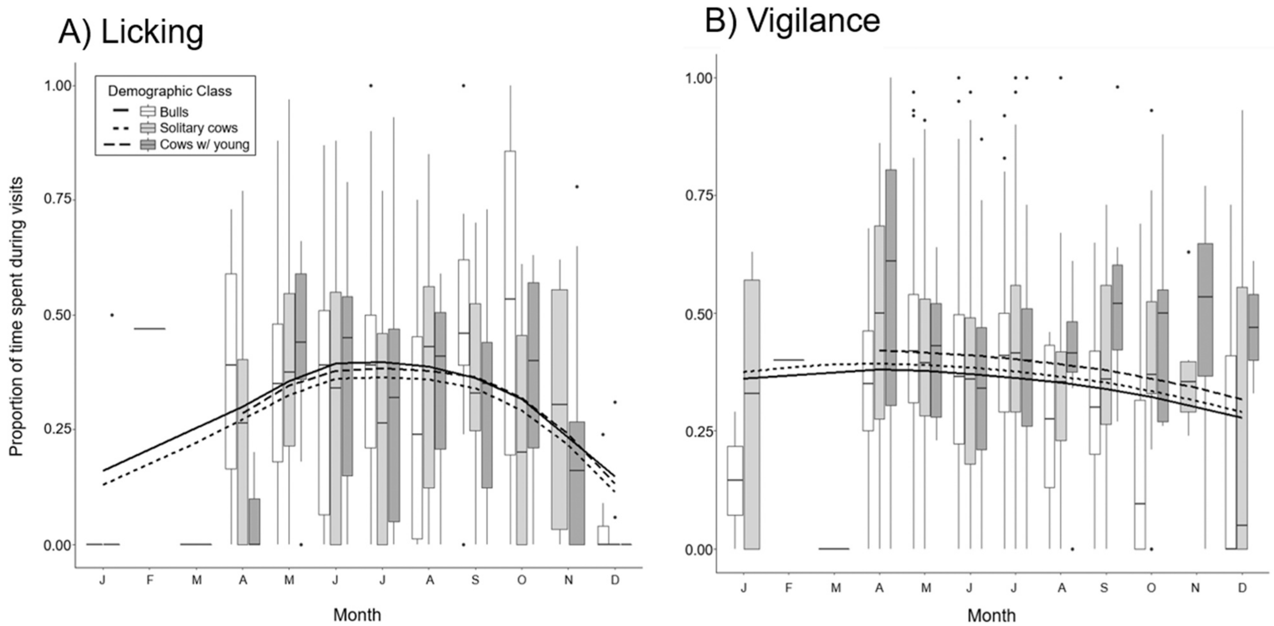

Fig. 6. Boxplots showing median (line), upper and lower 25th percentiles (boxes), and 90th percentile inclusion (whiskers) of the data of outputs for generalized additive mixed models for proportions of time adult moose of various demographic classes spent A) licking and B) vigilant at roadside mineral licks ($n = 5$) during independent visits in each month of the year in north-central British Columbia from July 2012–July 2020. Data are pooled across sites and years. To control for any variance due to site and year, these variables were entered as random effects in the models.

Hristienko, 1981), and may explain the patterns of use we observed. The number of visits we report is a conservative estimate as visits that occurred out of view of the cameras would not have been recorded.

Monthly visitation rates of bulls to RMLs nearly equalled that of solitary cows. This is surprising, as the estimated sex ratio of moose in north-central BC is 37 bulls:100 cows (Scheideman and Anderson, 2021). Even when bull visitation is compared to the combined visitation by solitary cows and cows with young, bulls still visited RMLs more than predicted, given the estimated sex ratio of the population. Bulls may have an increased mineral demand, which could be needed to produce antlers and support their large bodies. Calcium and phosphorous (often found in lick soils and water) are particularly important elements involved in antler production, and bulls likely require much more of these specific minerals than a cow needs for reproduction and lactation (Moen and Pastor, 1998). Further, bulls spent more time visiting RMLs than solitary cows, but less than cows with young. Because we did not identify individuals in our study, it is possible that increased bull visits represent the same individuals visiting repeatedly. Regardless, these findings may suggest RMLs are more important for bulls and reproductive females or that some classes (or individuals within classes) of moose are more comfortable near highways and traffic.

Most visits occurred in late spring (May) through mid-summer (July) and between sunset and sunrise. In our study area during the summer solstice, the latest time of sunset is 20:47 h, and the earliest time of sunrise is 03:39 h (Government of Canada, 2020). Peak visitation for all moose occurred between these times. Moose have been recorded as active throughout much of the day (Best et al., 1978; Dungan et al., 2010) but this was not evident in the activity we observed at RMLs. Others have also found moose activity at mineral licks to be highest between and around sunset and sunrise, increasing the risk of MVCs during this time (Tankersley and Gasaway, 1983; Couturier and Barrette, 1988; Rea et al., 2013; McDonald et al., 2019; Bíl et al., 2020; Borowik et al., 2021). Moose could be visiting primarily at night to avoid predators, thermal stress, and human disturbance (i.e., traffic) (Dussault et al., 2004; Klassen and Rea, 2008).

Times of sunrise and sunset change substantially throughout the seasons in northern BC, but times of peak traffic flow remain more constant. Generally, peak volumes of traffic flow are between 06:00–09:00 h and 16:00–19:00 h, regardless of the time of year (Nasir et al., 2014; FWHA, 2017). However, we found most moose visits occurred outside of peak traffic volume hours, despite most detections occurring in summer months when traffic volume is higher (BC MoTI, 2012). In north-central BC, MVCs peak between 17:00–05:00 h (O'Keefe and Rea, 2012), which roughly aligns with our observed visitation peak, but not with hours of peak traffic volume. While these MVCs occur mostly in winter, a smaller spike occurs in June, our peak month for moose visitation (O'Keefe and Rea, 2012). However, in other regions, MVCs peak in summer to early fall, declining in winter (Belant, 1995; Dussault et al., 2006). In winter, the hours of peak MVCs have little to no daylight. Reduced visibility and slippery road conditions may be the most important contributing factors to MVC risk in winter. In summer, MVCs occurring at night are also related to low visibility, but the increased presence of moose at RMLs that does not occur in winter is likely a major driver of the mid-summer MVC spike in our study area (Dussault et al., 2006).

4.2. Behaviours during visits

All moose spent most of their time at RMLs being vigilant and licking. These findings, plus the fact that very few visits involved multiple adult moose, demonstrate that moose were primarily visiting RMLs to ingest minerals contained in the lick waters and not gathering to socialize, which has been reported for naturally-occurring licks (Knight and Mudge, 1967; Couturier and Barrette, 1988). The RMLs in this study are next to busy highways, with traffic comprised of both passenger vehicles and large commercial vehicles, such as logging trucks. Moose recorded in our videos showed high levels of vigilance, often in response to passing traffic.

Extended periods of smelling RML water before licking, and between bouts of licking, were common. Proportions of time spent smelling suggested that moose may be highly selective in choosing a particular section of the RML to utilize, perhaps focusing on areas of high sodium concentration or other minerals of interest (Tankersley and Gasaway, 1983; Couturier and Barrette, 1988). Incidents of fleeing were infrequent but almost always observed in response to road traffic, which may pose a potential risk to motorists. Foraging was rarely recorded, suggesting that moose focused on obtaining minerals when at RMLs.

Moose spent the highest proportion of time per visit licking around late spring and mid-summer. This coincides with months of peak visitation reported in most other literature, further demonstrating moose use RMLs in a highly seasonal fashion for obtaining minerals (Courtier and Barrette, 1988). However, in some parts of the range, moose use roadside areas frequently in winter to lick salt directly from roads (Rea and Rea, 2005). Bulls spent a higher proportion of time licking per visit than solitary cows, which further illustrates that bull moose may have a higher mineral demand. This may also indicate that bull moose are at a higher risk of being involved in MVCs.

Low variability in vigilance by month and demographic class suggests this behaviour is equally important for all moose at RMLs throughout the year, though there was a slight peak in vigilance in April that remained relatively high throughout the spring and summer months. For cows with young, increased vigilance during this time could be related to care of newborns, which are typically born between mid-May and early June (Couturier, 1984; Keech et al., 2000). Because our RMLs exist in ditches off the shoulders of highways, moose that show high levels of vigilance in response to traffic may be less likely to be struck by vehicles than moose that are less vigilant. A moose that is still, watchful, and remains a safe distance from traffic could be less hazardous than moose engaging in other behaviours. However, the opposite could be true depending on where the moose is standing relative to traffic. Just as moose are often highly vigilant at RMLs, drivers should likewise show vigilance, especially when visibility is poor, keeping a watch for moose and sudden changes in their behaviour.

4.3. Reducing MVCs

A recent review by Hill et al. (2021) suggests that transportation corridors have negative numerous impacts for mammals in part due to attractants such as de-icing salts that accumulate in roadside ditches. The presence of RMLs and their seasonal use has been shown to increase the risk for ungulate-vehicle collisions (Dussault et al., 2006; Grosman et al., 2009; Leblond et al., 2007; Rea et al., 2014). Reducing moose attraction to salty roadside areas is a logical first step to reduce collisions. In Canada, NaCl is the most common road de-icer (Environment Canada and Health Canada, 2001) as it is relatively inexpensive and highly effective. Using less NaCl, deploying de-icers that are less attractive to moose (e.g., calcium or magnesium chloride, urea, ethylene glycol, grit), adding chemical repellents to RMLs (e.g., isobutyric acid, creosote, lithium chloride), and decommissioning RMLs should be considered to deter moose and other wildlife from the use of roadside areas (Fraser and Thomas, 1982; Warrington and Phelan, 1998; Brown et al., 2000; Leblond et al., 2007; Rea et al., 2021). Some of these approaches may have higher initial costs than NaCl but could reduce later costs associated with MVCs and NaCl damage. The effects and safety of chemical alternatives on moose and their habitats warrant further study.

Increasing driver awareness of moose presence and their behaviours around highways combined with knowledge of best practices to avoid collisions are also important strategies that should be considered by transportation agencies to reduce MVCs (Vanlaar et al., 2019). Identifying locations of RMLs and MVC hotspots, increasing signage, and encouraging or legally requiring motorists to reduce speed at times of increased MVC risk are feasible approaches for MVC reduction (Dussault et al., 2006; Rea et al., 2014; Visintin et al., 2018). Finally, reinstating and maintaining a detailed, standardized system and database for reporting wildlife-vehicle collisions in BC (e.g., WARS; Province of BC, 2022) will be helpful for researchers and transportation agencies to improve our understanding of MVC risk in the future.

5. Conclusions

Our study revealed that moose in north-central BC increased their visitation rates to RMLs in mid-summer and this behaviour (regardless of demographic class) corresponds directly with MVC data showing an increased risk of collision at the same time. While at RMLs, moose spent most of their time being vigilant and licking water, suggesting that once at the lick, the majority of behaviours may have minimal influence on collision risk relative to the behaviour of increased visitation. Our videos revealed that mineral-rich water appears to be the main attractant for moose seeking supplemental minerals following the annual spring leaf flush.

Moose are extremely large animals that can become major hazards to motorists as they traverse road corridors to access mineral resources at RMLs. Recognizing and understanding how the behaviours of moose at RMLs can be used to understand connections between their behaviours and collision risk is critically important for identifying ways to mitigate MVCs. For BC and other jurisdictions where moose cross roads, this requires data to be kept on when and where moose are struck so that collision hotspots can be identified and determinations made about possible links between collision risk and animal behaviours. Identifying where RMLs occur, establishing regional patterns of use of such features by moose and other species, and considering the development of site-specific collision countermeasures should be a priority for road safety planners and will help to make roads safer for both motorists and moose.

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Data statement

The data pertaining to this article may be found in the Supplementary material, or by contacting the authors.

CRediT authorship contribution statement

Candyce Eryn Huxter: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Roy Van Rea:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Ken A Otter:** Writing – review & editing, Supervision, Resources, Methodology, Formal analysis, Data curation. **Gayle Hesse:** Writing – review & editing, Investigation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.applanim.2024.106292.

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