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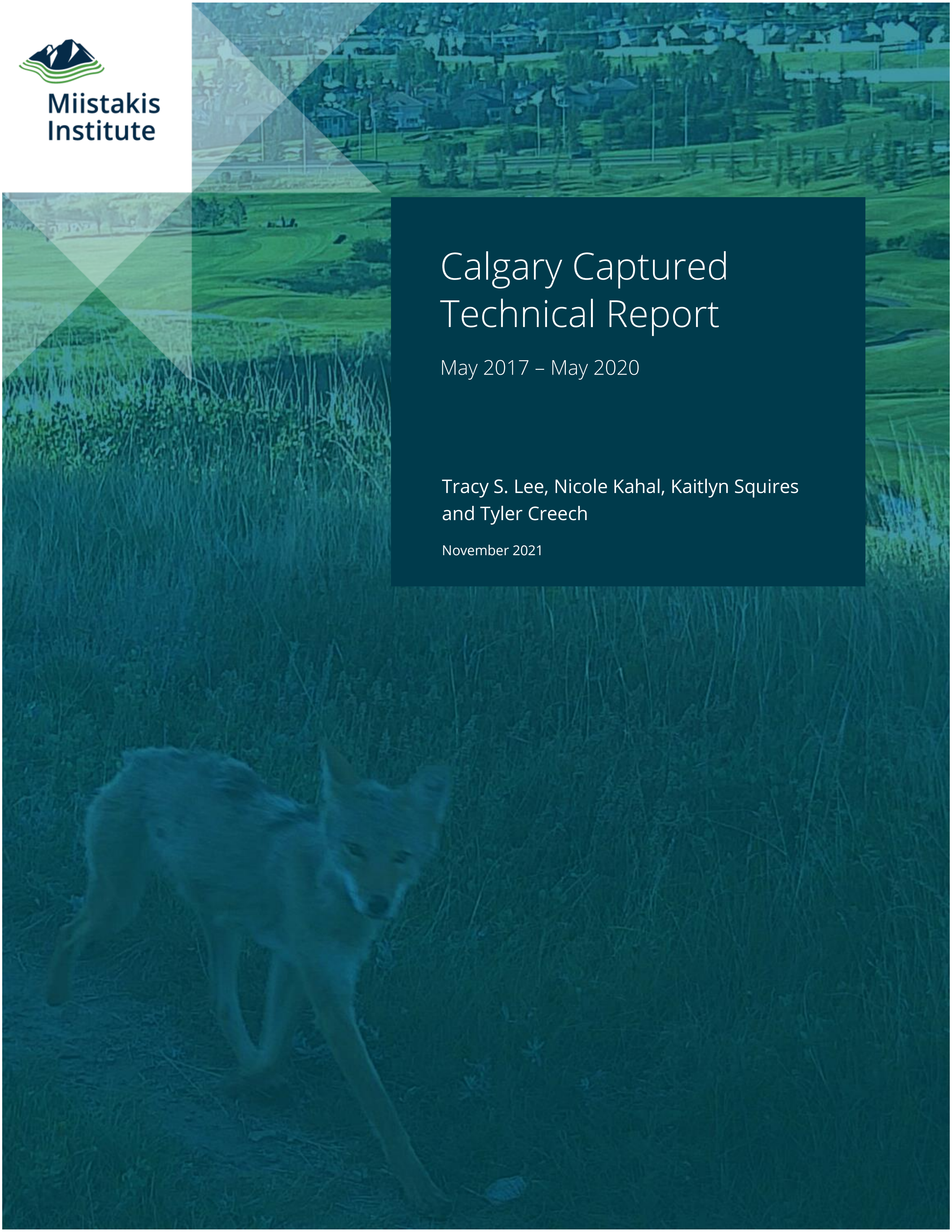

Calgary Captured Technical Report

May 2017 – May 2020

Tracy S. Lee, Nicole Kahal, Kaitlyn Squires and Tyler Creech

November 2021

Innovative research. Engaged communities. Healthy landscapes.

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Prepared by Tracy S. Lee, Nicole Kahal, Kaitlyn Squires and Tyler Creech

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Acknowledgements

CALGARY CAPTURED

Citizens engaged in urban wildlife monitoring

We would like to thank the citizen scientists that participated in the Calgary Captured program by classifying remote camera images on Zooniverse. Without them, we would not have this fantastic urban wildlife dataset. We would also like to thank Miistakis volunteers and Friends of Fish Creek Camera Crew volunteers who helped with data collection and image classification for images from Fish Creek Provincial Park using Wild Trax. Thank you to Sara Jordan-McLachlan for camera management role, and Ken Sanderson for his technical expertise.

Thank you to the following generous supporters, The Calgary Foundation, TD Friends of the Environment Foundation and Alberta Ecotrust. We would also like to acknowledge our program partners, The City of Calgary, Alberta Environment and Parks, Friends of Fish Creek Provincial Park Society and Weaselhead/Glenmore Park Preservation Society for their guidance, contributions, and enthusiasm for Calgary Captured.

Executive Summary

The Calgary Captured program aims to improve our understanding of how medium to large terrestrial mammals are using natural areas and moving around the urban landscape. The City of Calgary is well known for its park system, the entire system makes up over 70 km^2 of land. Additionally, the network is enhanced by Fish Creek Provincial Park, a large park (13 km^2) extending east from the city limits to the confluence of Fish Creek and the Bow River. Calgary Captured is a multiyear wildlife monitoring program that uses motion-activated camera traps placed in key natural environment parks and natural movement corridors. The resulting images provide insight into which animals live in Calgary, and how they move around the built environment. Cameras were placed on game trails and not on high human use trails within natural areas.

We set up 97 camera traps across 19 natural area parks between May 9, 2017 and May 31, 2020. The majority of events (76%) are either human with or without a dog (58%) or a domestic animal without a human (18%). The remaining events (24%) are wildlife and include deer (77%), coyote (19%) and 4% other species (including moose, red fox, bobcat, cougar, black bear, raccoon, and porcupine).

Wildlife activity levels and spatial distribution

Medium to large terrestrial mammals were detected in all natural areas in our camera traps. Distribution across natural areas varied among species, with white-tailed deer, coyote and mule deer occurring in all natural areas. White-tailed deer had the highest activity levels in the City and deer species (both mule and white-tailed) generally were the most active in natural areas. The exceptions were HD241, Tom Campbell, Winston Heights, North Glenmore and Edworthy where coyotes were more active. We found species diversity to be highest in Fish Creek Provincial Park, Griffith Woods, Bowmont and Weaselhead.

Less commonly detected species such as cougar, black bear and moose are predominately limited to natural areas closer to the city boundary such as Griffith Woods, Weaselhead and Fish Creek Provincial Park.

Seasonal and diel wildlife activity

We looked at seasonal activity pooled across cameras and study areas and found human use of parks exhibited a clear spring–summer peak. Seasonal activity rate was more consistent throughout the year for wildlife, with peaks observed in June, July and November.

Daily activity patterns also appeared to vary among seasons. Non-wildlife events were concentrated during daylight hours in all seasons. For wildlife, diel patterns were more complex: activity rate was relatively constant throughout the day during winter, exhibited moderate peaks at dawn and dusk during spring and fall, and strong dawn and dusk peaks during summer.

Human and domestic dog influence on wildlife

Almost all natural areas had higher levels of human use with or without domestic dogs than wildlife. Here, the exceptions were Inglewood (restricted access), Haskyne (restricted access), Edgemont and Griffith Woods.

We explored wildlife responses to non-wildlife (e.g., human and domestic dog, unaccompanied domestic dog, cattle, horse, domestic cat and goat) activity using three approaches to provide a picture of wildlife responses to non-wildlife activity from multiple perspectives.

Our analyses of the relationship between non-wildlife activity rate and proportion of wildlife activity occurring during nighttime suggest that wildlife is more active at night in locations with more non-wildlife activity. However, this relationship was weak for some species. Mule deer and coyotes are known to thrive in human-dominated systems, so it may not be surprising that our data suggest they are not as sensitive to human activity as other species. White-tailed deer, however, were more active at night in areas where there was a high level of human activity.

Temporal overlap analyses of human or dog activity and wildlife species activity suggested that some species, particularly carnivores such as cougar and red fox, are visiting Calgary's parks almost entirely during nighttime hours when humans and dogs are not present. However, other species such as coyote, and to a lesser degree deer and moose, seem to overlap with non-wildlife park users during morning and evening. Wildlife overlapped less with off-leash or unaccompanied domestic dogs than with humans or humans with dogs.

Avoidance-attraction ratios at the scale of one camera showed no evidence of any wildlife species avoiding camera locations immediately as a result of being visited by non-wildlife.

Wildlife species may have shifted their long-term diel activity patterns to minimize the probability of encountering humans and domestic dogs, but we did not observe short-term responses to these encounters.
The sensitivity of most medium to large terrestrial mammals, especially carnivores, to high levels of human activity and off-leash domestic dogs supports parks closures during nighttime hours.

We recorded off-leash dog activity in on-leash areas in all natural areas. Areas where education or enforcement could be considered include Nose Hill, Confluence, Edworthy and Southern portion of Fish Creek Provincial Park.

Introduction

The Calgary Captured program aims to improve our understanding of how wildlife is using natural areas and moving around the urban landscape. A multiyear wildlife monitoring program, Calgary Captured uses motion-activated camera traps placed in key natural environment parks and natural movement corridors to gain insight into which animals live in Calgary, how they move around the built environment and their responses to human activity. Managed by the Miistakis Institute and City of Calgary, this partnership also includes Alberta Environment and Parks, Friends of Fish Creek Provincial Park Society, and Weaselhead/Glenmore Park Preservation Society. Calgary Captured aims to use the information gathered to facilitate better development and management decisions that protect and enhance Calgary's ecological network. This report summarizes our findings for a three-year period (May 2017 to May 2020).

Background

The City of Calgary is well known for its park system that includes over 70 km^2 of land within city limits. This network is additionally enhanced by Fish Creek Provincial Park, a 13 km^2 protected area extending east from the city limits to the confluence of Fish Creek and the Bow River. The City recently published an ecological network in their Municipal Development Plan that outlines opportunities for wildlife movement; however, fragmentation of these areas due to urban growth is an ever-increasing threat to maintaining healthy wildlife populations.

Gathering information on the species that inhabit the City and urban parks improves our ability to maintain healthy wildlife populations. Calgary Captured aims to determine wildlife presence within City of Calgary Natural Areas to help inform our understanding and management of urban wildlife. The results of our analyses will inform strategic planning in relation to implementation of the Calgary BiodiverCity Strategy, Natural Areas Park Management Plan, Ecological Network, as well as individual park management plans. In addition, by involving citizen scientists to classify camera trap images, the program spreads awareness and encourages Calgarians to become champions for wildlife monitoring and conservation.

The program has developed the following objectives:

- Determine which species of large and medium sized mammals occur in Calgary's park system;
- Engage Calgarians in wildlife monitoring through the design and implementation of a citizen science program monitoring wildlife; and
- Improve the understanding of how wildlife responds to development and use of wildlife corridors in the City of Calgary.

Methodology

Camera trap methods

Motion sensor remote camera traps (Recoynx and Stealth models) were used to detect and record wildlife throughout parks in Calgary. The camera traps use an infrared flash invisible to people and most wildlife, to record the presence of medium and large sized mammals that pass within the camera's detection range. Over the duration of the program, we have placed 97 cameras in total at 106 sites in 19 parks. Sites were primarily located on game trails or human foot paths; busy human trails and paved pathways were avoided to reduce the need to process large numbers of human images. Cameras were active between May 9, 2017 and May 31, 2020.

A 1 km^2 grid was layered over park maps to systematically distribute cameras in each study area. In general, cameras were placed at the centre of each grid cell; however, there was some variability due to the smaller size of several parks and preference for choosing a location most likely to capture wildlife movement. The number of camera sites in each study area was roughly proportional to the size of the study area. Exceptions included Weaselhead Park (which had additional cameras in a few of the grid cells during the first 3 months of the study to support a Southern Alberta Institute of Technology program), as well as a few smaller natural areas that have more than one camera in a grid cell. Cameras were placed on a tree ~1 m from the ground and 1–3 m from the monitoring area (trail, open space). Each time motion was detected by the camera, three images were taken with the time and date recorded on each image. Monitoring was continuous from the time the cameras were set up. Occasionally, cameras were damaged or stolen. In such instances, a replacement camera was installed on a different trail within the same grid cell. If cameras were stolen twice from one grid cell, that grid cell was retired.

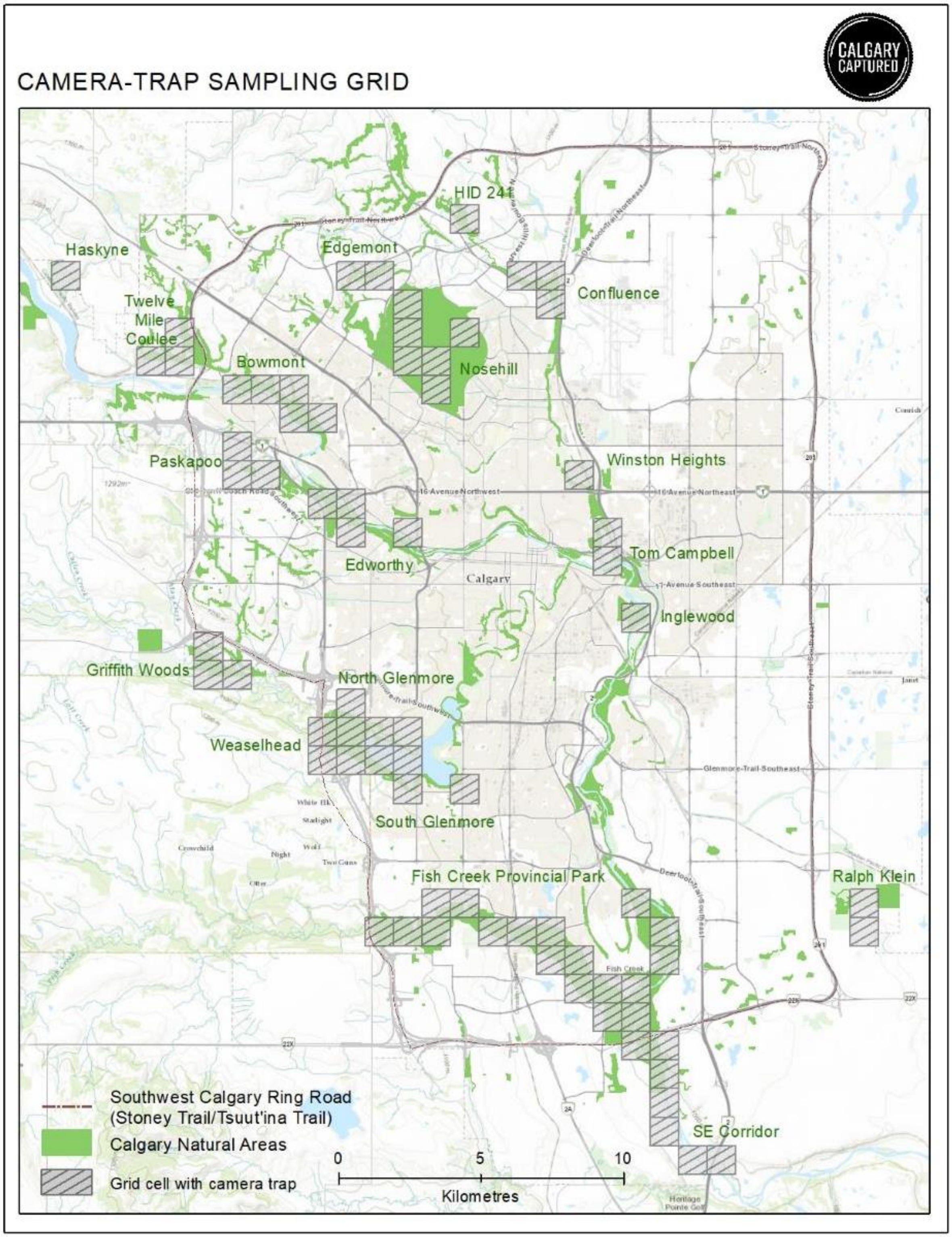

Figure 1: The 1 km^2 sampling grid used to establish camera locations in Calgary natural areas.

Camera trap survey limitations

- Failure to detect a species is not evidence of its absence, as an animal may travel out of a camera trap's detection range.
- Camera traps will unavoidably capture images of species that are unidentifiable. For example, 1% of events were classified as "unknown".
- Although camera traps were located within their own 1 km^2 grid, spatial autocorrelation (the statistical bias of counting one animal captured at two sites as two different animals) is difficult to avoid (Ancrenaz *et al.* 2012). To address this issue we limited our analysis to reporting wildlife activity as opposed to occupancy which requires cameras to be spatially independent.
- Issues, such as camera malfunction and theft, resulted in loss of data due to an inability to collect images while cameras were inoperative (prior to our knowledge of the issue). Cameras were replaced as soon as an issue was identified; however, this resulted in highly variable sample effort among study areas.

Species identification

Citizen scientists classified the wildlife images from natural areas using the online Zooniverse platform. Each wildlife image was classified by 5 to 8 individuals and images with fewer than 75% agreement on species in images were flagged for review. As well, images that resulted in Zooniverse classifications of rare or unusual species (bear, fox, etc.) were reviewed. Citizen scientists from Friends of Fish Creek helped classify images from Fish Creek Provincial Park using the Alberta Biodiversity Monitoring Institute (ABMI) Wild Trax Program.

Events

Human and wildlife events are considered independent if the time between consecutive images of the same species was more than 30 minutes apart. All images were processed through Artificial Intelligence classification software developed by the City of Calgary to separate images into blanks, human and wildlife. All folders were reviewed by Miistakis staff to ensure images were classified correctly to type. To protect privacy, all human images were deleted after classification and were not uploaded to the public Zooniverse site. If a dog was recorded in an image containing a human, we reviewed it to determine if it was on- or off-leash.

Summary Statistics

In this section we outline specific analytical methods and results based on the three year wildlife monitoring dataset. We highlight species diversity in natural areas, wildlife and non-wildlife temporal activity pattern, wildlife and non-wildlife activity spatial activity patterns, impact of non-wildlife (humans and domestic dogs) on wildlife behaviour and document domestic dog activity and off-leash activity across natural environment parks.

Sampling Effort

The total sampling effort, measured in camera-days (i.e., one camera operating for one day), was highly variable among study areas, ranging from 305 for Tom Campbell to 19,338 for Fish Creek. We accounted for this variation where necessary when analyzing data. This wide variation in sampling effort among study areas partly reflects the fact that the study areas also vary widely in size, with larger study areas generally having more camera sites. When controlling for study area size (i.e., camera-days per unit area), sampling effort at the largest study areas such as Nose Hill and Fish Creek is somewhat less than most other study areas (Fig. 2).

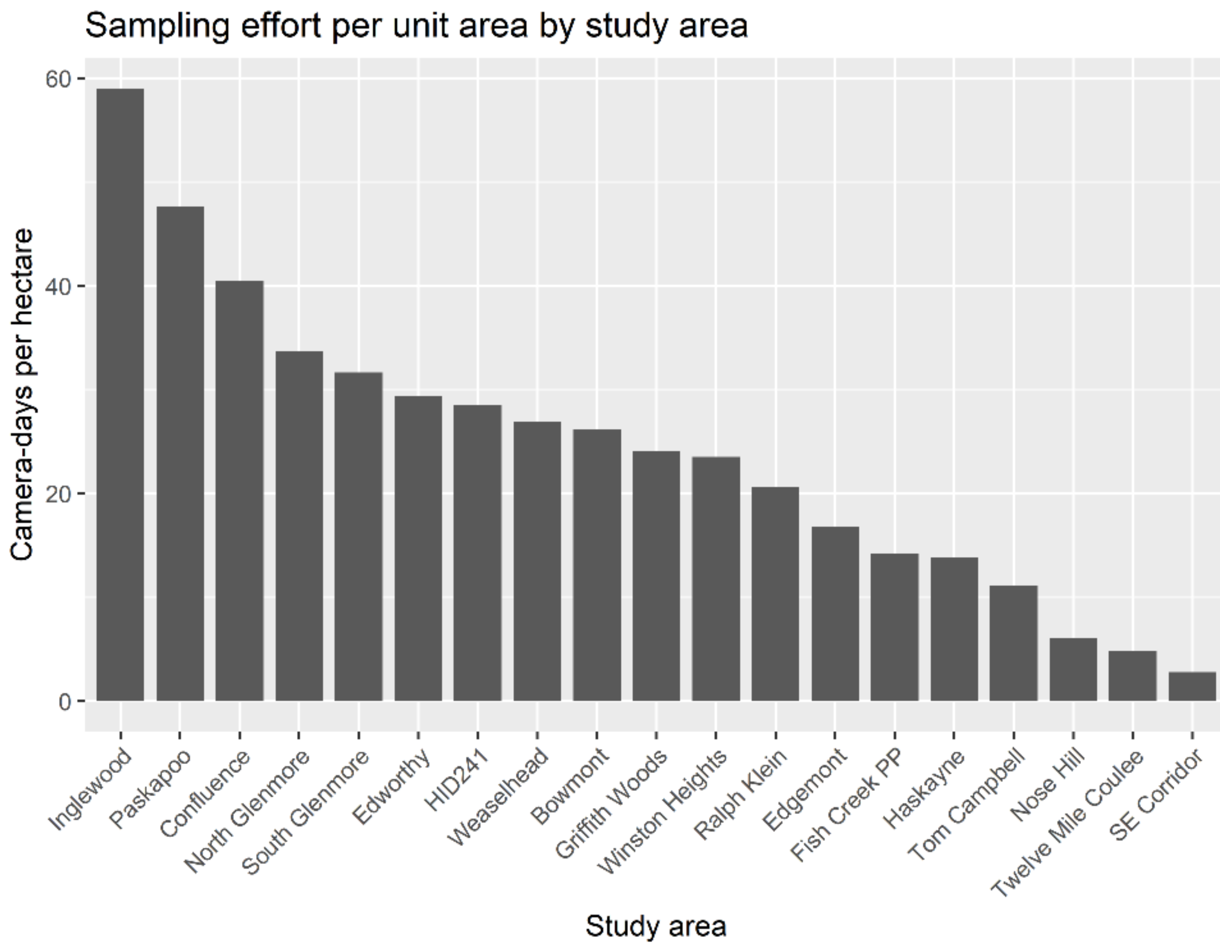

Figure 2: Variation in sampling effort and size among study areas. Sampling effort was measured in camera-days. Most study areas had multiple cameras operating simultaneously at different locations within the study area.

Human and Wildlife Events

Cameras recorded a total of 125,765 events during the study. Approximately 20% of these events were false triggers (i.e., no animals or humans recorded in images), and 1% were events for which the species could not be determined. We removed these false trigger and unknown species events from the dataset prior to further analysis. We also removed 5,784 events involving small animals (birds, insects, rabbits, hares, squirrels, chipmunks, marmots, mice, and voles) because the study was focused on medium-to-large mammals, and the camera height and distance between cameras were not set up to reliably capture small animals.

Of the remaining 95,100 events, approximately 58% included humans (with or without dogs), 24% were of wildlife, and 18% were of domestic animals unaccompanied by humans. Approximately 2% of the 95,100 events were recorded during periods when cameras were known or suspected to be recording incorrect dates and/or times. These data were only included in analyses for which timing was irrelevant (e.g., species composition), but were excluded from other time-dependent analyses (e.g., seasonal variation in activity rates).

Taxonomic Composition and Species Diversity

Deer (white-tailed and mule) dominated wildlife events (77%), followed by coyotes (19%) and raccoons (1%; Table 1, Appendix 2). All other wildlife species comprised less than 1% each of wildlife events (Fig. 3). In cases where the exact species of many animals captured in images was not identifiable, we assigned each event to family (i.e., two taxonomic levels above species). This allowed a more reliable estimate of species composition and diversity patterns within and across study areas. For instance, weasel, ermine, mink, and marten were all assigned to family Mustelidae.

Table 1: Counts of camera trapping events by wildlife species pooled across all cameras and study areas. Note that some events were not classified to the species level.

SPECIES	NUMBER OF RECORDED EVENTS
WHITE-TAILED DEER	10,847
MULE DEER	3,336
COYOTE	4,357
DEER (UNKNOWN SPECIES)	3,652
RACCOON	263
PORCUPINE	226
BOBCAT	139
MOOSE	79
RED FOX	42
COUGAR	17
STRIPED SKUNK	30
BEAVER	28
BLACK BEAR	9
WEASEL	4
MARTEN	2
MINK	1

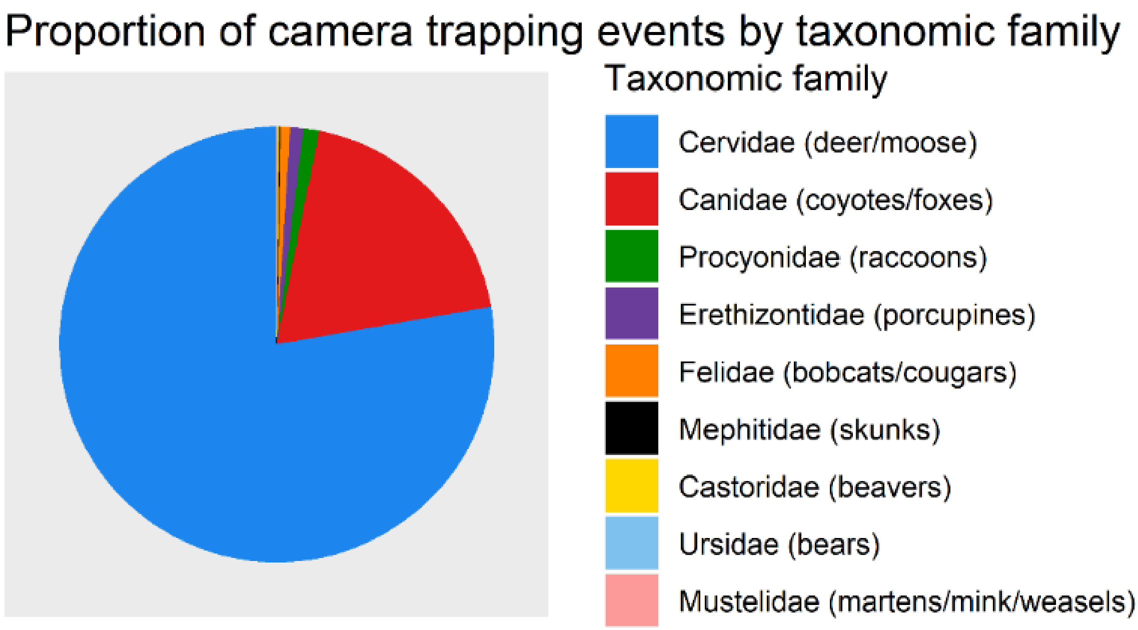

Figure 3: Overall taxonomic composition of wildlife events recorded by cameras. Events were pooled across all cameras and study areas.

We analyzed study areas for species richness (the number of unique taxonomic groups, i.e., species, genera, families, etc.) and diversity (richness accounting for the number of individuals detected from each species). Typically, richness is measured at the species level, but we measured richness at the family level for this analysis. Richness was calculated simply as the number of families observed at each study area. We calculated diversity using Simpson's index that has a possible range from 0 (no diversity) to 1 (greatest possible diversity).

Taxonomic composition was highly variable among sites, although the same few families were very common at nearly all sites in varying proportions (Fig. 4). The number of recorded families (i.e., richness) varied from 2 to 9 within study areas (Fig. 5). However, richness estimates are influenced by variation in sampling effort among study areas, with richness estimates higher in parks with more camera traps.

Estimates of overall diversity ranged from 0.58 for Edworthy, which contained observations of cervids, canids, and felids, to 0.05 for Inglewood, which was almost entirely cervid observations (Fig. 6).

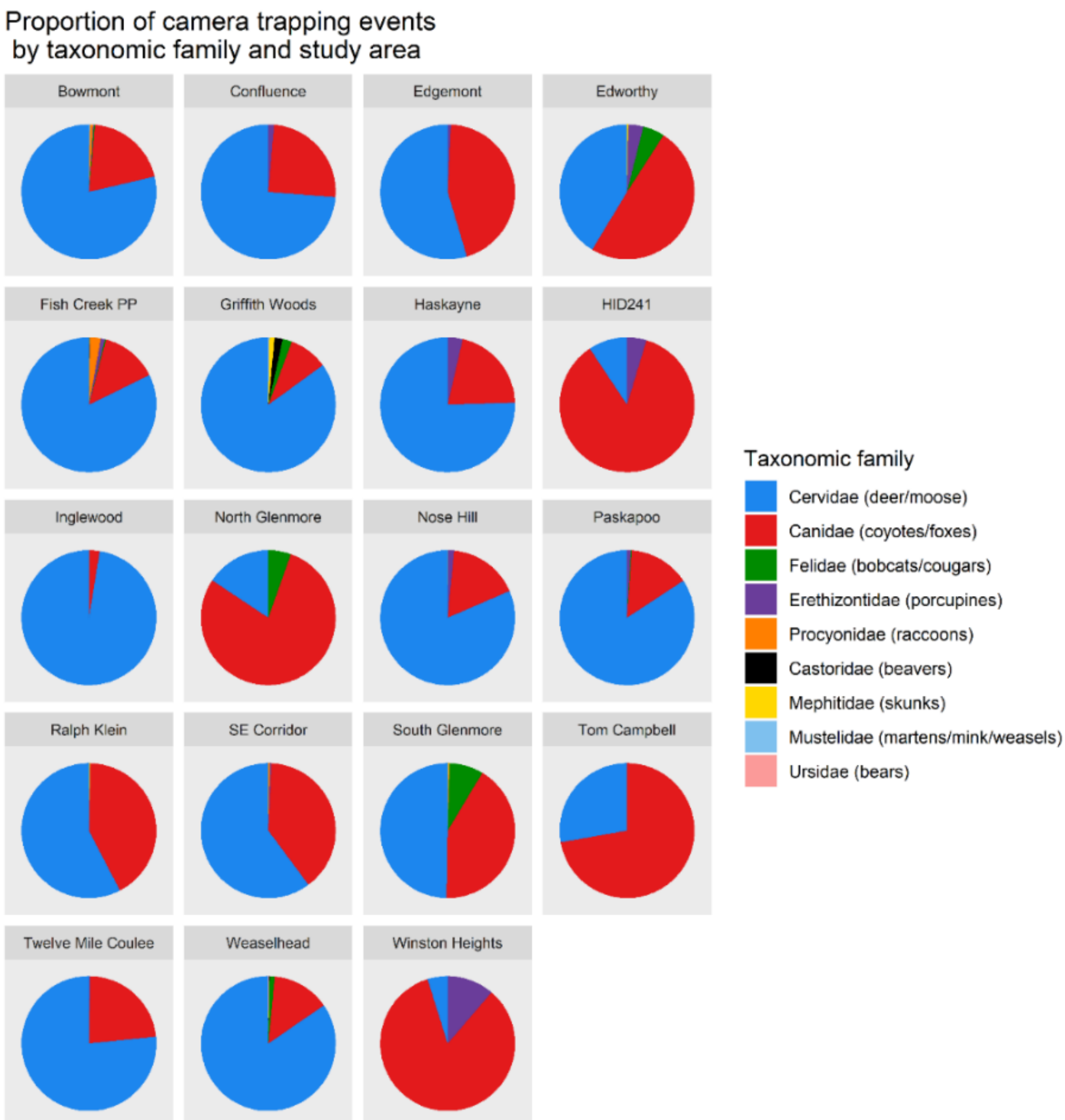

Figure 4: Taxonomic composition of wildlife events by study area. Events were pooled across cameras within each study area.

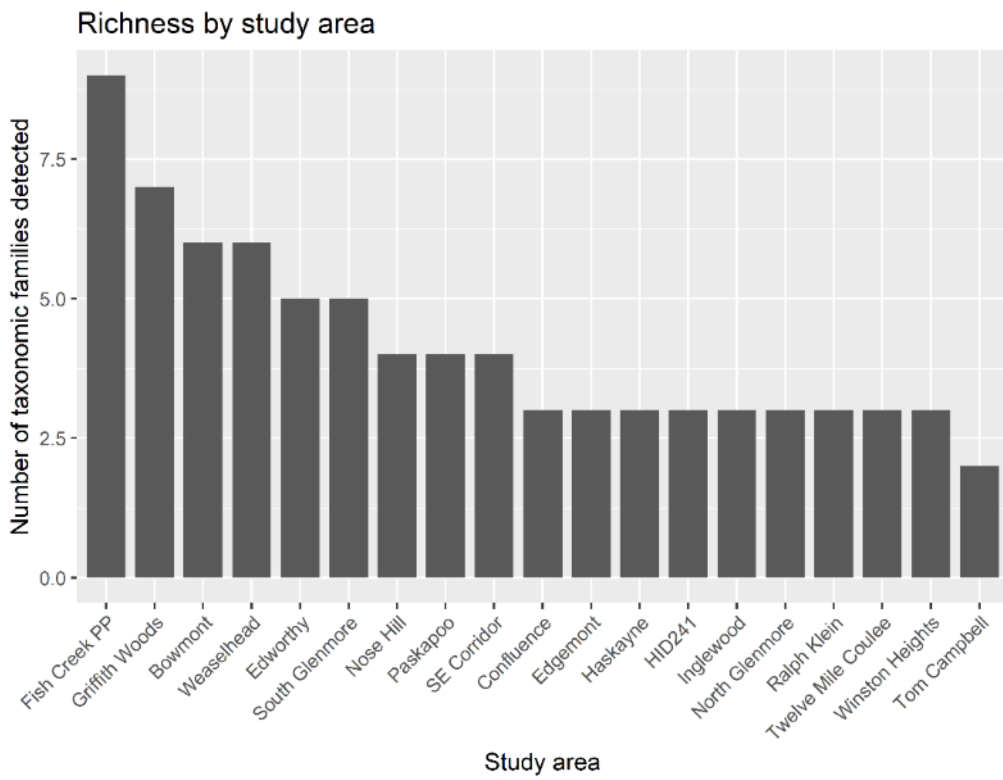

Figure 5: Taxonomic richness by study area. Richness was calculated as the number of families recorded by the cameras within a study area during the study.

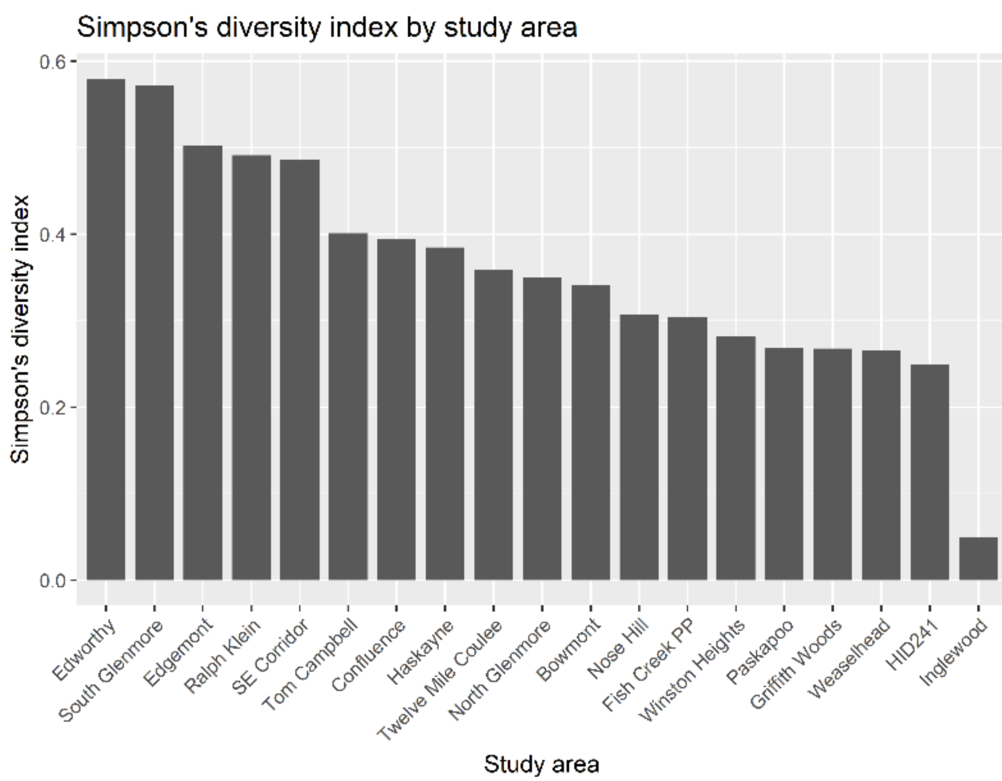

Figure 6. Taxonomic diversity by study area. Diversity was calculated using Simpson's index, which incorporates both richness and evenness. Simpson's index ranges from 0 (lowest possible diversity) to 1 (highest possible diversity).

Activity rates by study area

The total number of events recorded during the study varied widely among study areas (Fig. 6) and most study areas had more non-wildlife events (i.e., those involving humans and/or domestic animals) than wildlife events. In particular, far more wildlife and non-wildlife events were recorded within Fish Creek Provincial Park than within any other study area. However, these totals do not account for differences in sampling effort among study areas. After accounting for effort, the number of events recorded is more even among study areas (Fig. 7), especially for wildlife events.

Because the rate at which animals are recorded at a particular site is influenced by species abundance, movement patterns, camera set-up, habitat, and a variety of other potential confounding factors, it is most appropriate to interpret the rate at which animals are photographed as an *index* of animal activity at camera sites (Fig. 8) as opposed to a measure of absolute abundance.

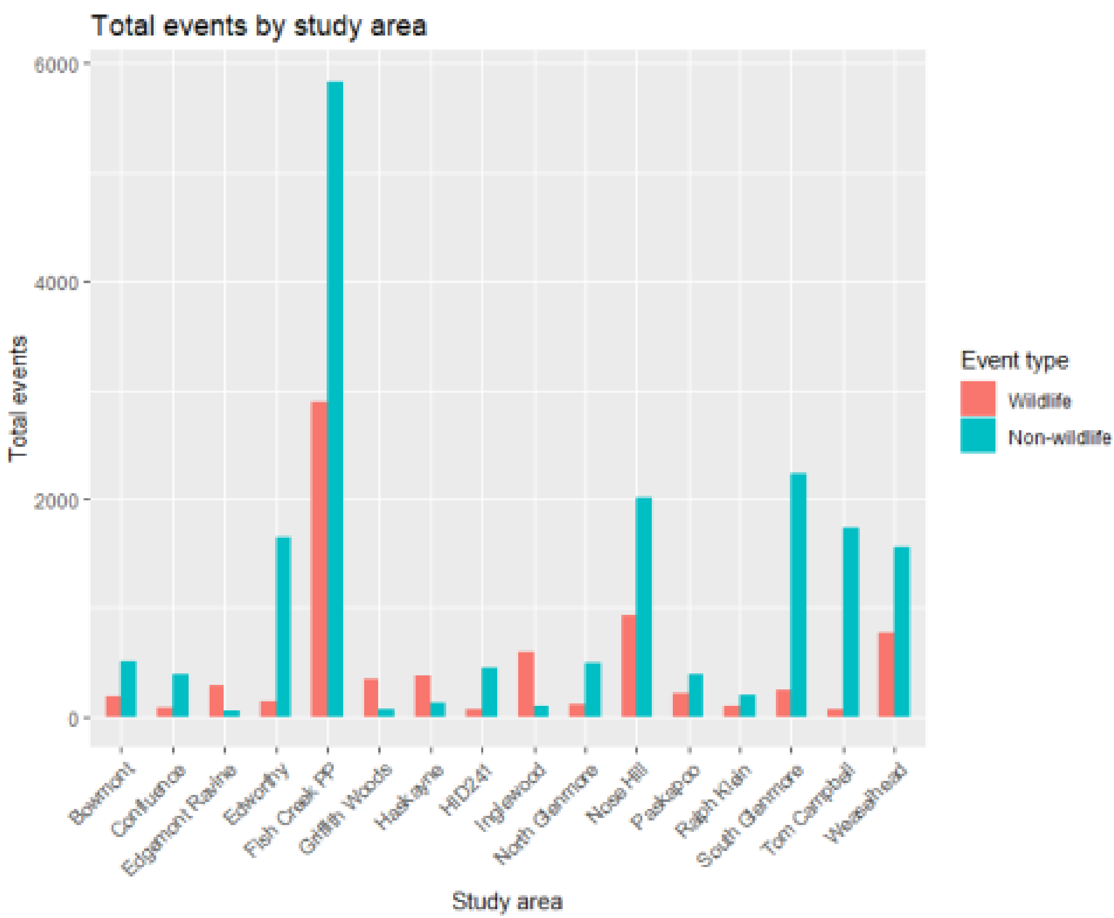

Figure 6: Total number of events recorded within each study area, broken down by event type (wildlife or non-wildlife).

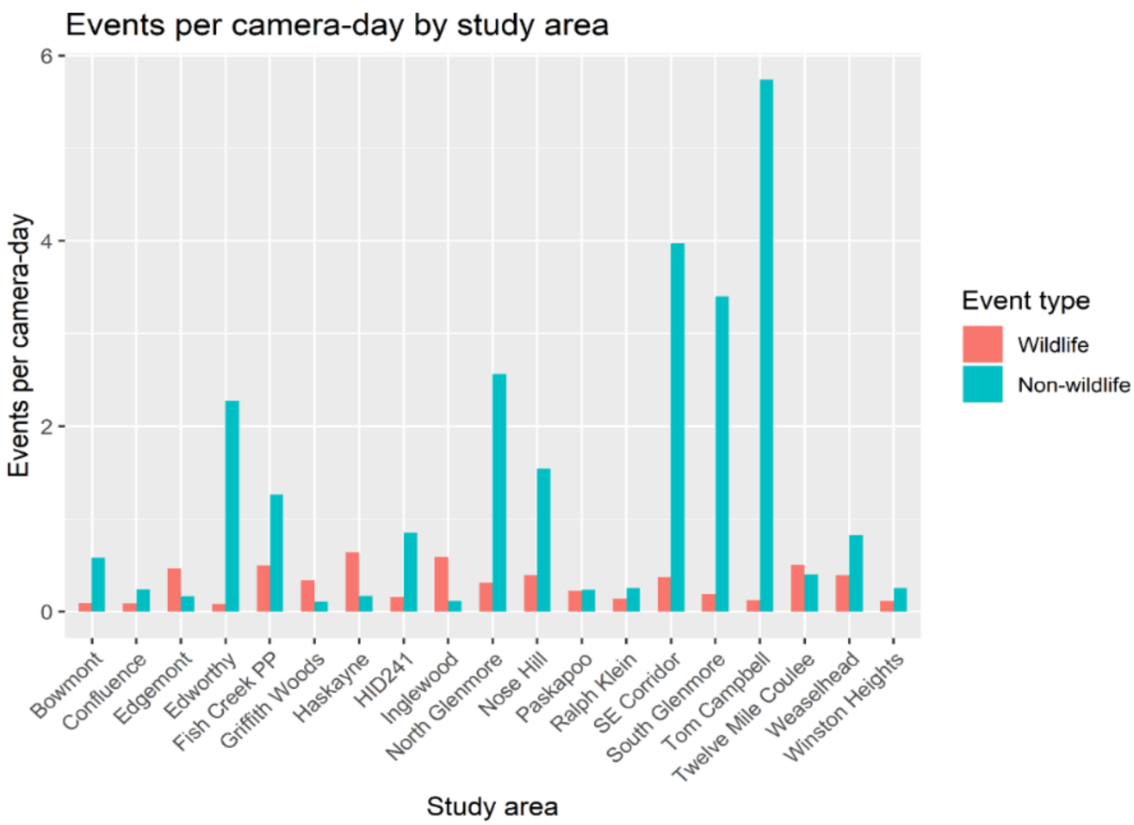

Figure 7: Rate of events recorded within each study area, broken down by event type (wildlife or non-wildlife), accounting for sampling effort.

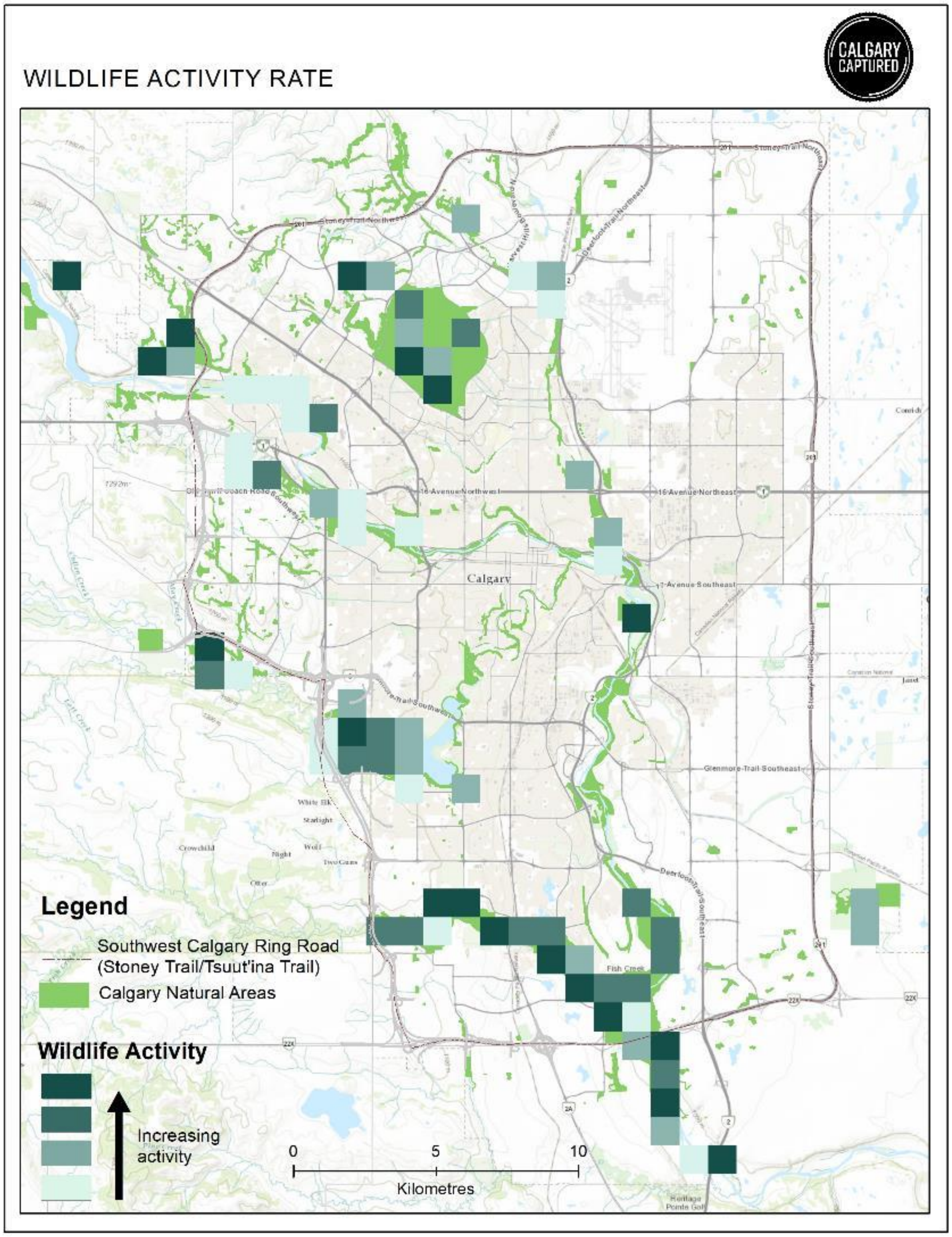

Figure 8: Map of wildlife activity rate among camera-trap study areas in Calgary, Alberta. Activity rates were calculated as the number of wildlife events per camera day for each grid cell. Activity rates depicted in 25% increments from most activity (dark green=top 25%) to least activity (light green=bottom 25%). Note that some grid cells included multiple cameras.

Seasonal & diel activity patterns

We observed seasonal variation in event rates for wildlife and non-wildlife (i.e., humans and domestic animals) when events were pooled across cameras and study areas (Fig. 9). Most notably, non-wildlife use of parks exhibited a clear spring–summer peak. Seasonal activity rate was more consistent throughout the year for wildlife, with highest rates observed in June, July, and November. We also examined seasonal activity patterns within three study areas selected for their large area and high use (Fish Creek PP, Nose Hill, and Weaselhead/Glenmore). We found that the seasonal patterns described above for the pooled data were also found for these individual study areas, although with some minor variation in the timing of wildlife and human activity peaks (Fig. 10).

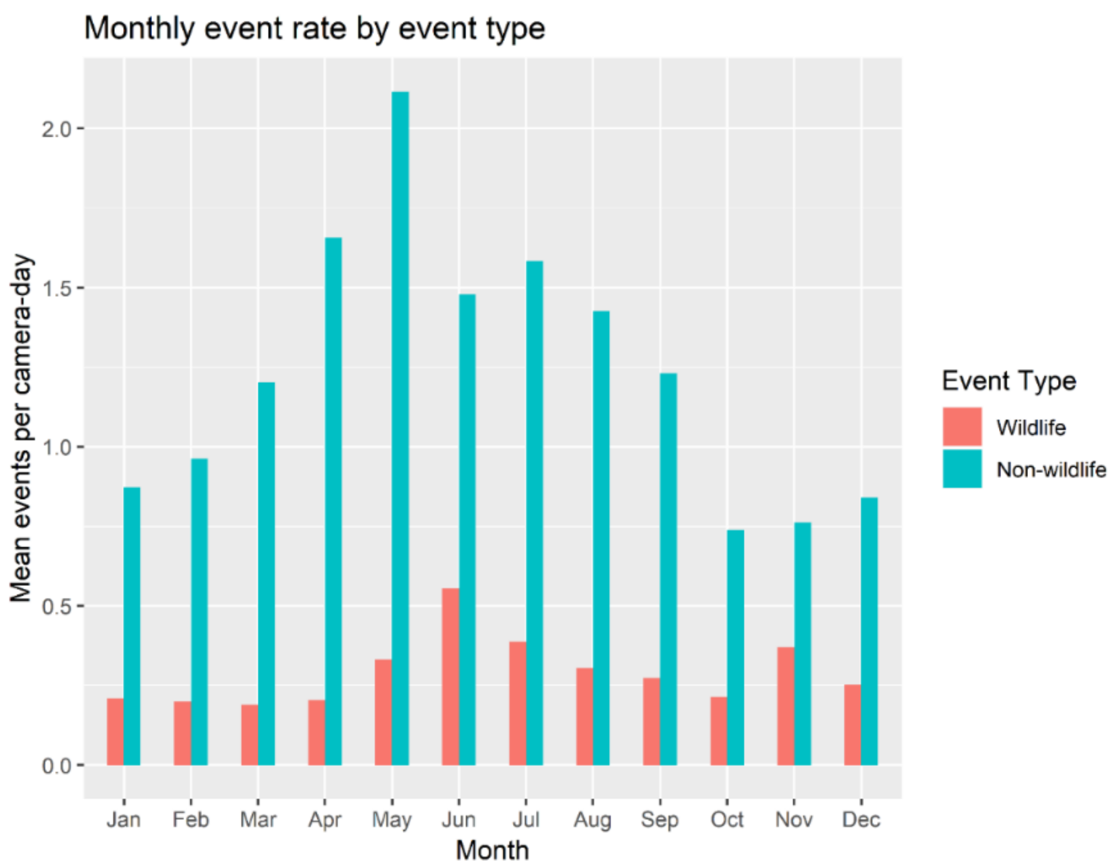

Figure 9: Monthly event rate for non-wildlife and wildlife events. Events were pooled across all cameras and study areas.

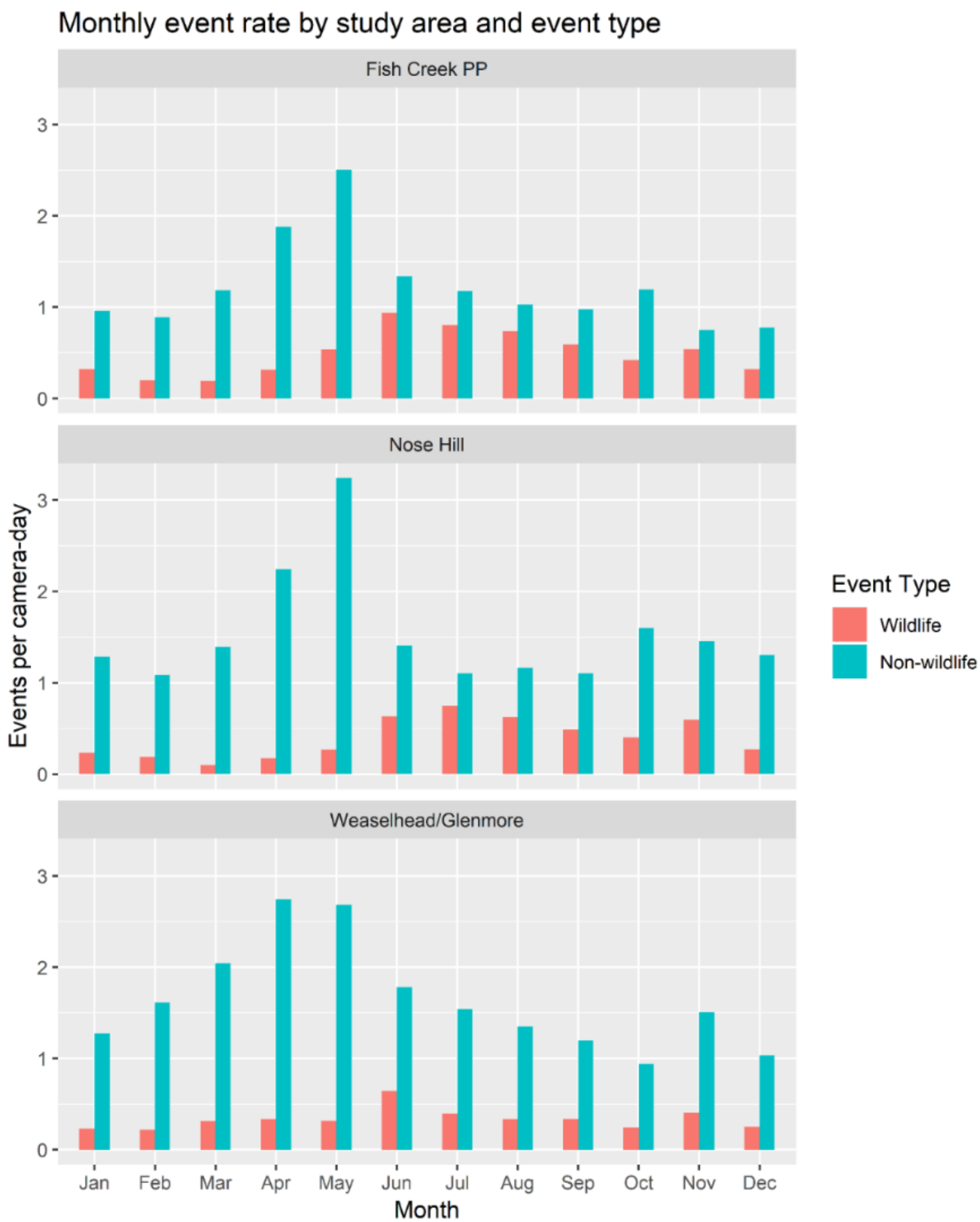

Figure 10: Monthly variation in rates of non-wildlife and wildlife events for select study areas. North Glenmore, South Glenmore, and Weaselhead study areas have been combined into a single unit (bottom panel).

We observed diel variation in event rates for non-wildlife and wildlife when events were pooled across cameras and study areas (Fig. 11). Diel activity patterns also appeared to vary among seasons. Non-wildlife events were concentrated during daylight hours in all seasons. For wildlife, diel patterns were more complex—activity rate was relatively constant throughout the day during winter, exhibited moderate peaks at dawn and dusk during spring and fall, and exhibited strong dawn and dusk peaks during summer.

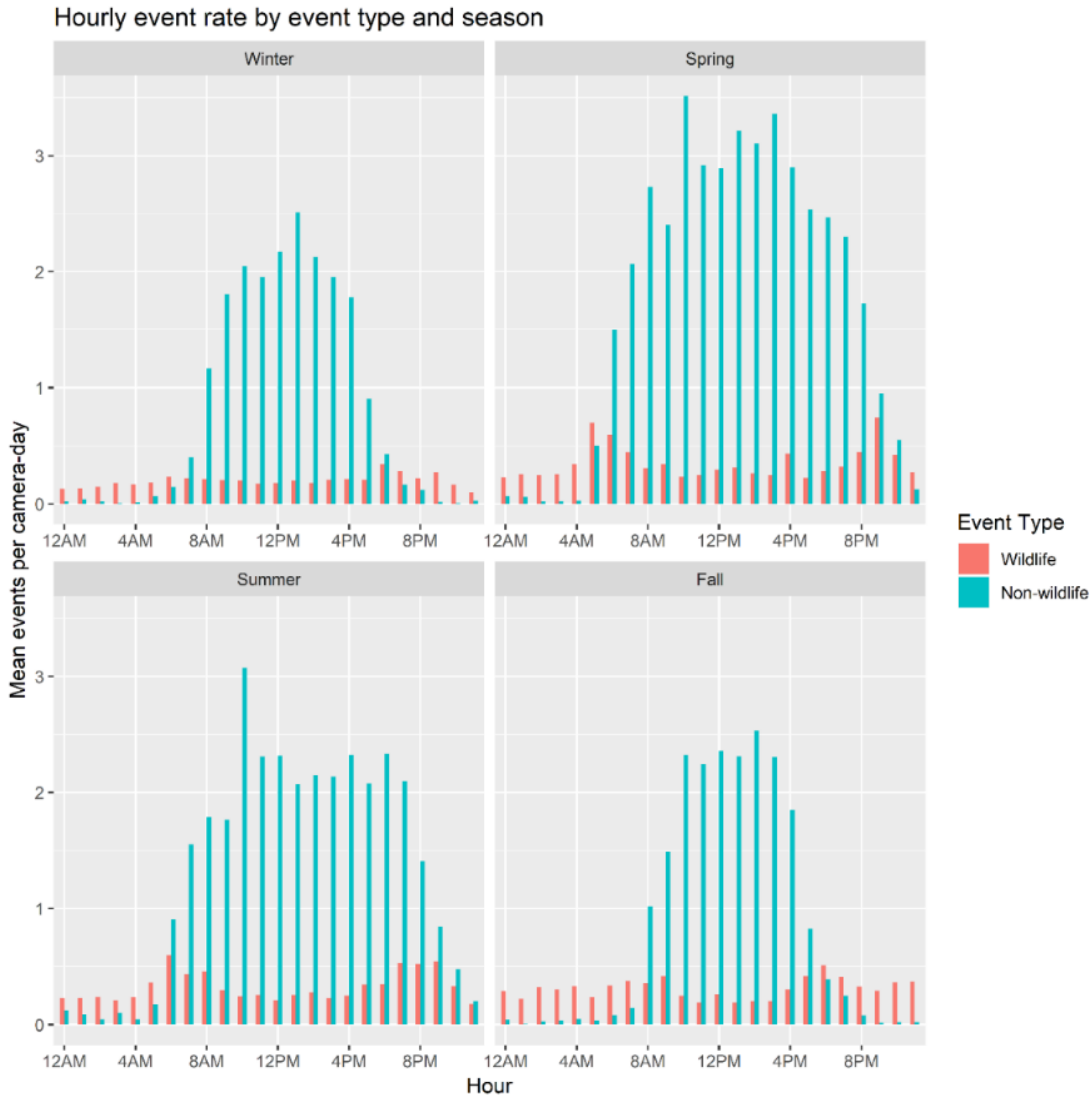

Figure 11: Diel variation in rates of non-wildlife and wildlife events, by season. Value on y-axis is the mean number of events per camera day, across all cameras within all study areas, during a particular hour of the day (x-axis). Winter=January–March; Spring=April–June; Summer=July–September; Fall=October–December.

We also examined diel patterns for three individual study areas: Fish Creek PP, Nose Hill, and Weaselhead/Glenmore (Figs. 12–14). There are some interesting differences among study areas. For instance, wildlife at Fish Creek and Nose Hill appear to exhibit stronger avoidance of humans (i.e., peak activity during hours when human use is lowest) than wildlife at Weaselhead/Glenmore. Fish Creek exhibits very strong dawn and dusk wildlife activity peaks in spring and summer, and a much lower wildlife activity rate in winter than in other seasons. Weaselhead/Glenmore has very dampened wildlife activity peaks during dawn and dusk, with similar activity level and timing in all seasons. Nose Hill has a much lower wildlife activity in winter than in other seasons, and an especially strong peak in wildlife activity around dusk in summer.

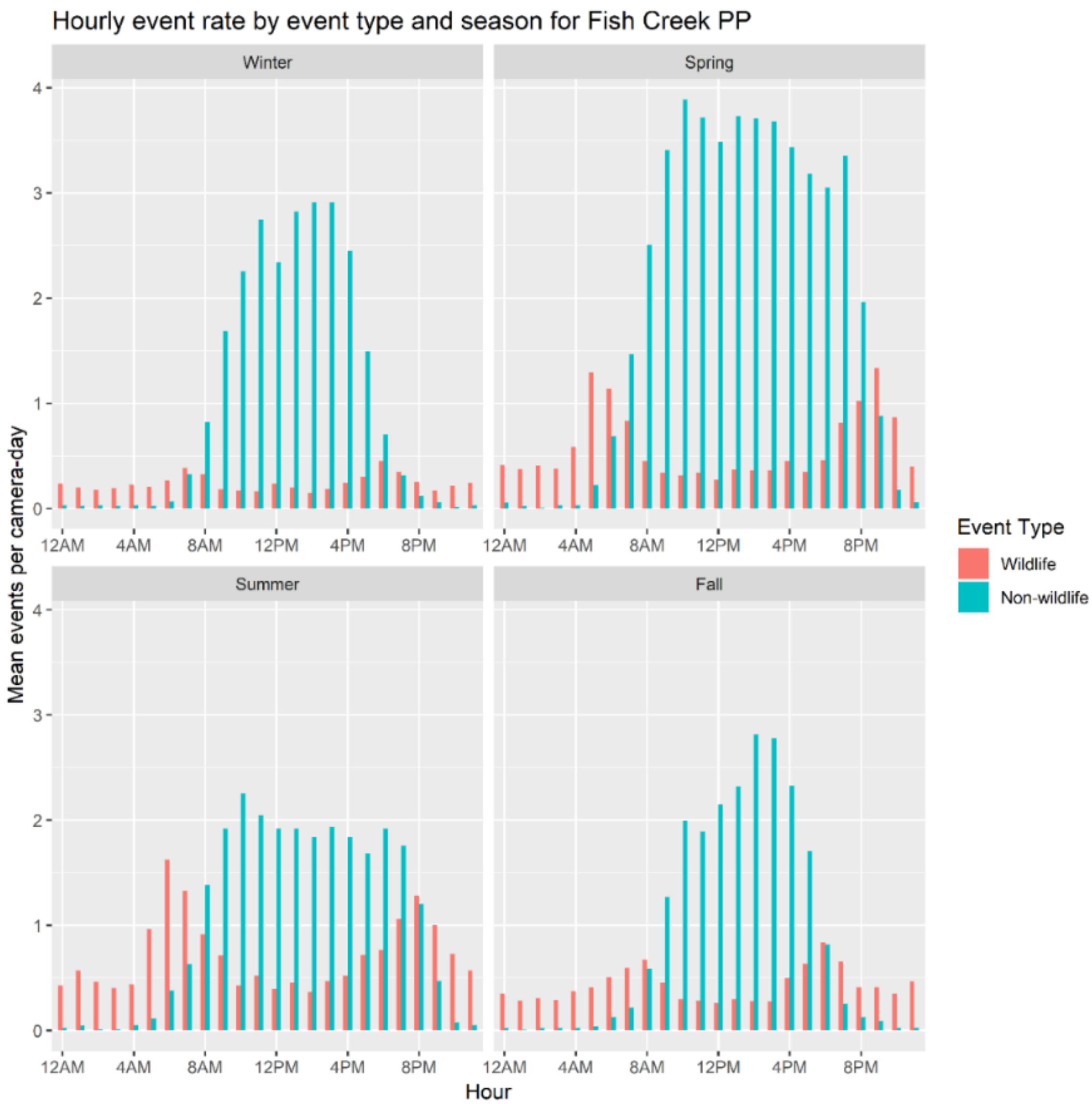

Figure 12: Diel variation in rates of non-wildlife and wildlife events, by season, for Fish Creek Provincial Park. Value on y-axis is the mean number of events per camera day, across all cameras within the study area, during a particular hour of the day (x-axis). Winter=January–March; Spring=April–June; Summer=July–September; Fall=October–December.

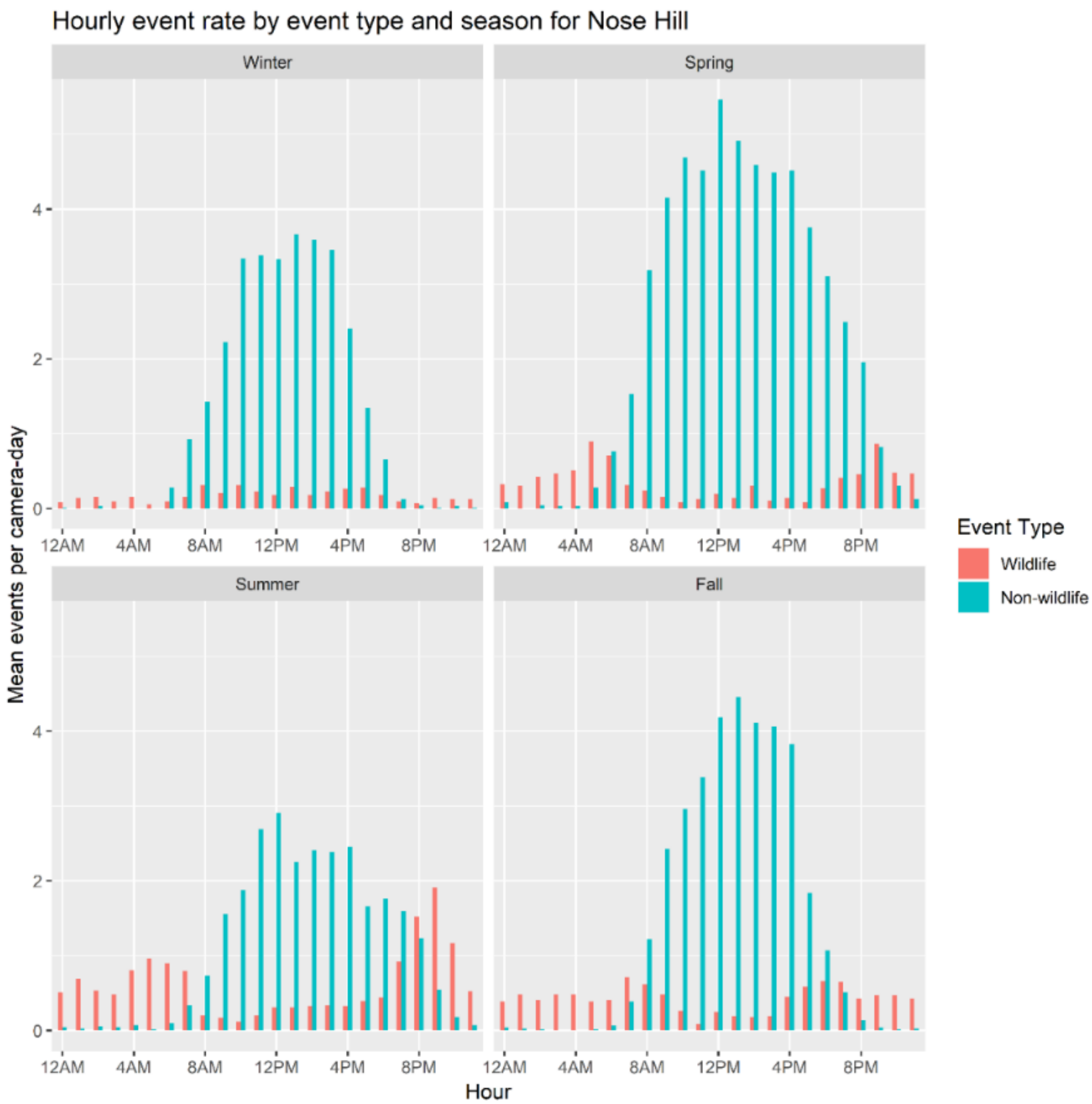

Figure 13: Diel variation in rates of non-wildlife and wildlife events, by season, for Nose Hill. Value on y-axis is the mean number of events per camera day, across all cameras within the study area, during a particular hour of the day(x-axis). Winter=January–March; Spring=April–June; Summer=July–September; Fall=October–December.

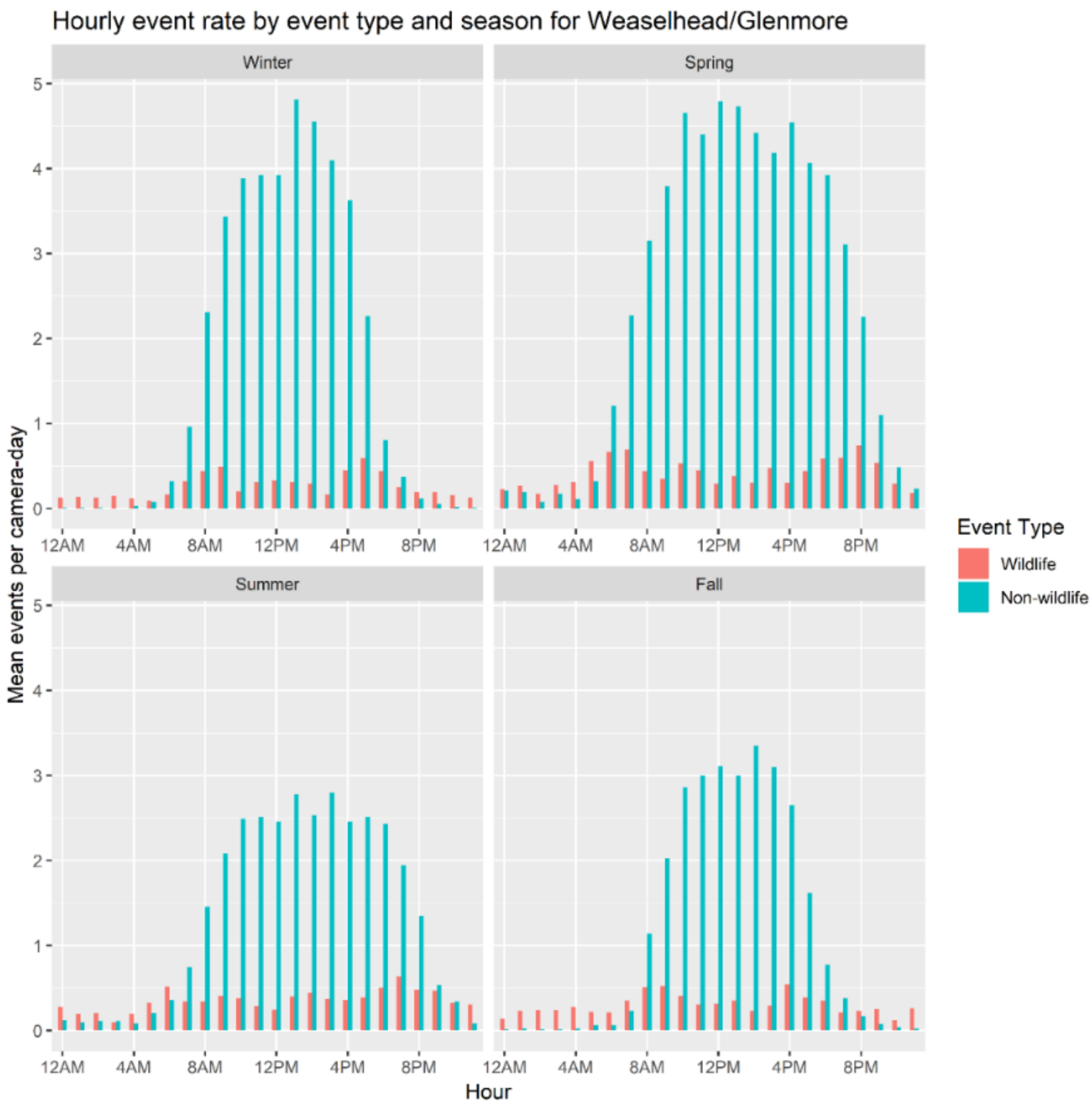

Figure 14: Diel variation in rates of non-wildlife and wildlife events, by season, for Weaselhead/Glenmore. Value on y-axis is the mean number of events per camera day, across all cameras within the study area, during a particular hour of the day (x-axis). Winter=January–March; Spring=April–June; Summer=July–September; Fall=October–December.

Wildlife responses to non-wildlife activity

We explored wildlife responses to non-wildlife (i.e., human and domestic dog) activity using three approaches. First, we used linear regression and t-tests to determine whether a relationship existed between non-wildlife activity rates at camera locations and the proportion of wildlife events occurring at night (defined as the period between sunset and sunrise) at these locations (Gaynor *et al.* 2018). If wildlife responds to non-wildlife activity by shifting their own activity to times when they are least likely to encounter humans and domestic animals (i.e., night), then we would expect to observe a positive relationship between non-wildlife activity rate and wildlife nocturnality across camera locations.

Because some cameras were located in close proximity to each other, the potential for spatial autocorrelation existed. A semivariogram analysis suggested no clear pattern of correlation related to distance between camera locations. We therefore treated all camera locations as independent.

A linear regression model of the relationship between non-wildlife activity rate and the proportion of wildlife events (all species combined) occurring at night across camera locations indicating a positive and statistically significant ($P = 0.001$) relationship (Fig. 15). We also ran regression analyses for four individual species (coyote, mule deer, white-tailed deer, and bobcat) and found similar results; weak but significant positive relationships ($P < 0.05$) for white-tailed deer but not for mule deer, coyote, or bobcat (Fig. 15).

It is interesting to see if wildlife become more active at night where daytime human activity is greater. To test this, we divided camera locations into two groups: locations of high and low non-wildlife activity with the median value across camera locations as a cutoff. We compared the mean proportion of wildlife events occurring at night among the groups using t-tests. As predicted, the shift from daytime to nighttime wildlife activity was greater where daytime non-wildlife activity was high. Where daytime non-wildlife activity was low, the difference in daytime and nighttime wildlife use was less pronounced. This was true for all wildlife species combined and for each individual species (coyote, mule deer, white-tailed deer, and bobcat), but the difference between group means was only statistically significant ($P < 0.05$) for white-tailed deer and for all wildlife species combined. Thus, wildlife appears to be generally more active at night in locations with higher use by humans and domestic animals, although the strength of this relationship varies among species. We found qualitatively similar results when we repeated the above analyses using only off-leash dog events to calculate the non-wildlife activity rate, which suggests that wildlife response to off-leash dogs is similar to their response to non-wildlife events (such as humans with or without leashed dogs) generally.

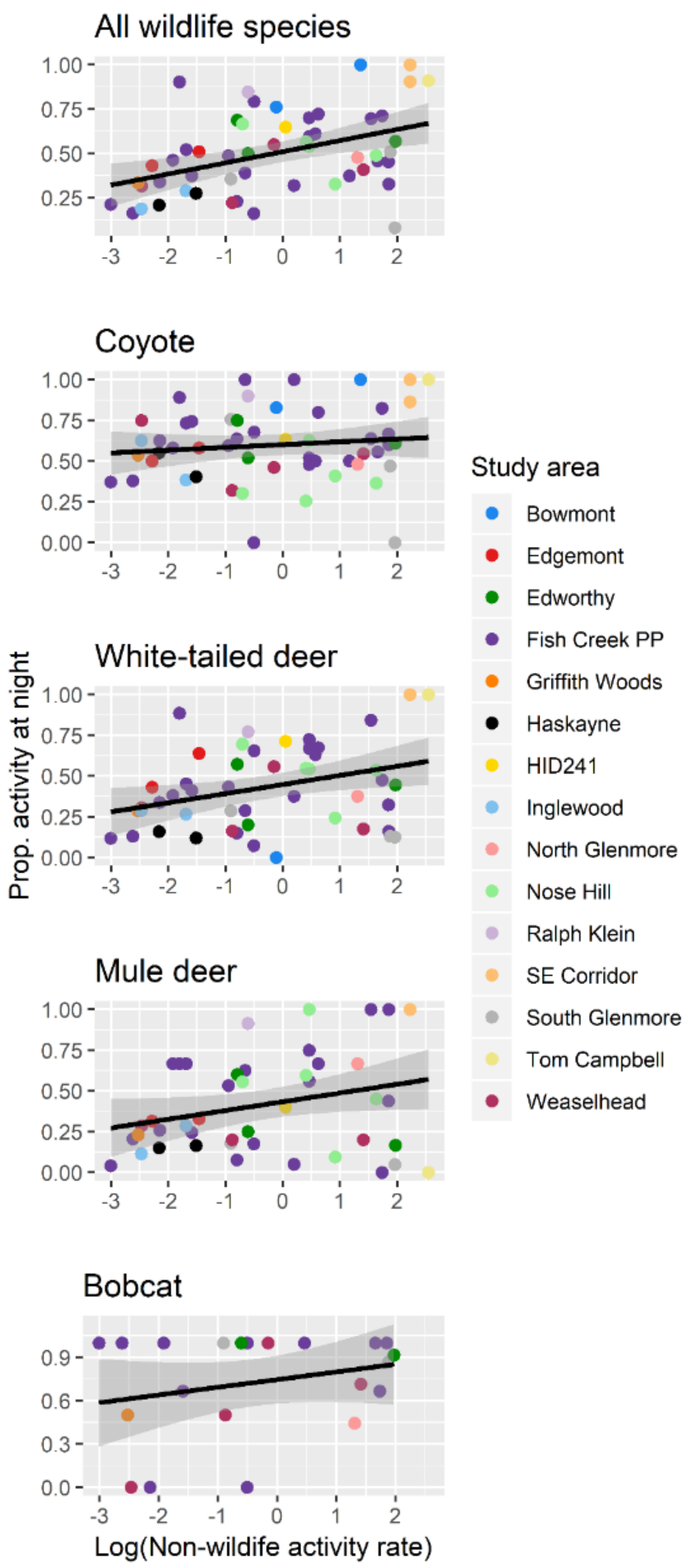

Figure 15: Relationship between non-wildlife activity rate and proportion of wildlife events at night. Each point represents a camera location, colour-coded by study area. Non-wildlife activity rate is log transformed to meet linear regression assumptions of linearity and non-correlated variation. Black line and dark grey band are best-fit line and 95% confidence interval from linear regression.

Second, we used the avoidance-attraction ratio examine short-term responses to individual non-wildlife events (Parsons *et al.* 2016; Naidoo and Burton 2020). AAR compares the time between a non-wildlife event and the next wildlife event to the time elapsed between that non-wildlife event and the previous wildlife event. If wildlife exhibit avoidance, we would expect the latter time interval to be longer on average than the former (i.e., wildlife stay away from the camera location longer following non-wildlife activity). For each camera location, we calculated AAR for all non-wildlife events and then used the median AAR value for these events as a summary measure of avoidance behavior at that camera location. We repeated this analysis for selected wildlife species (white-tailed deer, mule deer, coyote, bobcat, and red fox) individually. Results indicated that wildlife does not appear to exhibit short-term avoidance, nor short-term attraction, on average across all cameras (Fig. 16). This was true for all wildlife and for each of the selected species. Although the median of AAR ratios across camera locations was very close to 1, AAR for some individual camera locations was considerably larger or smaller than 1. However, we believe these outliers reflect the effects of small sample size rather than strong avoidance or attraction. We found qualitatively similar results when we repeated our AAR analyses using only off-leash dog events in lieu of all non-wildlife events.

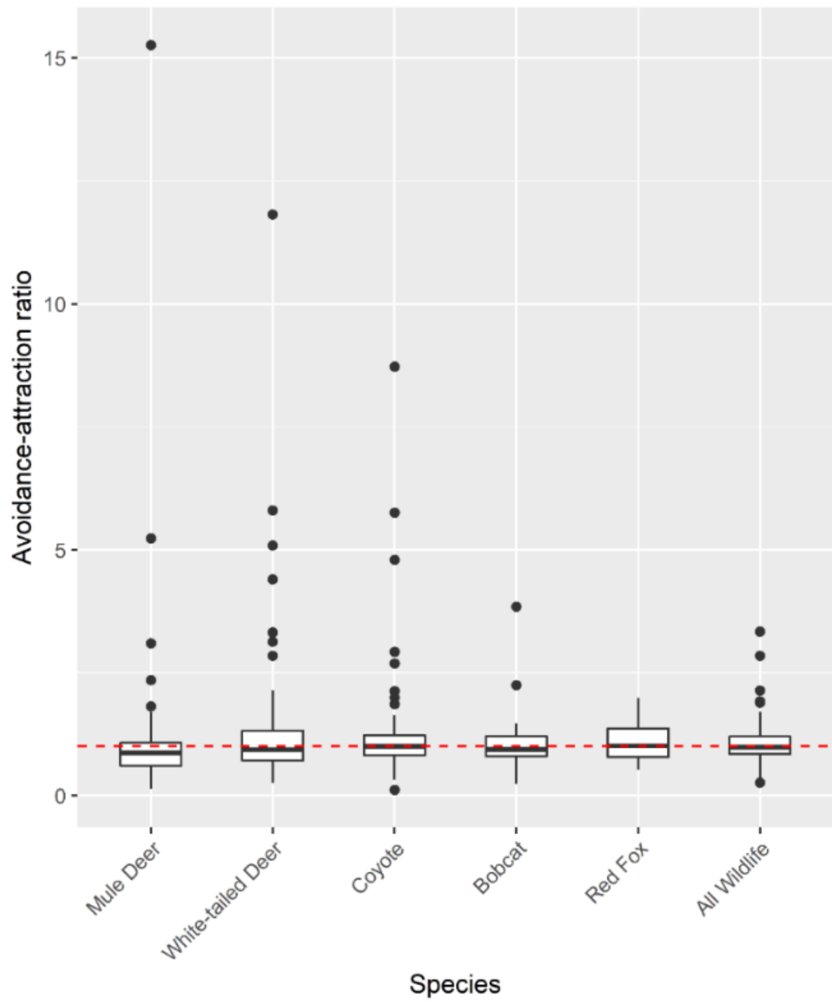

Figure 16: Distribution of median avoidance-attraction ratio (AAR) across camera locations for all wildlife and selected species. AAR values greater than 1 (dashed red line) indicate avoidance of non-wildlife (i.e., humans and dogs) by wildlife, while values less than one indicate attraction. Boxes show the interquartile range (IQR, values between 25th and 75th percentile) and whiskers extend to most extreme values within 1.5×IQR of the box; outliers are shown as individual points. Camera locations with 10 or fewer observations used to calculate AAR were excluded from the analysis, as they often resulted in extreme values.

Third, we used kernel density curves to compare diel activity patterns of humans and dogs to those of selected wildlife species and determine the degree of overlap (Frey *et al.* 2020; Lopucki and Kiersztyn 2020). Species that are highly sensitive to disturbance may be more active during periods when humans and dogs are least active in parks. We used data from all camera locations to fit kernel density curves for humans (with or without dogs), dogs (with or without humans), bobcat, cougar, coyote, moose, mule deer, red fox, and white-tailed deer. We then calculated a nonparametric estimator of the coefficient of overlap between human and wildlife species density curves, and between dog and wildlife species density curves. Values of $\hat{\Delta}$ can range between 0 (no temporal overlap) and 1 (complete temporal overlap). We used a bootstrap resampling approach to calculate 95% confidence intervals for overlap estimates. Analyses were performed using the *overlap* module in the R statistical package. Results indicated that the degree of temporal overlap between wildlife species activity and non-wildlife activity varied among species (Table 2, Figs. 17–18). Values of $\hat{\Delta}$ ranged from 0.19 (for cougars versus dogs) to 0.66 (for moose versus humans). In general, we observed greater temporal overlap with humans and dogs for ungulates than for carnivores. Humans and dogs were most active during daylight hours, with peak activity around midday. Ungulates were most active around sunset and sunrise. Carnivores were most active at night, except for coyotes, which were active at all hours. Wildlife overlaps with humans and with dogs were similar because humans and dogs exhibited nearly identical diel activity patterns. Overlap estimates for some species with small numbers of recorded events (e.g., bobcat, red fox) had very wide confidence intervals, suggesting that more data may be needed to characterize their activity patterns with high confidence.

Table 2: Overlap between activity patterns of non-wildlife (human or dog) and selected wildlife species. Overlap estimates range from 0 (no overlap) to 1 (complete overlap).

SPECIES	NON-WILDLIFE SPECIES	OVERLAP ESTIMATE ($\hat{\Delta}$)	95% CONFIDENCE INTERVAL
BOBCAT	HUMAN	0.39	0.33 – 0.45
COUGAR	HUMAN	0.24	0.14 – 0.36
COYOTE	HUMAN	0.57	0.56 – 0.58
MOOSE	HUMAN	0.66	0.57 – 0.74
MULE DEER	HUMAN	0.58	0.56 – 0.60
RED FOX	HUMAN	0.37	0.27 – 0.47
WHITE-TAILED DEER	HUMAN	0.56	0.55 – 0.57
BOBCAT	DOG	0.34	0.28 – 0.40
COUGAR	DOG	0.19	0.09 – 0.30
COYOTE	DOG	0.52	0.51 – 0.53
MOOSE	DOG	0.62	0.53 – 0.72
MULE DEER	DOG	0.53	0.51 – 0.51
RED FOX	DOG	0.31	0.22 – 0.41
WHITE-TAILED DEER	DOG	0.51	0.50 – 0.52

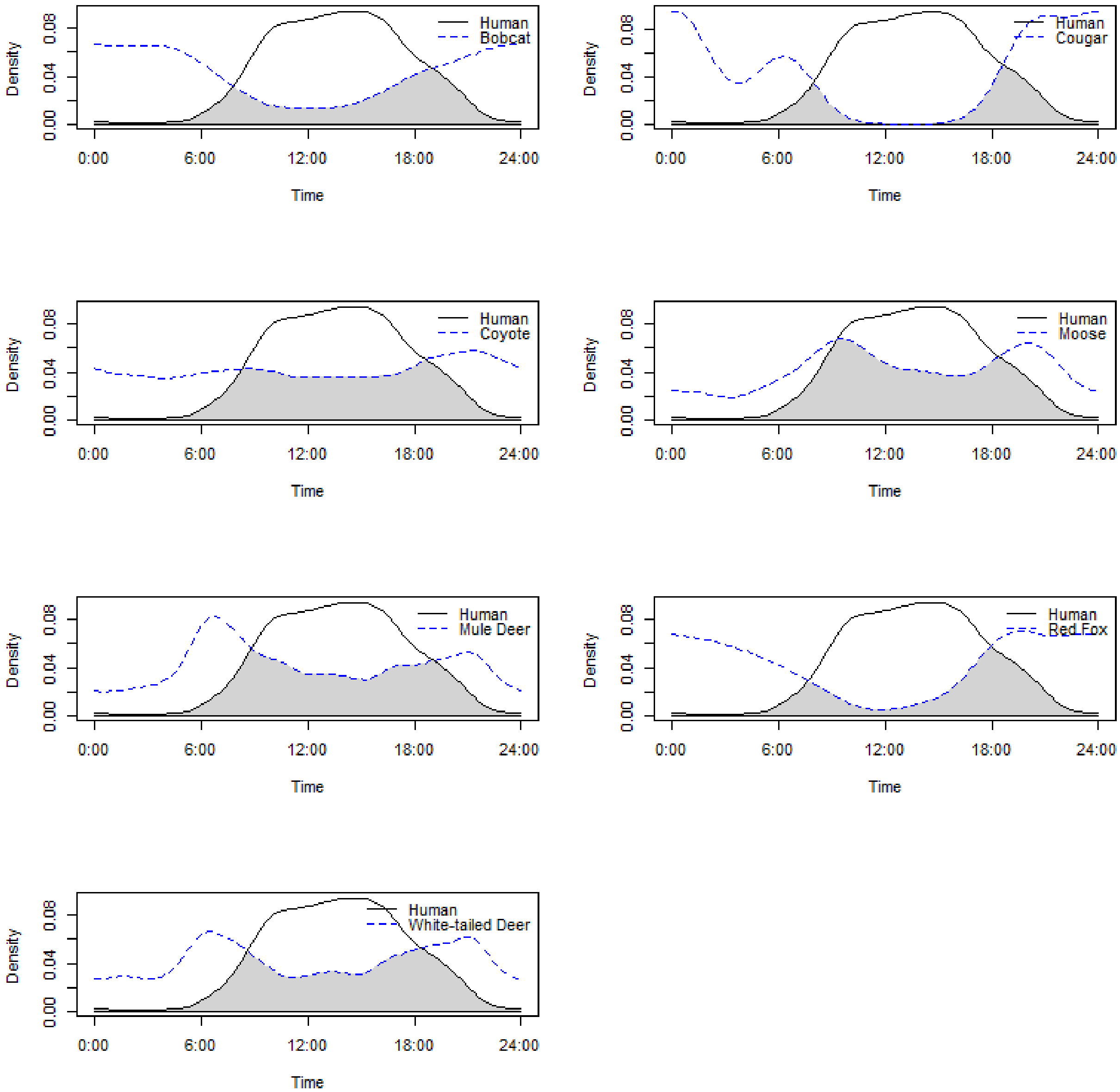

Figure 17: Overlap of diel activity patterns (as indicated by kernel density curves) for humans versus seven wildlife species.

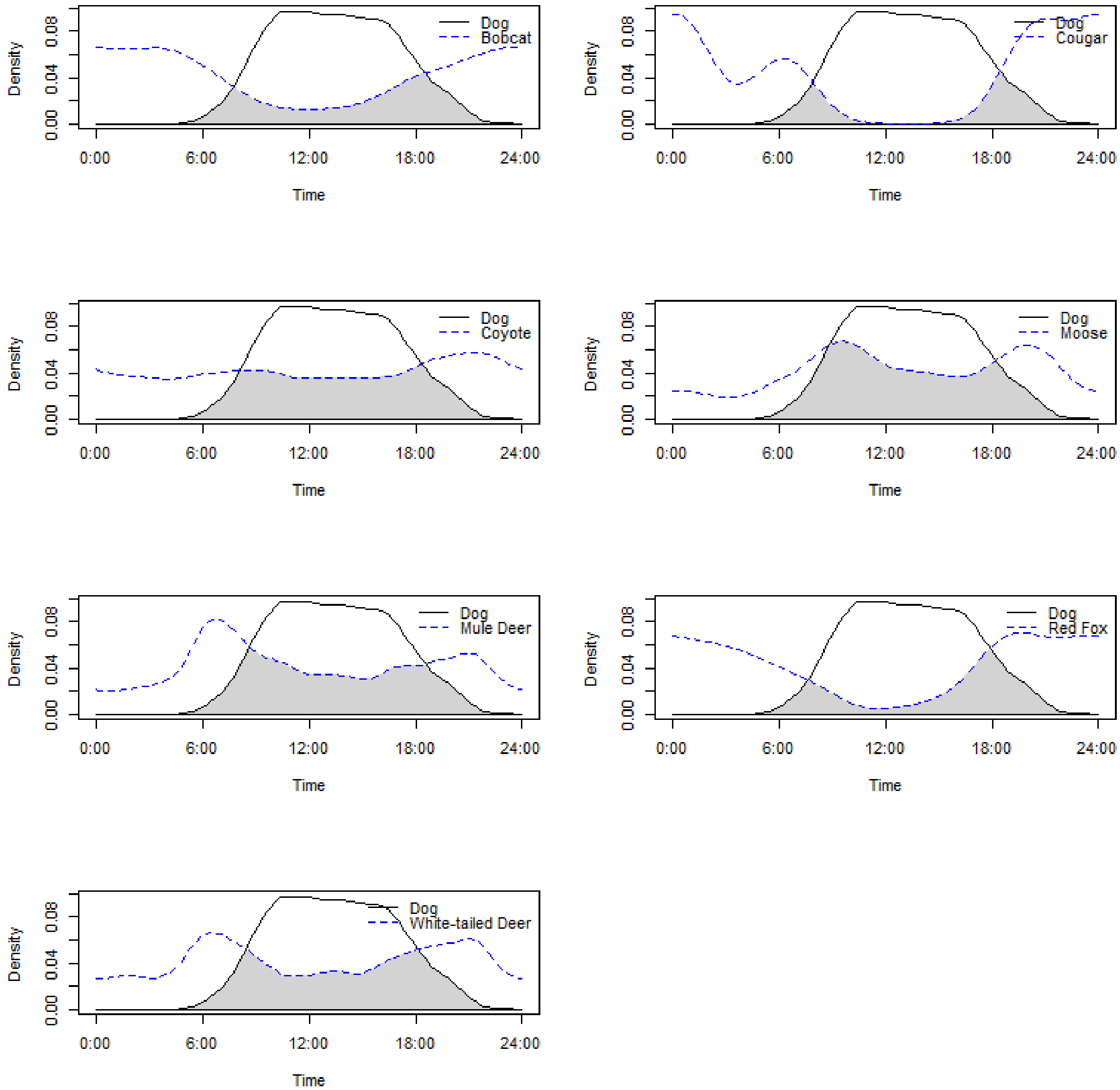

Figure 18: Overlap of diel activity patterns (as indicated by kernel density curves) for domestic dogs compared to seven wildlife species.

The three approaches we used present a mixed picture of wildlife responses to non-wildlife activity. Our analyses of the relationship between non-wildlife activity rate and proportion of wildlife activity occurring during nighttime suggest that wildlife is more active at night in locations with greater non-wildlife activity. However, this relationship was weak for some species. Temporal overlap analyses of human or dog activity and wildlife species activity suggested that some species, particularly carnivores such as cougar and red fox, are visiting Calgary's parks almost entirely during nighttime hours when humans and dogs are not present. However, other species such as coyote, and to a lesser degree deer and moose, seem to overlap with non-wildlife users of parks during morning and evening.

Finally, avoidance-attraction ratios showed no evidence of any wildlife species avoiding camera locations immediately after they were visited by non-wildlife. The differences in findings among the three approaches may be related to the time scale at which responses were measured. AAR analysis examines short-term responses to individual non-wildlife events, whereas the other two approaches examine shifts in diel activity patterns that may represent responses to long-term patterns of human and dog activity. Wildlife species may have shifted their diel activity patterns to minimize the probability of encountering humans and domestic dogs, but we did not observe short-term responses to these encounters.

There may be several explanations for why some of our analyses indicated weak or no response of wildlife species to non-wildlife activity. The non-wildlife event rate estimated from camera records may be an unreliable indicator of intensity of human and dog use because cameras were intentionally located in areas where humans were not likely to closely pass (i.e., away from roads and trails). This means that cameras would not have captured the majority of non-wildlife activity, although roughly three quarters of all recorded events were non-wildlife events suggesting that they did capture a significant amount of non-wildlife activity. However, off-camera non-wildlife events that were close enough to the camera location to cause wildlife to avoid that location remain a problematic possibility. Another possible explanation is that the wildlife species that make up the bulk of the camera trapping records (and for which we had a large enough sample size to conduct species-specific analyses) were habituated to human presence. Deer and coyotes are known to thrive in human-dominated systems, so it may not be surprising that our data suggest they are not very sensitive to human activity.

Relationship between activity rate and habitat connectivity

The ecological condition of natural areas and their connectivity with the surrounding natural landscape are both believed to influence wildlife populations. We used data on centrality (a network-based indicator of habitat connectivity) and estimated habitat condition provided by the City to explore the relationships between these habitat variables and two measures of wildlife population status: event rate (a proxy for relative abundance) and species richness. We found very weak but positive relationships between habitat connectivity and both wildlife variables (Figs. 19–20). Interestingly, we found a weak but negative relationship between habitat condition and event rate (Fig. 21), and no relationship between habitat condition and species richness (Fig. 22), although these patterns are probably not meaningful because they were based on a very small number of data points due to missing habitat condition data for more than ¾ of camera locations. The lack of strong, positive relationships that we expected may partially reflect limitations in the way that habitat connectivity and habitat condition are measured. For instance, the approach used by the City to derive centrality scores (our measure of habitat connectivity) for parks is sensitive to the extent of the region included in the analysis; parks near the edges of this region are likely to receive low centrality scores, when in fact they may be well connected to habitat located outside the analysis region.

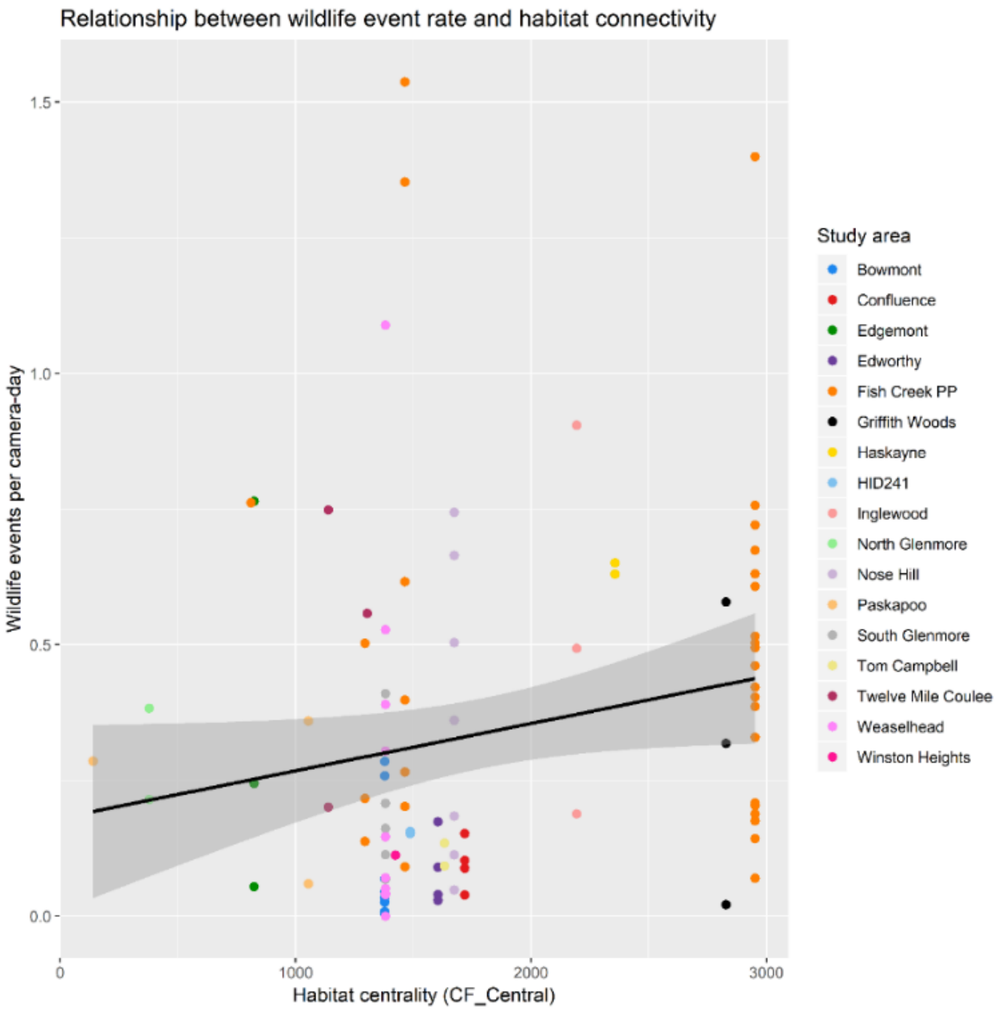

Figure 19: Relationship between habitat connectivity ("CF_Central" attribute from centrality shapefile) and wildlife event rate. Each point in the plot represents a single camera location, and points are colour-coded by study area. The black line and dark grey band are best-fit line and 95% confidence interval from simple linear regression.

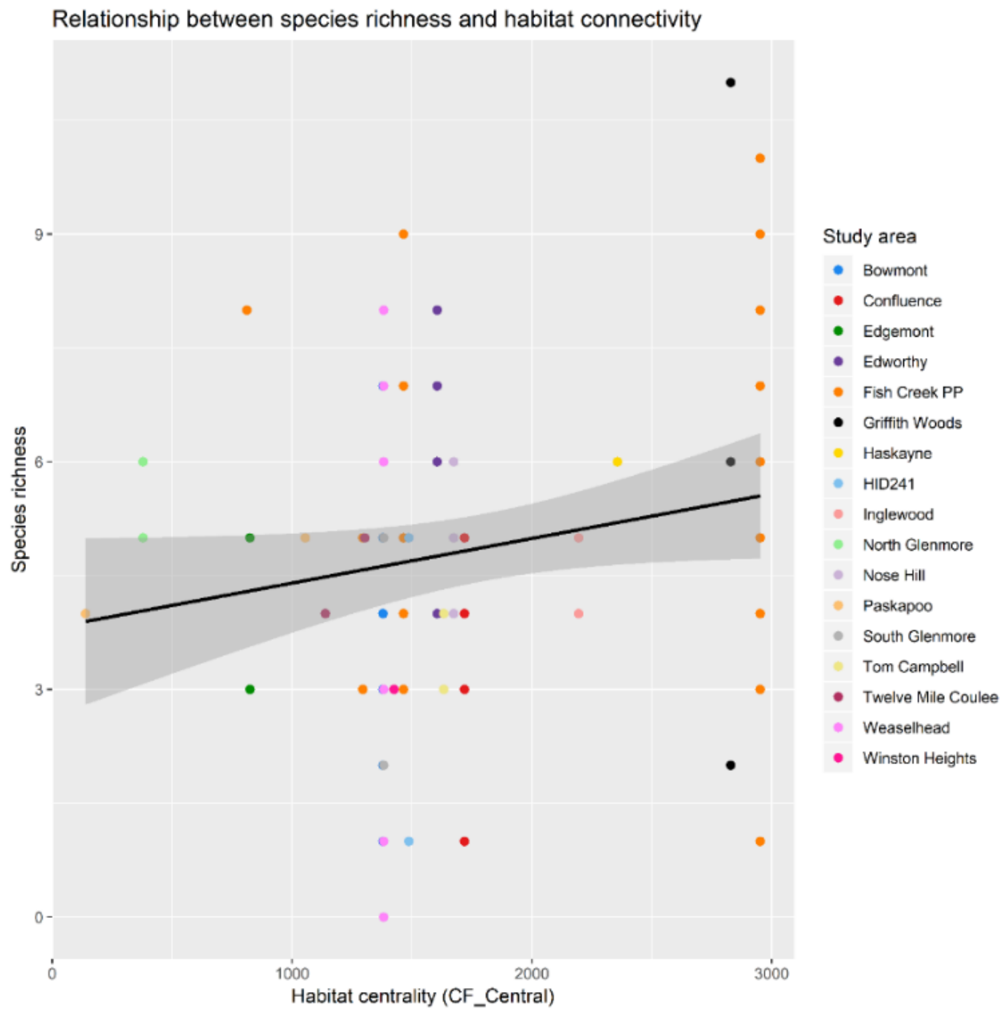

Figure 206: Relationship between habitat connectivity ("CF_Central" attribute from centrality shapefile) and wildlife species richness. Each point in the plot represents a single camera location, and points are colour-coded by study area. The black line and dark grey band are best-fit line and 95% confidence interval from simple linear regression.

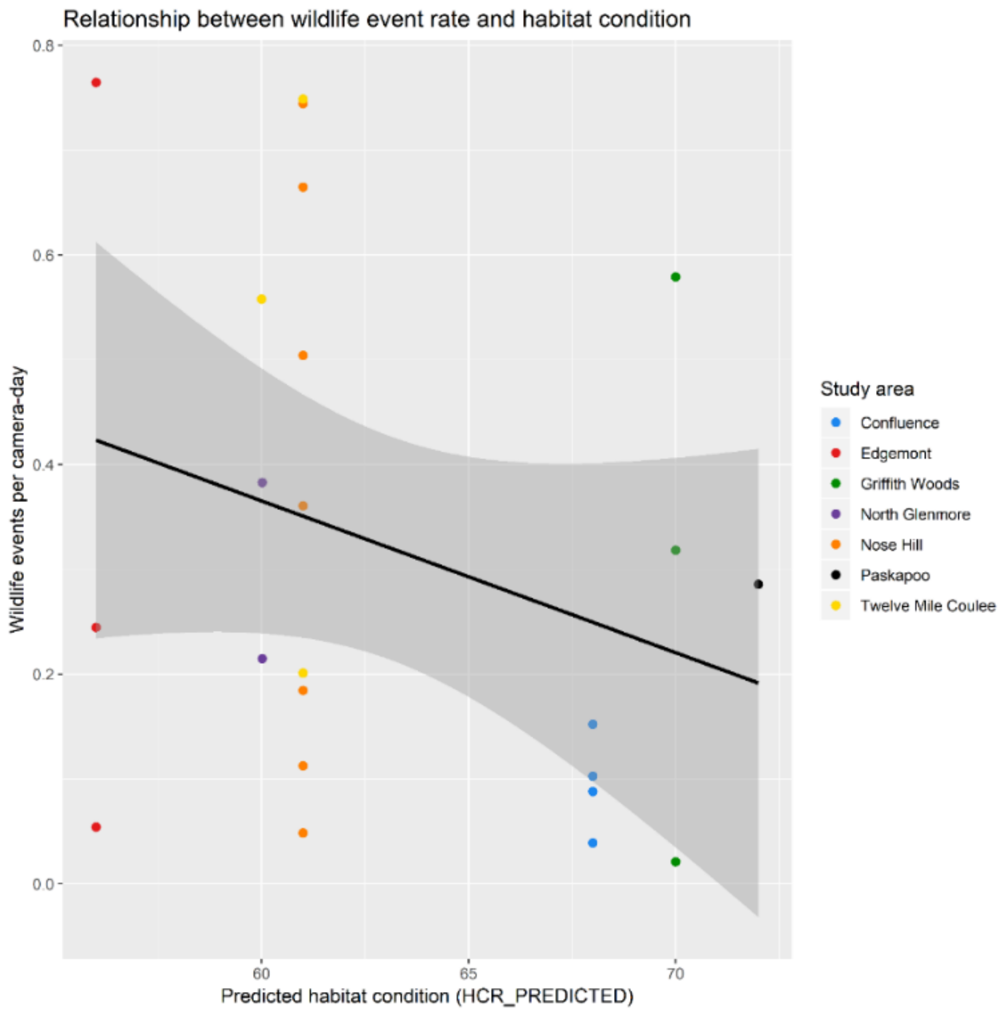

Figure 217: Relationship between habitat condition ("HCR_PREDICTED" attribute from habitat condition spreadsheet) and wildlife event rate. Each point in the plot represents a single camera location, and points are colour-coded by study area. The black line and dark grey band are best-fit line and 95% confidence interval from simple linear regression. Note that habitat condition data were available for <25% of camera locations. The Winston Heights study area has been removed as an outlier (predicted habitat condition = 27) from plot and regression model.

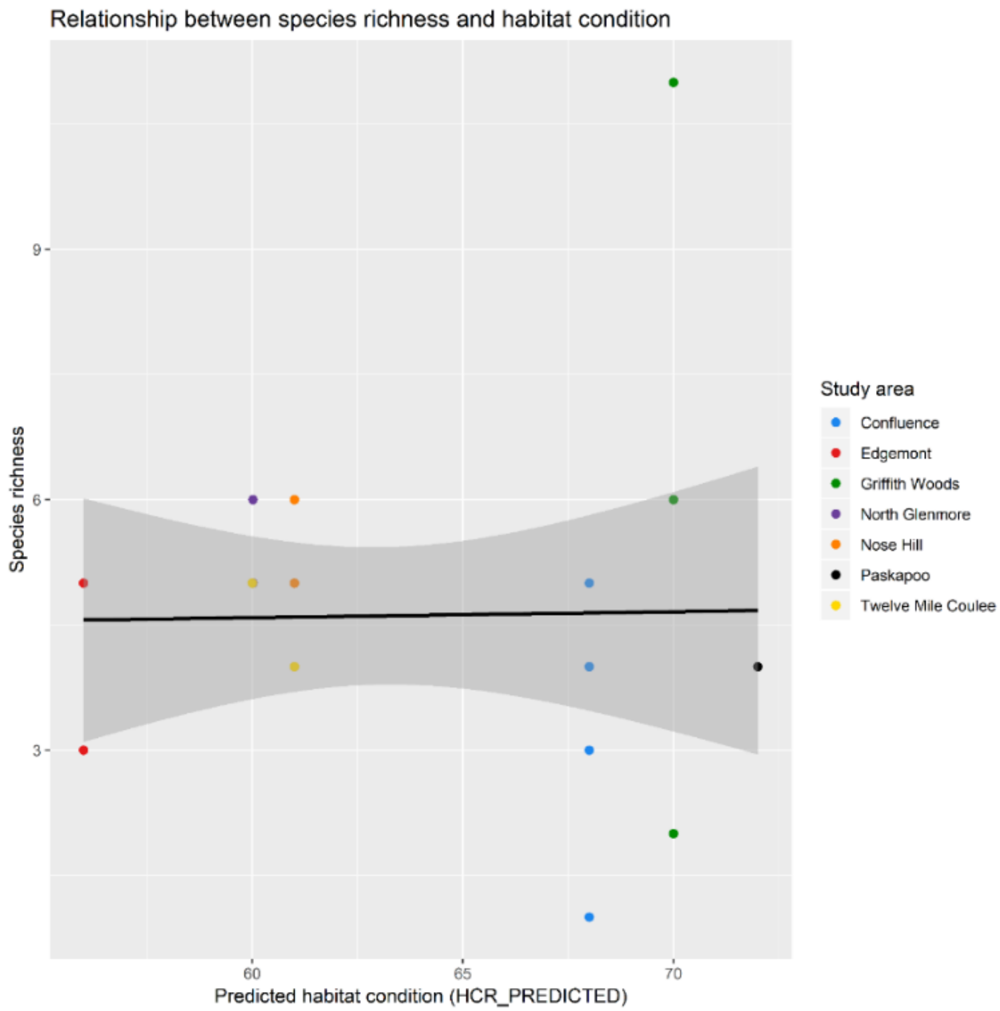

Figure 22: Relationship between habitat condition ("HCR_PREDICTED" attribute from habitat condition spreadsheet) and wildlife species richness. Each point in the plot represents a single camera location, and points are colour-coded by study area. Black line and dark grey band are best-fit line and 95% confidence interval from simple linear regression. Note that habitat condition data were available for <25% of camera locations. The Winston Heights study area has been removed as an outlier (predicted habitat condition = 27) from the plot and regression model.

Off-leash dogs

Cameras recorded 19,712 events involving off-leash dogs during the three-year study period, and 89% of these events were recorded by cameras located outside designated public off-leash areas. The rate at which events involving dogs were recorded was highly variable among cameras across the city, and even among cameras within the same study area (Fig. 23). The fraction of dog events in which dogs were leashed was also highly variable across the city (Fig. 24). Interestingly, a nearly identical proportion of dogs were leashed in designated off-leash versus on-leash parks (Fig. 25), suggesting that dog owners behave similarly with respect to dog leashing regardless of leash rules. Both of these results were similar to those found in previous studies (White 2009; Parsons *et al.* 2016; Cortés *et al.* 2021).

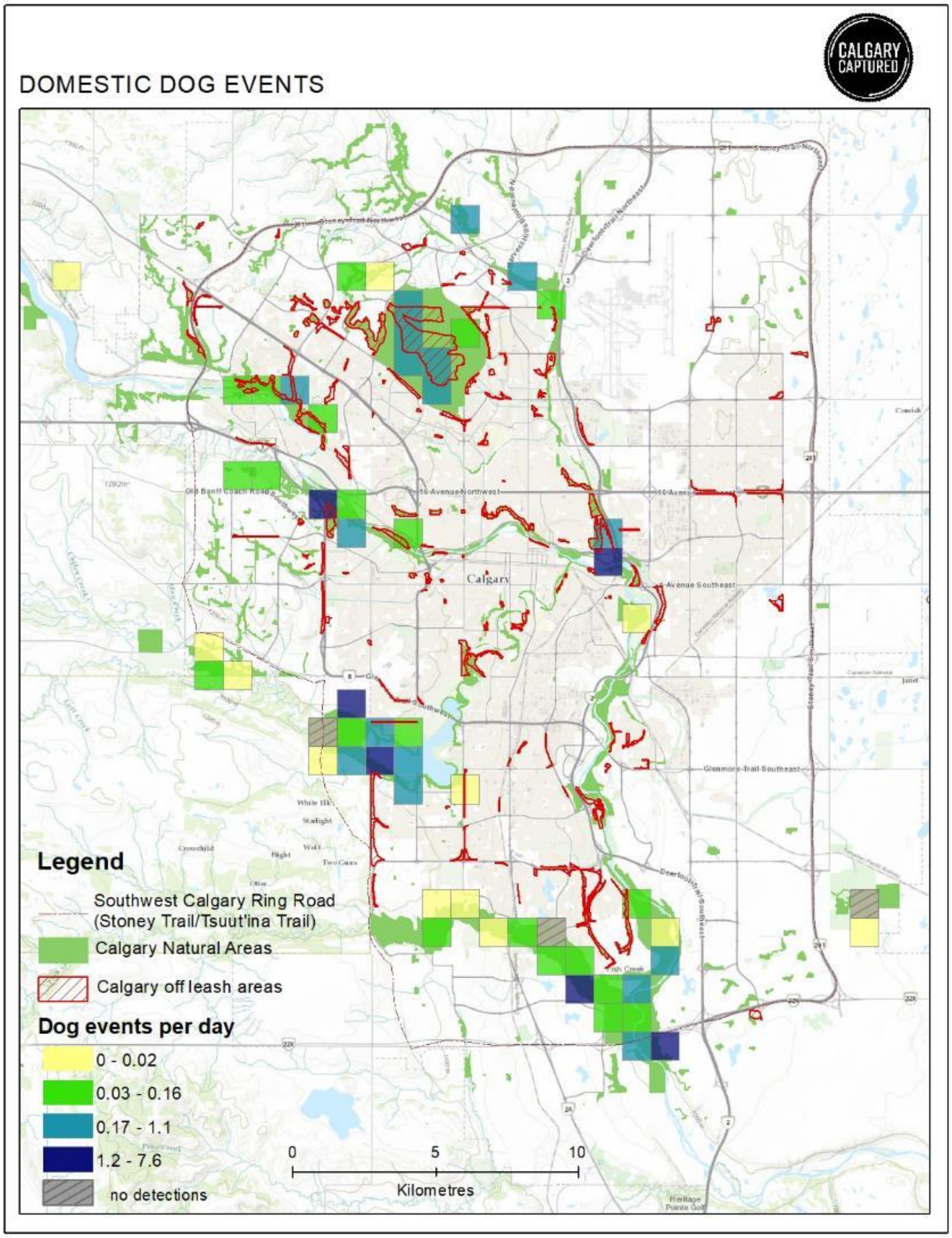

Figure 23: Total rate of dog events, both on- and off-leash, calculated as the number of dog events per camera day in each grid cell. Dark blue areas indicate areas that had a high rate of dog events.

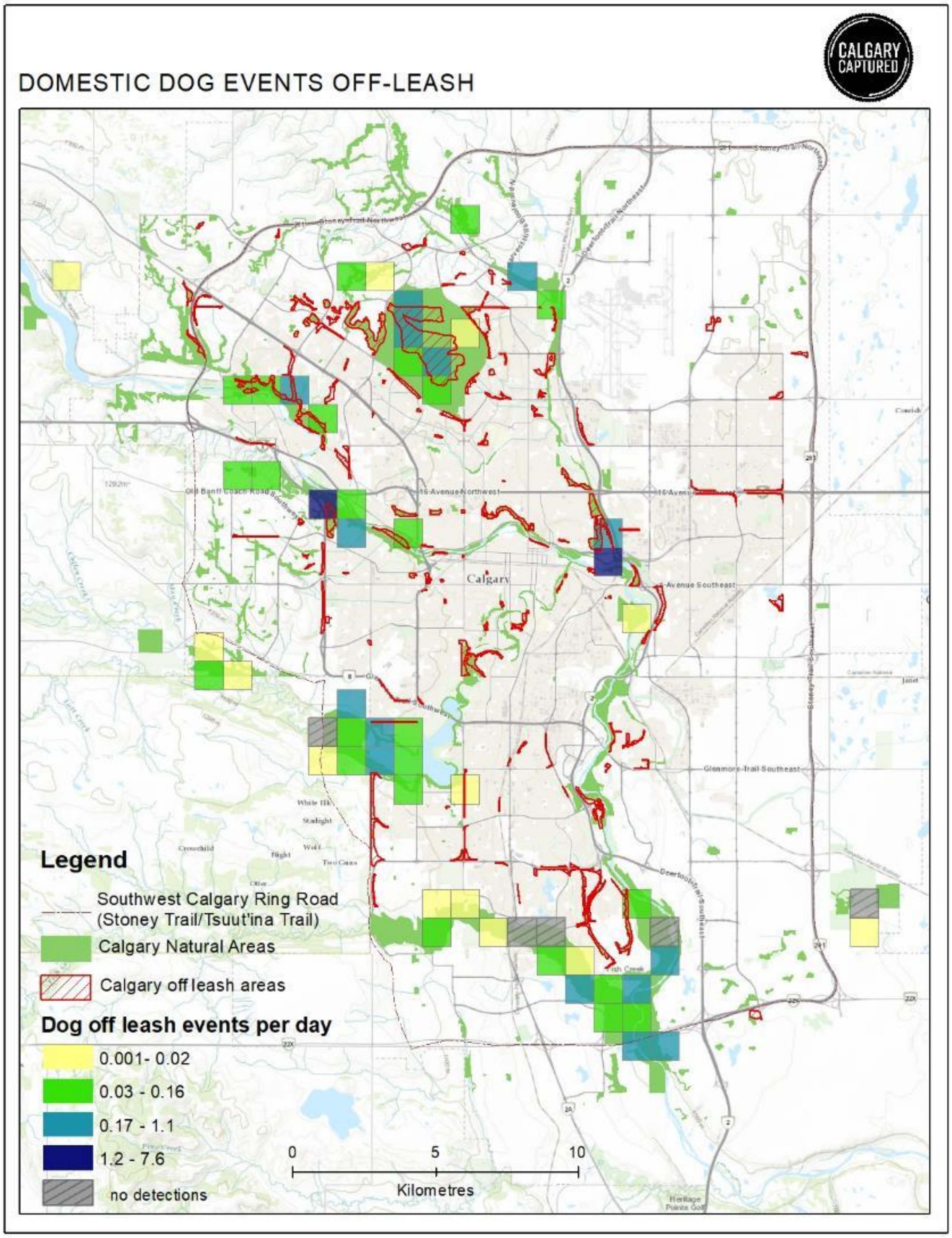

Figure 24: Dog off-leash activity. Dark blue areas indicate highest rate of off-leash dogs.

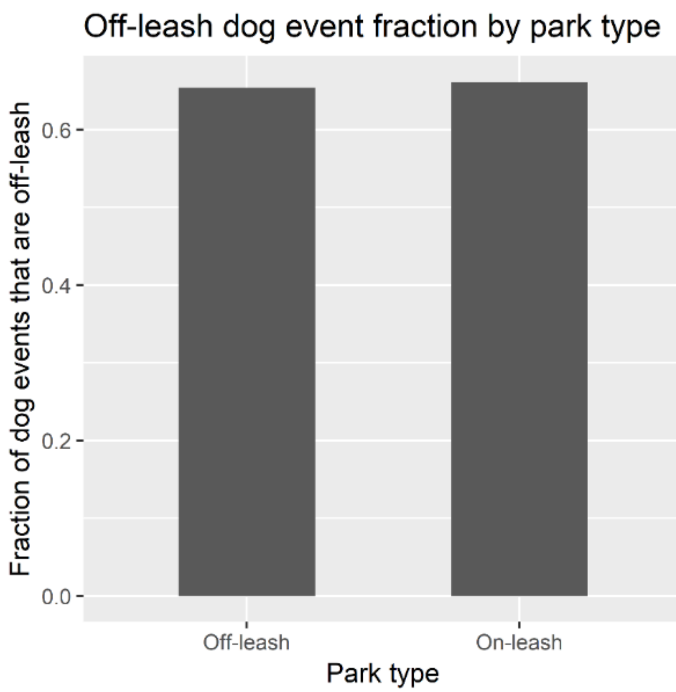

Figure 25: Fraction of dog events that involved off-leash dogs within designed off-leash areas versus outside these areas.

Even leashed dogs sometimes harass and injure wildlife including some of the focal species in this study(Hughes and Macdonald 2013). However, how these antagonistic interactions determine the composition, structure, and distribution of carnivore communities in urban spaces is not well understood. Because dogs are one of the most widely distributed terrestrial carnivores, filling this knowledge gap should be a key consideration for future studies to inform natural resource managers seeking to mitigate dogs' effects on consideration for future studies to inform natural resource managers seeking to mitigate dogs' effects on wildlife.

Next Steps

Miistakis and partners plan to continue Calgary Captured but with a focus on two natural areas, Fish Creek Provincial Park, and Glenmore Weaselhead parks for general wildlife monitoring, as well as monitoring of two ecological corridors to determine species activity levels between natural environment parks, and monitoring the use of transportation infrastructure built to enable safe movement of wildlife after new ring road construction.

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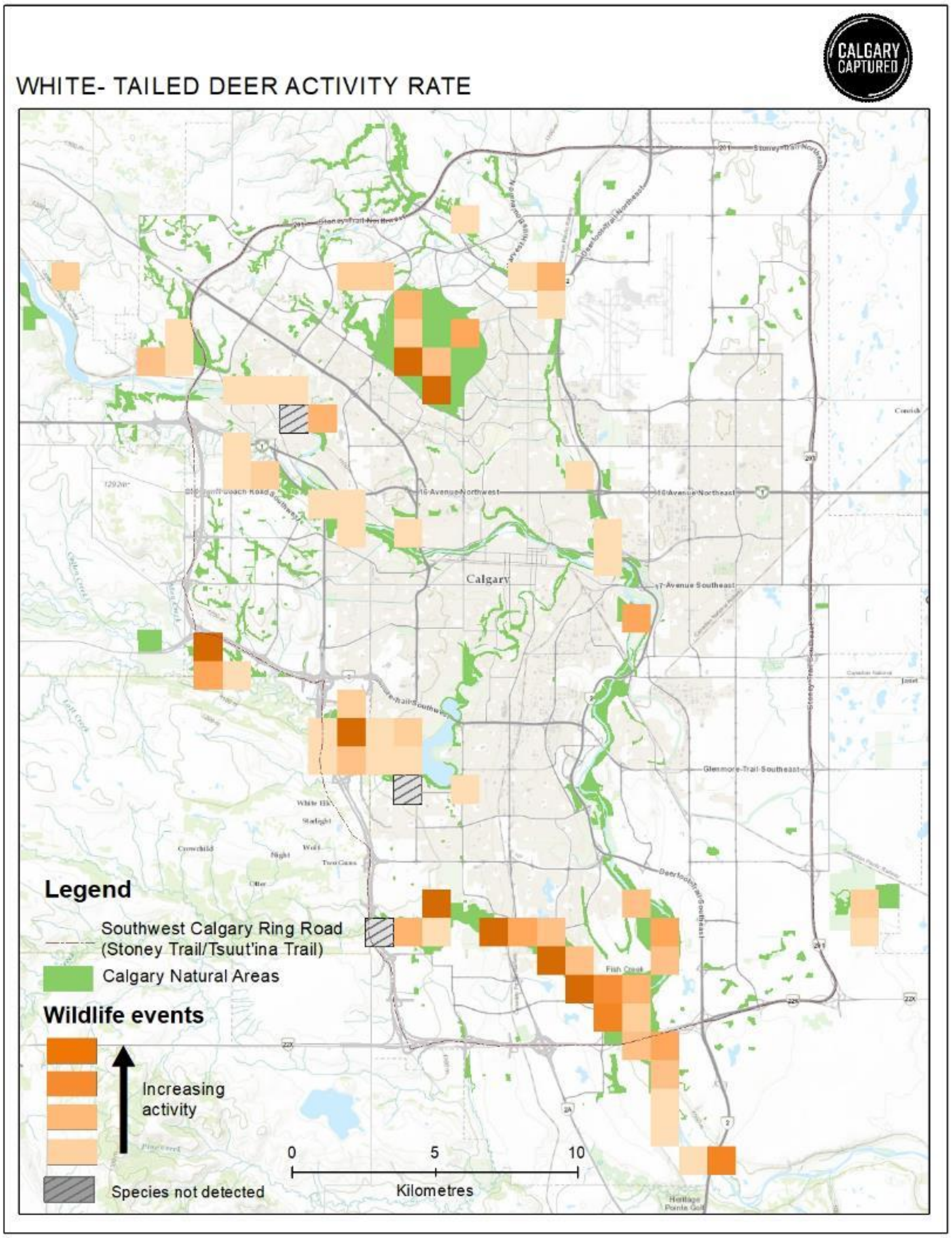
Appendix

Appendix I: Spatial patterns of species activity rates

Activity rates were calculated as the number of wildlife events per camera day for each cell within the sampling grid. Some grid cells included multiple camera locations. Activity rates were depicted on the maps in the same even intervals to allow for comparison between species.

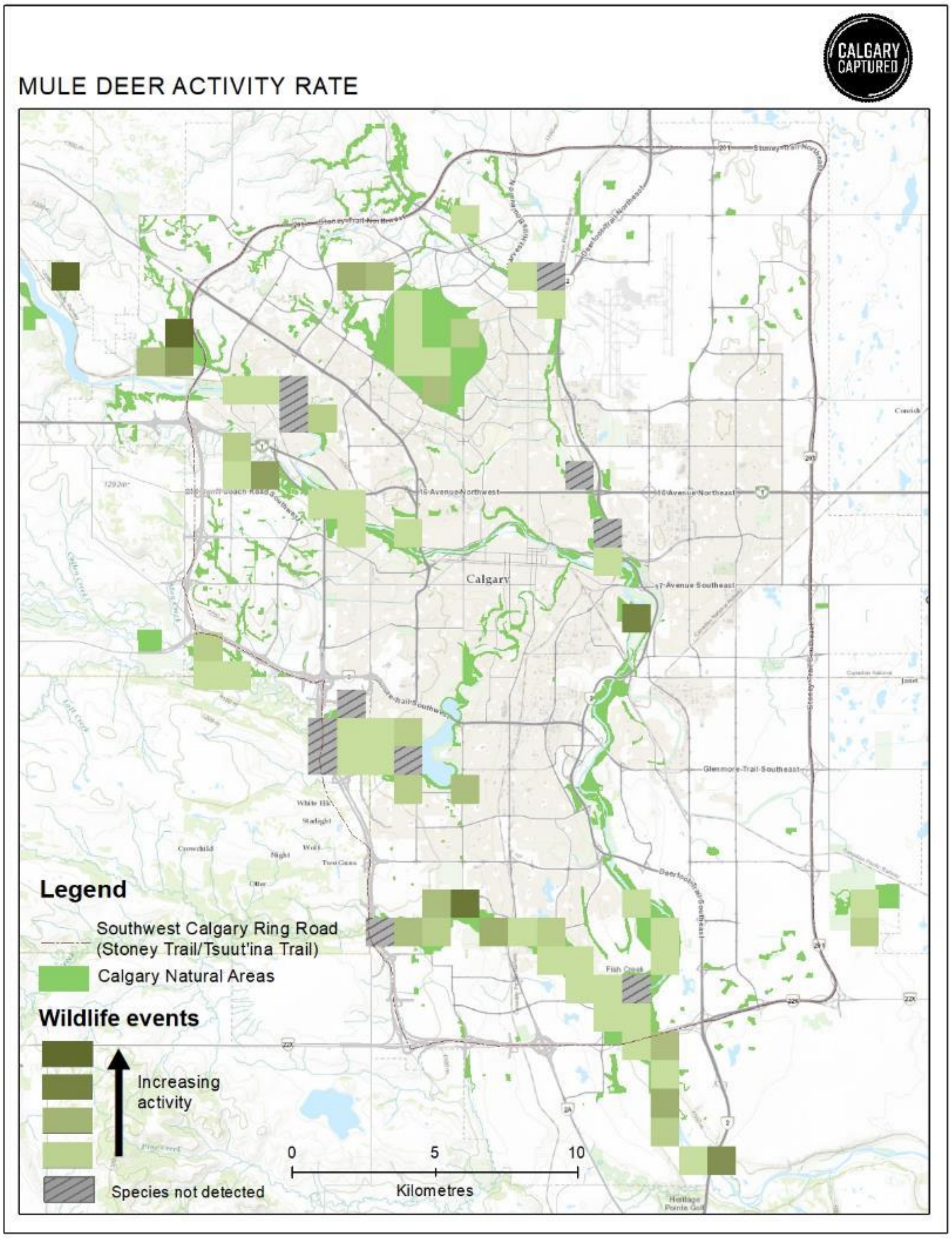
White-tailed deer

White-tailed deer were recorded at all study areas. White-tailed deer activity rates were highest at Griffith Woods, Weaselhead and Fish Creek Provincial Park.



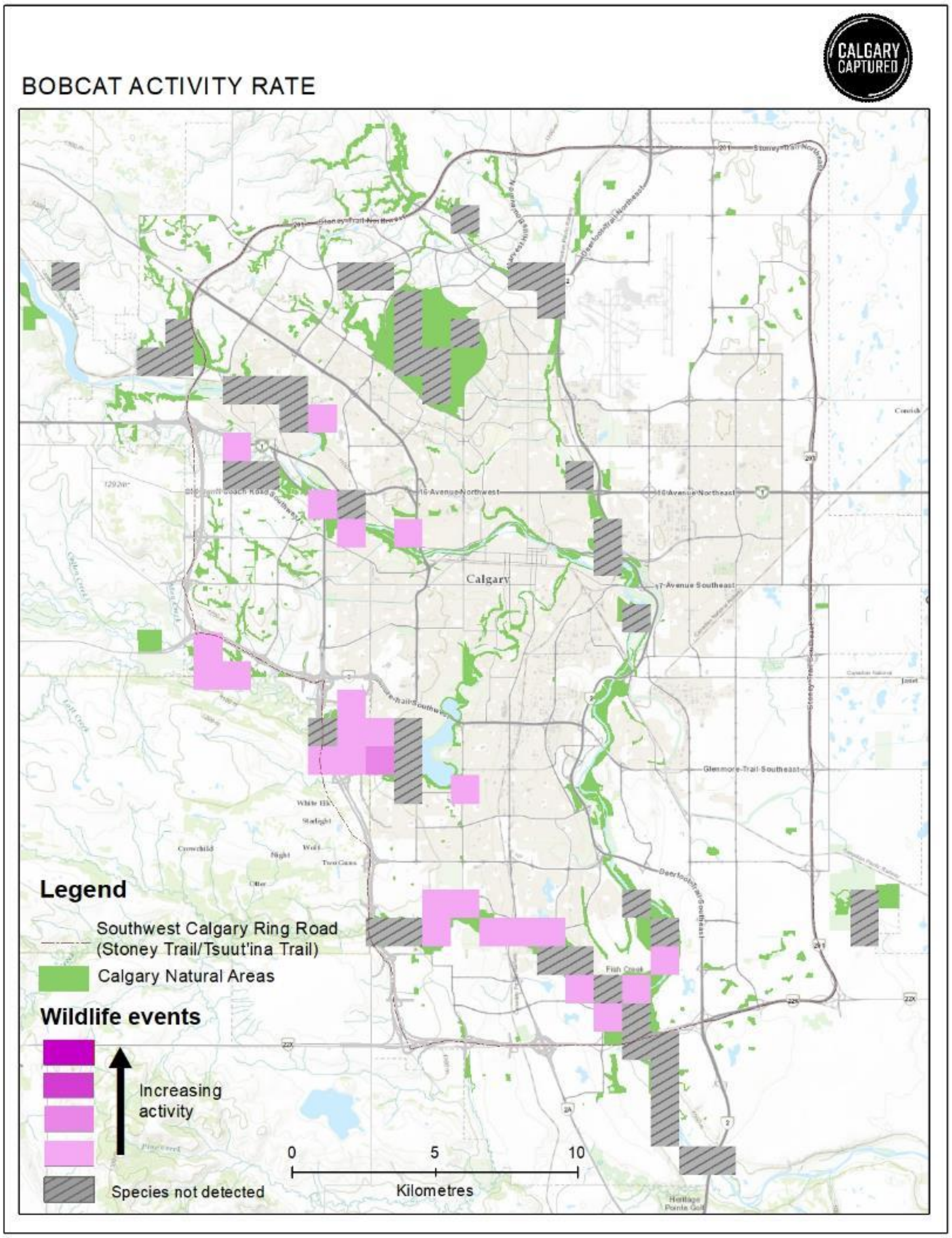
Mule deer

Mule deer activity rates were highest at Haskyne, Twelve Mile Coulee, Inglewood and the western portion of Fish Creek.



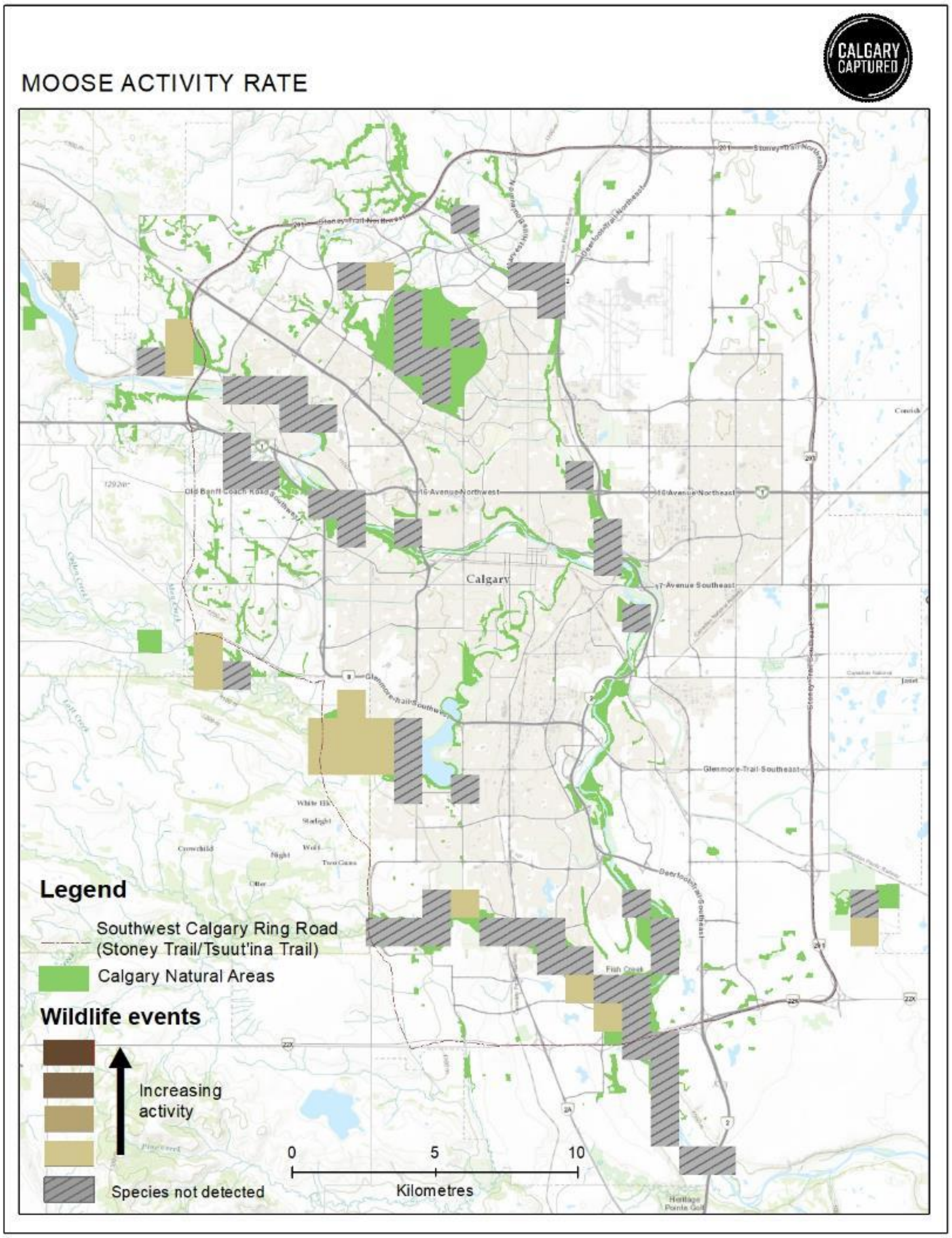
Bobcat

Bobcat were recorded on the western portion of the City including Edworthy, Fish Creek, Griffith Woods, Weaselhead, North Glenmore and South Glenmore and Fish Creek Provincial Park.



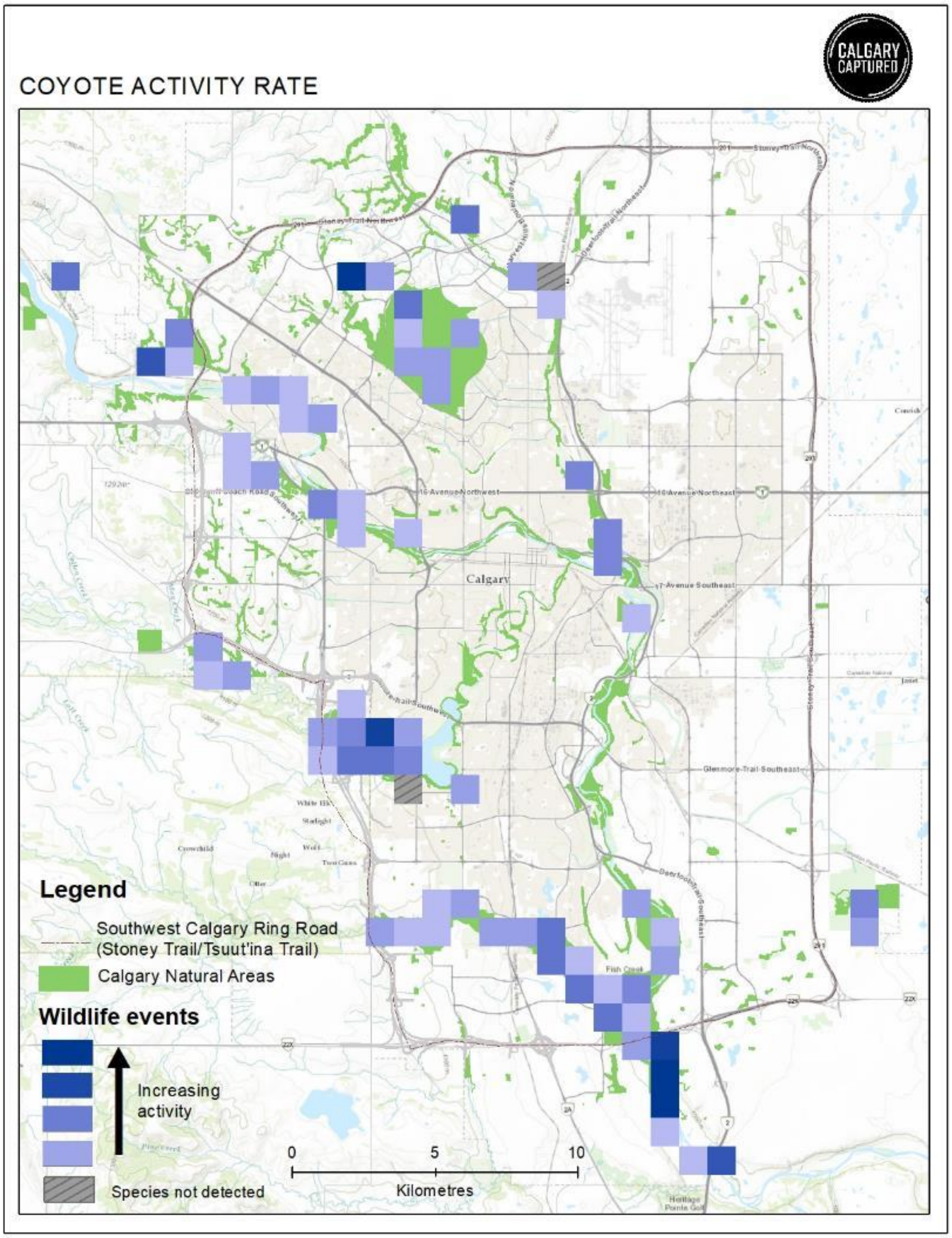
Moose

Moose were recorded at Griffith Woods, Haskayne, Twelve Mile Coulee, Ralph Klein, Fish Creek, South and North Glenmore and Weaselhead and Fish Creek Provincial Park.



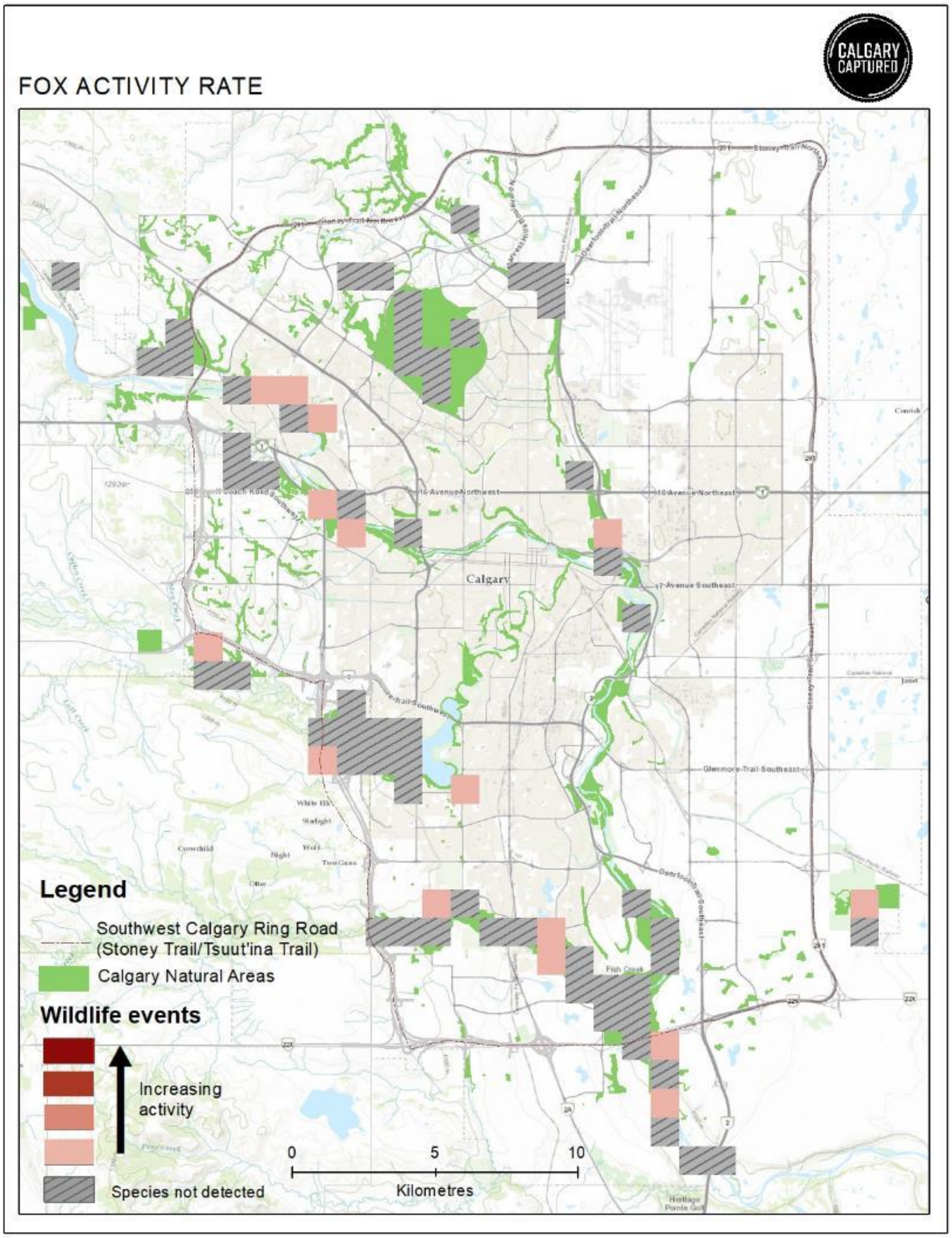
Coyote

Coyote were found in all natural areas.



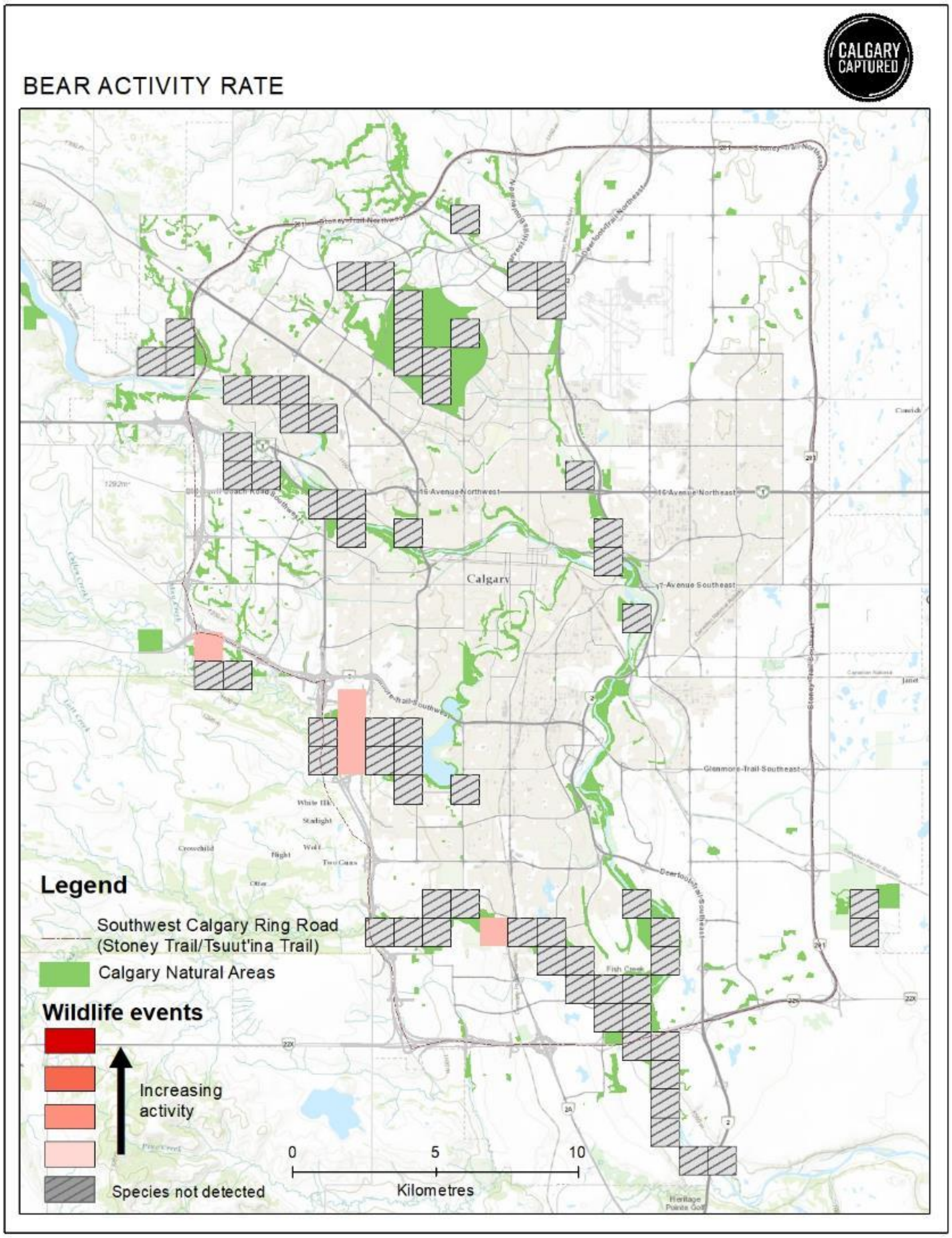
Fox

Fox were recorded at Bowmont, Griffith Woods, Ralph Klein, Tom Campbell and Weaselhead and Fish Creek Provincial Park.



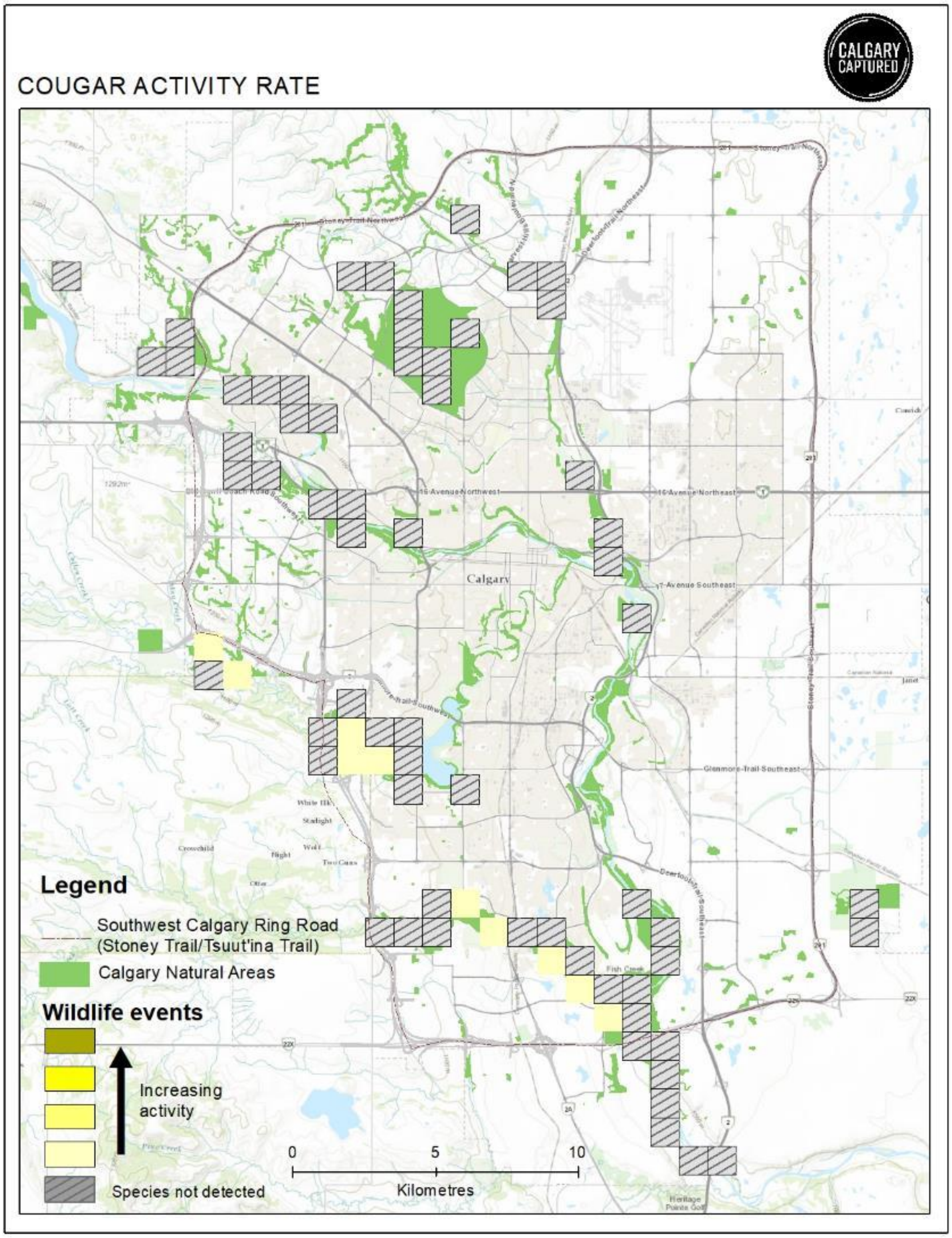
Black bear

Black bear occur infrequently in Calgary, but were recorded at Griffith Woods, Weaselhead, North Glenmore and Fish Creek Provincial Park.



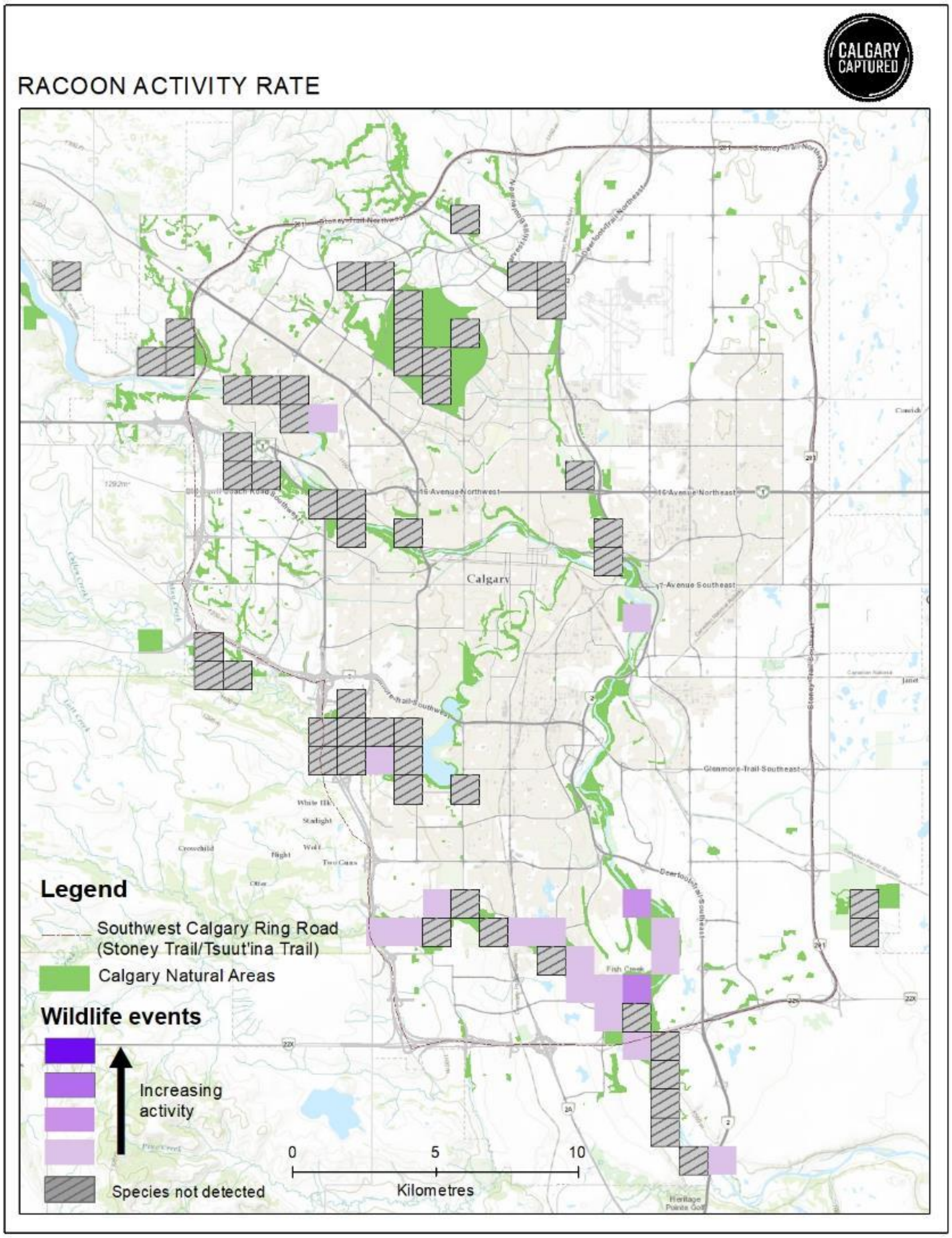
Cougar

Cougar occur infrequently in Calgary, but were recorded at Griffith Woods, Weaselhead, South Glenmore and Fish Creek Provincial Park.



Raccoon

Raccoon were recorded at South Glenmore and Fish Creek Provincial Park, Fish Creek SE Corridor, Inglewood and Bowmont.



Appendix 2: Species Events per Natural Area

Species	Events	Fish Creek PP	Nose Hill	South Glenmore	Edworthy	Weaselhead	North Glenmore	Bowmont	SE Corridor	HID241	Tom Campbell	Ralph Klein	Paskapoo	Edgemont	Griffith Woods	Inglewood	Confluence	Twelve Mile Coulee	Haskayne	Winston Heights
Human	49782	18713	7056	5886	4596	3881	2114	2060	1676	941	690	514	379	308	229	245	181	170	72	71
Domestic Dog	16968	4261	3200	1358	3344	844	1112	542	1006	81	548	1	49	41	105	2	317	69	20	68
White-tailed Deer	10847	5100	1632	101	49	1830	41	243	73	7	3	98	97	154	700	498	97	27	94	3
Human with Dog	5059	1734	720	469	743	310	302	49		78	512		28	1	10		100		3	
Coyote	4357	1348	461	173	150	333	363	68	97	166	25	118	64	446	88	33	54	69	249	52
Deer	3652	2195	357	16	46	130	10	45	4	6	6	21	83	180	128	209	43	30	143	
Mule Deer	3336	874	225	90	32	31	20	40	74	5	1	43	189	211	69	587	20	167	658	
Raccoon	263	257		1				3	1							1				
Porcupine	226	98	40		11			1	1	9			4	8			3	1	43	7
Domestic Cow	224																		224	
Bobcat	139	17		31	16	26	25	1					1		22					
Moose	79	3		1		45	1					1		1	15			6	6	
Red Fox	42	8		1	2	1		15	1		1	1			12					
Striped Skunk	30	11	2	1	1	1						1			13					
Beaver	28	6				1									21					
Cougar	17	8		3		4									2					
Domestic Horse	15			9		5			1											
Domestic Cat	11	6	4			1														
Black Bear	9	3				5									1					
Domestic Goat	9																9			
Weasels and Ermir	4	3						1												
Marten	2														2					
Mink	1	1																		