SPATIAL AND TEMPORAL OCCURRENCES OF PRAIRIE MOOSE ACROSS AN URBAN TO RURAL GRADIENT IN SASKATOON, CANADA

Kaitlyn E. Harris[1], and Ryan K. Brook[1]

[1]Department of Animal and Poultry Science, College of Agriculture and Bioresources, University of Saskatchewan, 51 Campus Drive, Saskatoon, Saskatchewan, Canada, S7N 5A8, keh731@usask.ca

ABSTRACT: The geographic range and abundance of North American moose (*Alces alces*) has varied over recent decades, with contractions in areas, recolonization of historical habitats and dispersals into new areas and, notably, increased moose sightings near developed, urban areas. The City of Saskatoon, Saskatchewan is located in semi-arid, open prairies and surrounded by high-intensity agriculture. Despite being atypical moose habitat, Saskatoon has experienced an increased frequency of moose observations at the urban-rural interface over the last several decades. We characterized spatial and temporal patterns in moose detections over the course of three study years (September 2020–September 2023) using data from 29 trail cameras distributed along an urban to rural gradient within the city boundary of Saskatoon. We quantified moose detections ($n = 60$) from photos ($n = 249$) collected at 12 of the camera trap sites. We detected moose each year of the study (8, 23, and 29 detections in years 1, 2, and 3, respectively). Moose detections were highest overall in July ($n = 15$) and at rural sites adjacent to the city ($n = 47$). Using generalized linear modeling, we found that moose were negatively associated with urban sites containing higher proportions of development (>50% impervious surface cover), and that detections occurred most frequently at night when darkness provided hiding cover and human activity was lowest. We provide suggestions and recommendations for future urban moose research and management.

ALCES VOL. 60: 45–57 (2024)

Key Words: *Alces alces*, detection, development, gradient, prairies, Saskatchewan, trail camera, urban-rural

Moose have long been recognized as a cold-adapted boreal forest specialist with a broad circumpolar geographic range that incorporates much of northern Canada (Teitelbaum et al. 2021), including the Taiga Plains, Hudson Plains, Boreal Plains, Boreal Shield, Boreal Cordillera, Taiga Shield, and Taiga Cordillera Ecozones (Pastor et al. 1988, Wilken et al. 1996, Jensen et al. 2018). Although populations and range dynamics of moose have fluctuated over time, Timmermann and Rodgers (2017) found that of the 12 Canadian jurisdictions with moose populations, 3 remained stable (Yukon, British Columbia, Nova Scotia), 2 were increasing (Quebec, New Brunswick), 5 were decreasing (Alberta, Saskatchewan, Manitoba, Ontario, Newfoundland), and 2 had no available estimates (Northwest Territories, Nunavut). Despite forage availability being one of the primary limitations to moose populations (Tape et al. 2016), warming climates have led to longer growing seasons and increased primary productivity that have contributed to a northern range expansion (Zhou et al. 2022). At the southern extent, climate change has been hypothesized to be a limitation due to heat stress (Wattles et al. 2018a, DeCesare et al. 2024). However, while some southern populations have been declining, many others have actively expanded into areas that experience daily ambient temperatures far above the reported tolerance range. This is thought to be explained by behavioural adaptations for reducing thermal heat stress, such as shifting away from the preferential selection of regenerating forest habitats towards forested wetlands and coniferous forest (Wattles et al. 2018a), along with other potential factors such as absence of primary predators.

Logging may positively influence populations through the development of early successional habitats that are favorable for moose (Anderson et al. 2017, Ordiz et al. 2021). However, because moose have shown strong negative responses to both high-density road infrastructure and high road use intensity (Wattles et al. 2018b), transportation infrastructure may limit the distribution of moose and their use of available habitat patches. The risk of moose-vehicle collisions also increases with increasing road density and human activity (Joyce and Mahoney 2001), and this risk is highest during crepuscular times and during the seasons associated with increased moose movement (e.g., spring dispersal, fall rut; Laliberté and St-Laurent 2020). Non-lethal human disturbance, such as off-trail hiking or snowmobile use, has prompted avoidance behaviour in moose although typically only for a short duration when at low to moderate frequencies (Neumann et al. 2011).

The potential establishment of "farmland moose" populations, characterized as living primarily on agricultural-dominated lands (Laforge et al. 2016), has several important socio-economic implications. Moose feeding activities and trampling can detrimentally impact ecosystems, leading to altered vegetation communities (Persson et al. 2000). The substantial habitat overlap among wild ungulates in the prairies has also increased the risk for the transmission and spread of infectious diseases (Weiskopf et al. 2019). Furthermore, moose can cause considerable damage to agricultural crops, fence lines, and machinery (Laforge et al. 2017b, Tranulis and Tryland 2023), which may harm human livelihood within agriculture-dominated regions such Saskatchewan. This may necessitate increased spending on compensation measures for affected landowners (Hanbury-Brown et al. 2021), or the implementation of a harvest process to help manage the population through increased annual hunting opportunities (Timmermann and Rodgers 2005).

Wildlife and resource managers would benefit from a contemporary understanding of moose activity on an urban mixed prairie and planted tree landscape embedded within an extensive agriculture-dominated landscape. Using a network of wildlife monitoring trail cameras distributed within the city boundary of Saskatoon, Saskatchewan, Canada, our objectives were to: 1) quantify moose detections along an urban to rural gradient, 2) relate spatial patterns of detections to vegetation canopy cover and height, and to the proportion of impervious surface cover (e.g., roads, buildings, parking lots) at each site, and 3) identify annual, monthly, and daily trends in moose detections.

STUDY AREA

We defined the study area as the city boundary of Saskatoon, Saskatchewan, Canada (Fig. 1), which had a population of 266,000 residents and a land area of 227 km^2 (Statistics Canada 2021). Saskatoon is situated in the Prairie Ecozone of Canada, which has a semi-arid climate, and experienced summer temperatures highs in July (mean daily temperature: 19^{o} C) and winter lows in January (mean daily temperature: -21^{o} C; Government of Canada 2024). Saskatchewan contained approximately 24.5 million hectares of total farm area, with 67% designated as cropland (St. Pierre and Mhlanga 2022). The dominant

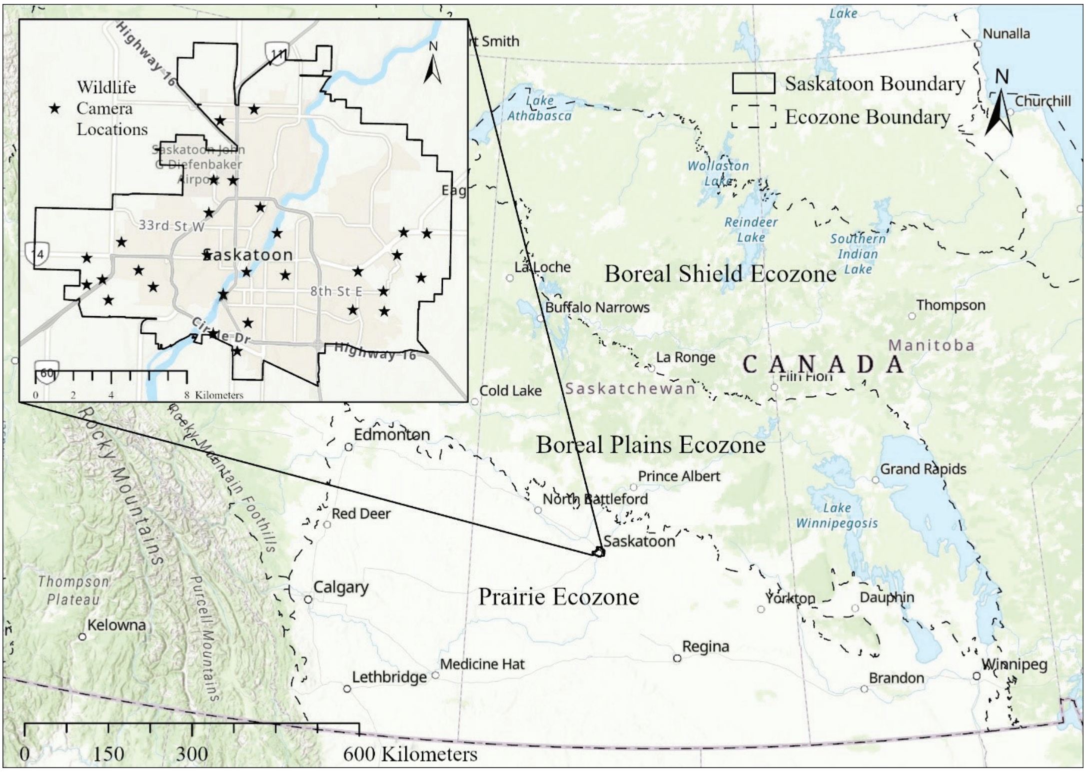

Fig. 1. The location of the study area relative to the Boreal Shield, Boreal Plains, and Prairie Ecozones, and the distribution of wildlife monitoring trail cameras (n = 29) deployed in a stratified random distribution along an urban to rural gradient within the city boundary of Saskatoon, Saskatchewan, Canada, 2020-2023.

farmland crop was canola (30% of total cropland), followed by spring wheat (18%), durum wheat (12%), lentils (9%), and barley (9%). Saskatchewan is also included in the Prairie Pothole Region (PPR) of Canada and contains thousands of small wetland potholes embedded within the complex agro-ecosystem (Pennock et al. 2010). Wetlands in the PPR are often ringed by deciduous trees and shrubs that provide ungulates with opportunities for forage, cover, shelter, and thermoregulation through submersion in standing water (Laforge et al. 2016).

The moose population in Saskatchewan was estimated as 45,516 in 2000, with a mean density of 0.29 moose/km^2, and most (69%) of the population supported by the primary range within the Boreal Plains Ecozone (Arsenault 2000). This range experienced a decline in moose population density averaging 30% since 2000 (Arsenault et al. 2019). The agricultural secondary range consisted of pockets of suitable habitat scattered across the Prairie Ecozone, south of the Boreal Plain. This region contained approximately 2% of the provincial population (Arsenault 2000) and was considered unable to sustain high-density populations due to high-intensity agriculture, human settlement, and higher ambient temperatures.

The City of Saskatoon was within the Saskatoon Wildlife Management Zone (WMZ SMZ) that had a resident-only draw moose hunting season in October and November for individuals to harvest one moose of either sex (rifle hunting not permitted). The 2023 Hunter Harvest Survey estimated 10 moose harvested in this zone (approximately 0.002 moose/km^2; Government of Saskatchewan 2024b). Indigenous subsistence harvest of moose was legal throughout the year, but nothing is currently known about past or current harvest levels. Population estimates within Saskatoon are unknown, but media reports have documented numerous sporadic occurrences of moose throughout Saskatoon, including well within urban environments (Global News 2020, 2021, 2022, CKOM News 2024).

METHODS

We quantified moose detections using data from a larger, comprehensive multi-species trail camera study to monitor wild mammal distribution and diversity in Saskatoon that was designed in accordance with the protocols provided by the Urban Wildlife Information Network (UWIN; Magle et al. 2019). This minimally invasive research was exempt from University of Saskatchewan Animal Research Ethics Board approval.

Camera trap locations were determined by stratifying Saskatoon into 6 primary land cover classifications (agricultural, aquatic, built (i.e., impervious surface area), forested and shrubland, grassland, and greenspace (i.e., parks, golf courses)) using the Meewasin Valley Authority Natural Areas Inventory land cover map (Hooey 2021). We created 2 perpendicular transects (North—South, 16 km; East—West, 20 km) originating from a central downtown location (52°7’24” N 106°39’50” W) and extending outwards to the city boundary, using ArcGIS Pro (v. 10.7.1, ESRI Inc. 2019). We used stratified quasi-random sampling to locate 5 camera traps within each of the 6 land cover classifications ($n = 30$), enforcing 1 km minimum distance between points that were within 1 km of either side of the transect.

We quantified the proportions of each identified land cover within a 500 m radius buffer zone surrounding each camera trap. Areas with incomplete land cover data were assigned an initial value of “null” and visually quantified using City of Saskatoon orthoimagery. The landcover classification was further used to build the urban-rural gradient by identifying unique categories of development within the landscape of our study area, based on the level of human development. We defined human development by a measure of built land cover, which identified the proportions of impervious surface area (i.e., developed surface cover such as roads, buildings, parking lots) within each zone. Camera sites were sorted into 3 development classes: rural, peri-urban, or urban. We defined rural zones as those containing < 25% impervious surface area, peri-urban zones as containing 25-50% impervious surface area, and urban zones as containing > 50% impervious surface area. Our camera trap sample had 9 cameras (30%) within rural areas, 9 (30%) within peri-urban areas, and 12 (40%) within urban areas. Within each zone, 4 potential camera trap locations were selected based on accessibility and suitability of the location for year-round monitoring and likelihood of mammal encounters (e.g., proximity to water source, natural trails or paths). We used ground truthing and landowner discussions to finalize camera trap placements (1 camera per zone).

Data Collection

We used Browning Dark Ops HD Pro X motion-activated infrared trail cameras on their default settings (trail mode with high detectability) and set to obtain a burst of three images at 1 second intervals each time it was motion-triggered and a 30 second minimum delay between trigger events. We deployed cameras from 8 September 2020 to

9 September 2023. We positioned cameras 1.5-2 m above the ground and, where possible, facing a potential travel corridor (i.e., an area of land such as a riverbank or ditch that connects habitat patches) or trail (e.g., foot trail, deer path) with minimal vegetation in front to reduce accidental triggering. Camera traps operated continuously year-round, and were serviced every 1-4 weeks by research staff. We retrieved and replaced camera cards during each visit. Over the 3-year study period, 14 cameras on 9 sites were found temporarily inoperable and replaced, limiting data loss to <15 total days per site. However, we censored from analyses data from 1 site with repeated camera failures. We tagged each photo with metadata (i.e., species data, image time and date, camera number, site identifier, camera GPS location coordinates), and removed data that might identify individual people. At each site we estimated the green canopy cover (%) above each camera using the Canopeo application (Patrignani and Ochsner 2015). We calculated the mean height of vegetation at each site based on field measurements collected during peak greenness in July of the highest point of herbaceous vegetation below and 10 m in front of each camera.

We quantified moose "detections" and "events" for each camera trap. We defined a "detection" as any time a camera took 1 initial photo of a moose, and an "event" included all moose photos consecutively captured by the same camera within a 1-hour timeframe (Laforge et al. 2017a). Most events (75%) were < 1 minute in duration and only one event exceeded 10 minutes. Any group of images within a 1-hour event were assumed to be the same moose (counted as $n = 1$ detection for that event) unless we could confidently distinguish a unique individual through identifiable features (e.g., $n = 2$ detections for that event). We documented the year, month, time-of-day, and dominant landcover type associated with each event. The time-of-day classification was standardized based on hours of daylight to account for the annual fluctuations in Saskatoon daylength. Hours of daylight were calculated as the total difference in hours between the true sunrise and sunset times (obtained from: timeanddate.com) for each event. We defined events during the first 25% of daylight hours as morning, the following 50% of daylight hours as afternoon, the final 25% of daylight hours as evening, and after sunset or before sunrise as night. Where possible, moose were classified by age and sex through visual examination of photographs using key identifier characteristics. We considered moose adults at one year of age.

Statistical Analysis

We employed generalized linear modelling (GLM) to assess the significance of detection covariates using program R (v. 4.2.1, R Core Team 2024), with a negative binomial distribution (Package: "MASS") of the response variable (Ver Hoef and Boveng 2007). Models contained temporal predictor variables (month and time-of-day) and habitat categories (green canopy cover, mean vegetation height, dominant landcover class, development class). We employed a stepwise selection process to compare candidate models, removing non-significant predictors one at a time using Akaike's Information Criterion (AIC) and a likelihood ratio test. The best fit model was selected when removal of any predictor variable reduced model performance based on higher AIC scores.

Because one camera site accounted for 57% of all moose detections, we conducted a separate analysis with and without this outlier. We report in Results the analysis excluding the outlier and present the results of the model including this site in Supporting Material.

RESULTS

We collected a total of 249 moose photos at 12 of 29 camera traps, comprising 53 unique moose events and 60 moose detections (Fig 2). Overall, 13% of events contained 2 moose and the remainder contained what appeared to be a single individual. The mean number of photos per event was 4.7 (minimum = 1, maximum = 27). Among events, 17% were of a single photograph (i.e., event length = 0:00 minutes). Of the events with > 1 photograph, 68% were < 1 minute in length and the mean event length time was 2:33 minutes.

We detected 8 moose during study year 1, 23 during year 2, and 29 during year 3. Monthly detections were in: July (*n* = 15), April (*n* = 10), June, August, and December (all *n* = 6), September (*n* = 5), with other months < 5. No detections occurred during February. We detected 18 adult females, 14 adult males, 5 cow-calf pairs, 4 calves, and sex and age were undetermined in 14 detections.

Moose were primarily detected in rural parts of the city (*n* = 47), with most found along the eastern edge (Fig. 2). Ten detections were at peri-urban sites, and 3 at urban sites. No detections occurred in the northern, industrial section. The dominant landcover class for most camera sites was built (*n* = 17), followed by agriculture (*n* = 8), greenspace (*n* = 2), aquatic (*n* = 1), and grassland (*n* = 1). No sites had forest and shrub as dominant landcover. Although trees and/or shrubs were present at all sites, only 4 sites contained > 7% total forest and shrub cover, and most sites contained < 2%.

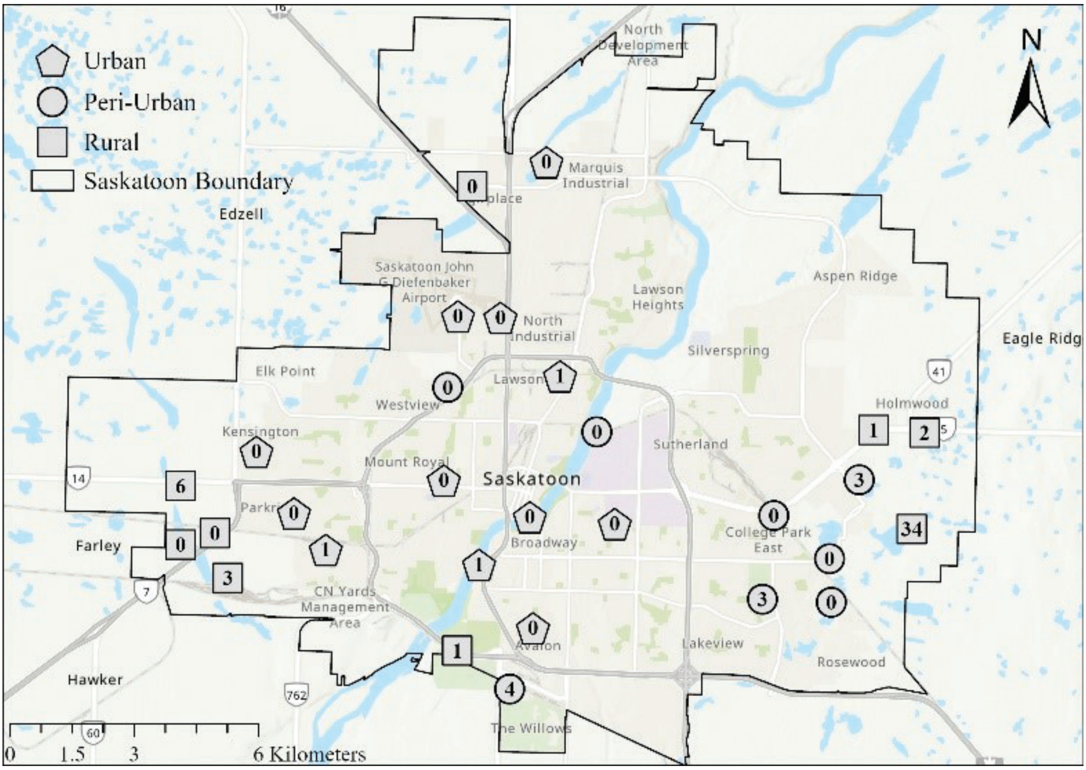

Fig. 2. Moose detections (*n* = 60) obtained from trail cameras (*n* = 29) deployed in Saskatoon, Saskatchewan, Canada, September 2020–September 2023.

Statistical Model

We analyzed moose detections at 28 camera sites, following exclusion of 2 cameras sites. Candidate model comparison and AIC results indicated no significant loss of explanatory power ($P > 0.05$) and a better fit (< AIC) after dropping month, dominant landcover class, green canopy cover, and vegetation height from the base model (Table 1). The best fit model had the lowest AIC score (223.9) and contained variables for time-of-day ($x^2 = 30.55$, $df = 3$, $P < 0.001$) and development class ($x^2 = 10.38$, $df = 2$, $P = 0.0056$). Moose were detected most frequently at night ($z = 2.908$, $SE = 0.765$, $P = 0.0036$; reference category "Afternoon," Fig. 3), and they selected against urban sites ($z = -2.694$, $SE = 0.678$, $P = 0.0071$, reference category "Rural").

A model containing the outlier site (with 57% of all moose detections) included the month and dominant landcover class variables as significant predictor variables (Table S1).

DISCUSSION

Moose have been thought unable to thrive in the Canadian prairies due to the semi-arid climate, lack of forest cover, high road density, extensive agriculture, and landscape composition (Laforge et al. 2016). However, moose are also highly mobile and capable of dispersing broadly (Arsenault 2000). Historically, conditions were not favorable for their establishment in agriculture-dominated areas. Fifty years ago, agricultural areas had large families that hunted intensively, but as rural populations have declined, hunting has waned dramatically. Although moose hunting is allowed around the City of Saskatoon, there is no hunting within city limits. Saskatoon may be functioning as a sanctuary for moose, with no hunting pressure and few, if any, medium to large predators (Perry et al. 2020). Saskatoon is surrounded by farmland with high yearly

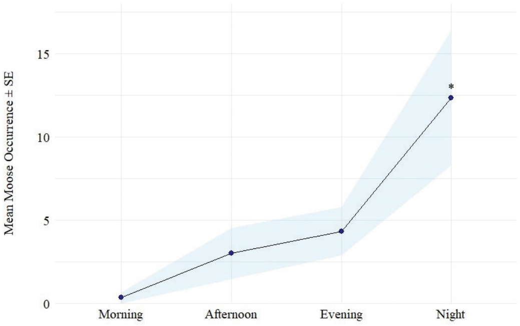

Fig. 3. Mean and standard error (SE) of moose detections per time-of-day from trail cameras in Saskatoon, Saskatchewan, Canada, 2020-2023. Asterix (*) indicates a significant statistical difference between variable levels (reference category "Afternoon") based on best fit model results ($P < 0.05$).

Table 1. GLM candidate model comparison results for selecting the best fit model of moose occurrence ($n = 28$ cameras) in Saskatoon, Saskatchewan, Canada, 2020-2023. Number of model variables (K), evaluation of model fit (AIC), and AIC difference between best fit and other candidate models (ΔAIC). Lowest AIC score indicated best fit model.

Model	K	AIC	ΔAIC
Time_of_Day + Development	2	223.9	0.0
Time_of_Day + Development + Avg_Veg_Height	3	224.2	0.3
Time_of_Day + Development + Avg_Veg_Height + Canopy_Cover	4	224.6	0.7
Time_of_Day + Development + Avg_Veg_Height + Canopy_Cover + Dom_Landcover	5	226.3	2.4
Month + Time_of_Day + Development + Avg_Veg_Height + Canopy_Cover + Dom_Landcover	6	232.7	8.8

seeding rates of high-value crop types including oilseeds such as canola and soybeans, and pulses such as field peas and lentils among others (Government of Saskatchewan 2024a). The selection of agricultural lands by moose was found to increase with higher densities of oilseed and pulse crops, as well as with the density of cover crops and forest (Laforge et al. 2017b), and this is likely an important influence on moose presence in our study area. Historically, moose occasionally dispersed through these areas, but as they adapted to using agricultural crops with extremely high nutritional value, utilizing pothole wetlands for cooling in summer heat, and finding safety from hunters and primary predators, survival has likely increased (Laforge et al. 2016, Laforge et al. 2017b). We believe these factors have contributed importantly to the ongoing moose expansion into the prairies and their establishment near urban environments.

Moose have also colonized other urban and peri-urban landscapes, including in Alaska (Welch et al. 2015), Utah (Wolfe et al. 2010), Massachusetts, New York, and Connecticut, among others (Wattles and DeStefano 2011). The high levels of primary productivity often found in suburban areas (e.g., gardens, greenways, and parks) may be an attractant for moose (Welch et al. 2015). Road salt is used in the winter to de-ice roads, and this may also be a contributing factor to increased moose presence near urban areas through the formation of roadside mineral licks created by spring runoff (Leblond et al. 2007, Rea et al. 2021). The presence of very young calves of the year and cow-calf pairs detected yearly in our study area both during and following the calving season, as well as the year-round occurrences of adults of both sexes, suggests to us an established population that likely uses a mix of the urban, peri-urban, and adjacent farmland habitats. The negative association we found within highly developed, urban sites in our study area may reflect some degree of avoidance to areas with high human activity and density, or simply the lack of natural features or suitable travel corridors that are typical of many inner-city areas. However, although moose presence was greatest in the rural sites, our research findings and recent media stories confirm that moose occasionally move through almost any part of the city. The high moose detections found at the single location east of the city is notable. This site was surrounded by farmed cropland and adjacent to a tree-ringed wetland pothole. It is likely that some combination of these habitat features (such as cover, forage, and shelter) had created highly favorable conditions that either attracted or kept moose in this area.

Diurnal detection patterns in our study area were as expected. Moose detections were least likely during daylight hours, with detections increasing in the evening and peaking at night. This is consistent with the known activity patterns of moose being most active at crepuscular and night times (Risenhoover 1986, Dussault et al. 2006). Consequently, moose-vehicle collisions tend to occur in the highest frequencies at dawn, dusk, and night (Dussault et al. 2006, Klassen and Rea 2008). Between 2000-2020, 52% of all fatal wildlife-vehicle collisions in Canada involved moose (Barrett et al. 2023). Increased moose presence in Saskatoon may also increase the risk potential for moose-vehicle collisions related to heightened exposure to high road density and traffic volume (Joyce and Mahoney 2001).

Management Implications

Moose living in peri-urban and urban environments present significant risks to human safety. Vehicle collisions can occur any time moose are associated with streets and highways (e.g., 5 Saskatchewan highway collisions involving moose occurred within 30 minutes in a single evening; CBC News 2024). Further risk considerations include the potential for private and public land property damage (e.g., gardens, fences, trees, shrubs, etc.), safety issues related to aggressive behaviour, and property damage and likelihood of injury or death from collisions with trains and other modes of transportation. Management preparation and response considerations should include increasing public awareness and education, installing fencing to keep moose out of areas that are of highest concern as well as one-way fencing that will allow moose to escape while preventing them from returning, improved signage that is larger and lighted to better warn drivers in high-risk areas, and continued support of wildlife immobilization and translocation programs that appear to be effective (Brook et al. 2018, unpublished data). Future research should consider the use of GPS collars and a broader network of trail cameras to better understand population and habitat use dynamics in the peri-urban environment, and further investigate seasonal and temporal patterns with respect to annual variations in human activity, camera detectability, environmental conditions, and crop cover and growth stage.

ACKNOWLEDGEMENTS

Our study was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC), the Urban Wildlife Information Network (UWIN), the University of Saskatchewan, the College of Agriculture and Bioresources, the Department of Animal and Poultry Science, the Saskatoon Forestry Farm Park and Zoo, the Alexander Malcolm Shaw Memorial Graduate Scholarship, the Harris and Lauretta and Raymond Earl Parr Memorial Scholarship in Agriculture, the Putnam Family Memorial Postgraduate Scholarship, the L.H. Hantelman Postgraduate Scholarship, the Gabriel Dumont Scholarship Foundation, the Margaret Skeel Graduate Student Scholarship, and the John Baerg Scholarship. We thank our partners at Meewasin Valley Authority, Wild About Saskatoon, the Saskatoon Forestry Farm Park and Zoo, the City of Saskatoon, and the Saskatoon Parks Department. We also thank G. Hooey, C. Savage, R. Grilz, D. Clark, and EcoQuest for their individual contributions.

REFERENCES

Anderson, M., B. N. McLellan, and R. Serrouya. 2017. Moose response to high-elevation forestry: implications for apparent competition with endangered caribou. The Journal of Wildlife Management 82(2): 299-309. doi: 10.1002/jwmg.21380

Arsenault, A. A. 2000. Status and management of moose (Alces alces) in Saskatchewan: fish and wildlife technical report 00-1. Saskatchewan Environment and Resource Management, Saskatoon, Saskatchewan.

Arsenault, A. A., A. R. Rodgers, and K. Whaley. 2019. Demographic status of moose populations in the Boreal Plain Ecozone of Canada. Alces 55: 43-60. doi: 10.1002/jwmg.21380

Barrett, H., W. G. M. Vanlaar, and R. D. Robertson. 2023. Wildlife-vehicle collisions in Canada: 2000-2020. Traffic Injury Research Foundation, Ottawa, Canada.

Brook, R.K., M. Laforge, A. Wheeler, and N. Michel. 2018. Habitat selection, home range, movements, and reproduction success of adult female moose in the agricultural landscape of Saskatchewan. Unpublished Technical Report, Saskatoon, Canada.

CBC News. 2024. Drivers urged to watch for wildlife after 5 collisions involving moose in 30-minute window: Sask. RCMP. https://www.cbc.ca/news/canada/

saskatoon/moose-collisions-1.7379484 (Accessed December 2024).

CKOM News. 2024. Moose wandering around Saskatoon rescued and relocated. https://www.ckom.com/2024/12/31/moose-wandering-around-saskatoon-rescued-and-relocated/ (Accessed December 2024).

DeCesare, N.J., R.B. Harris, M.P. Atwood, E.J. Bergman, A.B. Courtemanch, P.C. Cross, G.L. Fralick, K.R. Hersey, M.A. Hurley, T.M. Koser, R.L. Levine, K.L. Monteith, J.R. Newby, C.J. Peterson, S. Robertson, and B.L. Wise. 2024. Warm places, warm years, and warm seasons increase parasitizing of moose by winter ticks. Ecosphere 15(3): e4799. doi: 10.1002/ecs2.4799

Dussault, C., M. Poulin, R. Courtois, and J.-P. Ouellet. 2006. Temporal and spatial distribution of moose-vehicle accidents in the Laurentides Wildlife Reserve, Quebec, Canada. Wildlife Biology 12(4): 415-425.

ESRI Inc. 2019. ArcGIS Pro. Environmental Systems Research Institute, Redlands, California.

Global news. 2020. More moose being spotted in Saskatoon since May, surprising neighborhood: 'It didn't feel real." https://globalnews.ca/news/7046915/moose-appearance-saskatoon-neighbourhood/ (Accessed December 2024).

Global News. 2021. Moose crashes through window of Sylvia Fedoruk School in Saskatoon. https://www.cbc.ca/news/canada/saskatoon/moose-crash-sylvia-fedoruk-school-1.6237194 (Accessed December 2024).

Global News. 2022. Two moose wander the streets of Saskatoon before being captured by police. https://globalnews.ca/video/8969419/two-moose-wander-the-streets-of-saskatoon-before-being-captured-by-police/ (Accessed December 2024).

Government of Canada. 2024. Canadian climate normals 1981-2010 station data. https://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=3328&autofwd=1 (Accessed January 2025).

Government of Saskatchewan. 2024a. Agriculture and environment: regional conditions. https://dashboard.saskatchewan.ca/agriculture?region=East%20Central (Accessed January 2025).

Government of Saskatchewan. 2024b. Hunter harvest survey. https://www.saskatchewan.ca/residents/parks-culture-heritage-and-sport/hunting-trapping-and-angling/hunting/hunter-harvest-survey (Accessed March 2025).

Hanbury-Brown, A. R., J. W. Stackhouse, and L. T. Macaulay. 2021. Elk conflict with beef and dairy producers poses wildlife management challenges in northern California. Ecology and Society 26(1): 23. doi: 10.5751/ES-12283-260123

Hooey, G. 2021. State of the valley: Meewasin Valley assessment report 2014-2018. Meewasin Valley Authority, Saskatoon, Saskatchewan.

Jensen, W. F., J. R. Smith, M. Carstensen, C. E. Penner, B. M. Hosek, and J. J. Maskey, Jr. 2018. Expanding GIS analyses to monitor and assess North American moose distribution and density. Alces 54: 45-54.

Joyce, T.L., and S. Mahoney. 2001. Spatial and temporal distributions of moose-vehicle collisions in Newfoundland. Wildlife Society Bulletin 29(1): 281-291. doi: 10.2307/3784010.

Klassen, N. A., and R. V. Rea. 2008. What do we know about nocturnal activity of moose? Alces 44: 101-109.

Laforge, M. P., D. A. Clark, A. L. Schmidt, J. L. Lankshear, S. Kowalshuk, and R. K. Brook. 2017a. Temporal aspects of polar bear (*Ursus maritimus*) occurrences at field camps in Wapusk National Park, Canada. Polar Biology 40: 1661-1670.

Laforge, M. P., N. L. Michel, and R. K. Brook. 2017b. Spatio-temporal trends in crop damage inform recent climate-mediated expansion of a large boreal herbivore into an agro-ecosystem. Scientific Reports 7(15203). doi: 10.1038/s41598-017-15438-x.

Laforge, M. P., N. L. Michel, A. L. Wheeler, and R. K. Brook. 2016. Habitat selection by female moose in the Canadian prairie ecozone. The Journal of Wildlife Management 80(6): 1059-1068. doi: 10.1002/jwmg.21095.

Laliberté, J., and M.-H. St-Laurent. 2020. In the wrong place at the wrong time: moose and deer movement patterns influence wildlife-vehicle collision risk. Accident Analysis and Prevention 135(105365). doi: 10.1016/j.aap.2019.105365

Magle, S. B., M. Fidino, E. W. Lehrer, T. Gallo, M. P. Mulligan, M. J. Ríos, A. A. Ahlers, J. Angstmann, A. Belaire, B. Dugelby, A. Gramza, L. Hartley, B. MacDougall, T. Ryan, C. Salsbury, H. Sander, C. Schell, K. Simon, S. St Onge, and D. Drake. 2019. Advancing urban wildlife research through a multi-city collaboration. Frontiers in Ecology and the Environment 17(4): 232-239. doi: 10.1002/fee.2030.

Neumann, W., G. Ericsson, and H. Dettki. 2011. The impact of human recreational activities: moose as a case study. Alces 47: 17-25.

Ordiz, A., M. Aronsson, J. Persson, O.-G. Støen, J. E. Swenson, and J. Kindberg. 2021. Effects of human disturbance on terrestrial apex predators. Diversity 13(2): 68. doi: 10.3390/d13020068.

Pastor, J., R. J. Naiman, B. Dewey, and P. McInnes. 1988. Moose, microbes, and the boreal forest. Journal of Biosciences 38(11): 770-777.

Perry, T.A., M.P. Laforge, E. Vander wal, T.W. Knight, and P.D. McLoughlin. 2020. Individual responses to novel predation risk and the emergence of a landscape of fear. Ecosphere 11(8): e03216. doi: 10.1002/ecs2.3216.

Persson, I.-L., K. Danell, and R. Bergstrom. 2000. Disturbance by large herbivores in boreal forests with special reference to moose. Annales Zoologici Fennici 37: 251-263.

Patrignani, A., and T. E. Ochsner. 2015. Canopeo: a powerful new tool for measuring fractional green canopy cover. Agronomy Journal 107(6): 2312-2320. doi: 10.2134/agronj15.0150.

Pennock, D., T. Yates, A. Bedard-Haughn, K. Phipps, R. Farrell, and R. McDougal. 2010. Landscape controls on N2O and CH4 emissions from freshwater mineral soil wetlands of the Canadian Prairie Pothole region. Geoderma 155(3-4): 308-319. doi: 10.1016/j.geoderma.2009.12.015.

R Core Team. 2024. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rea, R. V., M. C. Scheideman, G. Hesse, and M. A. Mumma. 2021. The effectiveness of decommissioning roadside mineral licks on reducing moose (*Alces alces*) activity near highways: implications for moose-vehicle collisions. The Canadian Journal of Zoology 99(12): 1009-1019.

Risenhoover, K. L. 1986. Winter activity patterns of moose in interior Alaska. The Journal of Wildlife Management 50(4): 727-734. doi: 10.2307/3800990.

St. Pierre, M., and S. Mhlanga. 2022 Saskatchewan continues to live up to the title of breadbasket of Canada. https://publications.gc.ca/site/eng/9.912408/publication.html (Accessed January 2024).

Statistics Canada. 2021. 2021 Census of Population. https://www12.statcan.gc.ca/ (Accessed June 2024).

Teitelbaum, C. S., A. P. K. Sirén, E. Coffel, J. R. Foster, J. L. Frair, J. W. Hinton, R. M. Horton, D. W. Kramer, C. Lesk, C. Raymond, D. W. Wattles, K. A. Zeller, and T. L. Morelli. 2021. Habitat use as indicator of adaptive capacity to climate change. Diversity and Distributions 27(4): 655-667. doi: 10.1111/ddi.13223.

TAPE. K. D., D. D. GUSTINE, R. W. RUESS, L. G. ADAMS, and J. A. CLARK. 2016. Range expansion of moose in Arctic Alaska linked to warming and increased shrub habitat. PLoS One 11(4): e0152636. doi: 10.1371/journal.pone.0152636.

TIMMERMANN, H. R., and A. R. RODGERS. 2005. Moose: competing and complementary values. Alces 41: 85-120.

TIMMERMANN, H. R., and A. R. RODGERS. 2017. The status and management of moose in North American – circa 2015. Alces 53: 1-22.

TRANULIS, M. A., and M. TRYLAND. 2023. The zoonotic potential of chronic wasting disease – a review. Foods 12(824). doi: 10.3390/foods12040824.

VER HOEF, J. M., and P. L. BOVENG. 2007. Quasi-poisson vs. negative binomial regression: how should we model overdispersed count data? Ecology 88(11): 2766-2772.

WATTLES, D. W., and S. DESTEFANO. 2011. Status and management of moose in the northeastern Unites States. Alces 47: 53-68.

WATTLES, D. W., K. A. ZELLER, and S. DESTEFANO. 2018a. Range expansion in unfavorable environments through behavioural responses to microclimatic conditions: moose (*Alces americanus*) as the model. Mammalian Biology 93: 189-197.

WATTLES, D. W., K. A. ZELLER, and S. DESTEFANO. 2018b. Response of moose to a high-density road network. The Journal of Wildlife Management 82(5): 929-939. doi: 10.1002/jwmg.21459

WEISKOPF, S. R., O. E. LEDEE, and L. M. THOMPSON. 2019. Climate change effects on deer and moose in the Midwest. The Journal of Wildlife Management 83(4): 769-781. doi: 10.1002/jwmg.21649

WELCH, J. H., P. S. BARBOZA, S. D. FARLEY, and D. E. SPALINGER. 2015. Nutritional value of habitat for moose on urban and military lands. Journal of Fish and Wildlife Management 6(1): 158-175.

WILKEN, E.B., D. GAUTHIER, I. MARSHALL, K. LAWTON, and H. HIRVONEN. 1996. A Perspective on Canada's ecosystems: an overview of the terrestrial and marine ecozones. The Canadian Council on Ecological Areas (CCEA), Ottawa, Canada.

WOLFE, M. L., K. R. HERSEY, and D. C. STONER. 2010. A history of moose management in Utah. Alces 46: 37-52.

ZHOU, J., G. P. KOFINAS, K. KIELLAND, R. B. BOONE, L. PRUGH, and K. D. TAPE. 2022. Climate change, moose, and subsistence harvest: socio-ecological assessment of Nuiqsut, Alaska. Ecology and Society 37(3): 29. doi: 10.5751/ES-13175-270329.

SUPPLEMENTARY TABLE

Table S1. GLM candidate model comparison results for selecting the best fit model of moose occurrence (*n* = 29 cameras) in Saskatoon, Saskatchewan, Canada, 2020-2023. Number of model variables (K), evaluation of model fit (AIC), and AIC difference between best fit and other candidate models (ΔAIC). Lowest AIC score indicated best fit model.

Model	K	AIC	ΔAIC
Month + Time_of_Day + Development + Dom_Landcover	4	378.1	0.0
Month + Time_of_Day + Development + Canopy_Cover + Dom_Landcover	5	379.8	1.7
Month + Time_of_Day + Development + Avg_Veg_Height + Canopy_Cover + Dom_Landcover	6	381.8	3.7