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Original Research

Web-GIS, Citizen Science, and Human-Coyote Encounters in Calgary, Alberta (2010-2012)

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Abstract

Urban coyotes (*Canis latrans*) live in habitat remnants, often supplementing natural food sources with anthropogenic alternatives that bring them into close contact with humans. We analyzed 781 citizen reports submitted to the web-GIS mapping tool, *Living with Coyotes*, between 2010 and 2012, in Calgary, Alberta. Encounters were classified into 5 types and the frequency of reporting was evaluated, including by biological season, time of day, and spatial attributes. Type 1 encounters (sightings) overwhelmed the database (n=713). When omitting Type 1 and comparing Types 2 through 5 (n=68), we found a significant difference (P<0.05) in frequency. Type 3 encounters (following/stalking) were most common (41%) and Type 5 (attacks) were lowest (16%). When aggregated into 'non-conflict' (Types 2 and 3) and 'conflict' (Types 4 and 5), we found significantly more (P<0.05) 'non-conflict' encounters (63%). The frequency of encounters varied significantly by biological season (P<0.001), as did encounter type (Fisher's test = 0.02). Although Type 1 to 4 encounters were reported most during Dispersal season and Type 5 during Pup-Rearing (45%), only Types 1 and 2 were significantly different across seasons (P<0.001 and P<0.025, respectively). 'Conflict' encounters did not vary significantly across seasons (P>0.05). Frequency of encounters varied significantly (P<0.001) by time, with most reported during the Daylight time category (47%). Encounter type did not vary by time of day (Fisher's test = 0.08). Over 50% of encounters were reported in the NW quadrant of Calgary, which coincides with the most park area (37%). The NE quadrant had the least reports (2%) and the lowest park area (9%). Encounter type did not vary by quadrant (Fisher's test = 0.99). Our results reinforce those previously found using phone-in reports, yielding evidence that web-based citizen science tools can provide reliable data that can benefit ecological and human-dimensions research, as well as coexistence strategies.

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Key Words: Alberta, *Canis latrans*, Citizen Science, Coyote, GIS, Online-mapping.

INTRODUCTION

As humans and coyotes (*Canis latrans*) co-occur in many habitats – from urban, to agricultural, to undeveloped spaces – encounters between the 2 species are inevitable. Most human-carnivore interactions are benign, but some turn into conflict (Fox and Papouchis 2005; Alexander and Quinn 2011; Lukasik and Alexander 2011). We define human-coyote 'conflict' as a direct attack on a person or pet that results in bites or scratches and, in some cases, death of pets. Precursors to an attack may include growling, snapping, or charging (Lukasik and Alexander 2011). While we consider the latter behaviours to be 'conflicts' for the purpose of our analyses, it is important to note that they may be defensive actions or warnings that are natural responses to threats posed by humans.

Prescribing how the environment, human behaviour, and animal behaviour intersect to create conflict has been attempted for several carnivores. While such encounters can be highly individual and context specific, commonly cited precursors to conflict include: habituation of wildlife, food conditioning, entering a den, availability of natural prey, an animal's health, or getting between a mother and her young (Timm *et al.* 2004; Schmidt and Timm 2007; Lukasik and Alexander 2011; Magle *et al.* 2014; Murray *et al.* 2015; Penteriani *et al.* 2016).

While coyotes are generally wary of humans, food conditioning is often cited as a key precursor to conflict (Schmidt and Timm 2007; White and Gehrt 2009; Alexander and Quinn 2011). Coyotes are adept at negotiating human-modified landscapes and cities provide easy food sources including garbage, bird seed, pet food, and fruit trees (Schmidt and Timm 2007; Grubbs and Krausman 2009; Lukasik and Alexander 2011). Such attractants may result in coyotes spending more time around human settlements, and lead to direct depredation of cats (*Felis catus*) and small dogs (*Canis lupus familiaris*). In contrast, medium and large dogs tend to be chased or attacked when coyotes are defending territory or denning sites (Alexander and Quinn 2011). While killing coyotes has been a *de facto* approach to mitigating conflict, it is generally considered ineffective (Connolly and Longhurst 1975; McManus *et al.* 2014; Proulx and Rodtka 2015; Kilgo *et al.* 2017).

As such, non-lethal coexistence strategies – which we define as humans and wildlife peacefully sharing and overlapping in space – are gaining popularity (Fox 2006; Alberta Environment and Parks 2018; City of Calgary 2018; Human Society of the United States 2019; Stanley Park Ecological Society 2019). Examples include strategies aimed at modifying human behaviour (Fox and Papouchis 2005; Penteriani *et al.* 2016) and reshaping wildlife behaviour using hazing techniques (Mazur 2010; Bonnell and Breck 2017). Since we expect success to vary by context, effective deployment of coexistence strategies will certainly be improved with better understanding of how coyote behaviour, human behaviour, and environmental conditions overlap to create conflict. Collecting data to examine these at a scale broad enough to improve understanding can be costly to researchers, sometimes prohibitively so. Furthermore, the dependence of most research on a singular method (e.g., field ecology vs. interviews, etc.) can result in the type of data collected being constrained to the method, causing valuable interactions to remain undetected. We, therefore, believe citizen science may offer a viable alternative to overcome these challenges.

Citizen science can be gathered through many forms (e.g., phone-in reporting, web-based GIS, geocaching apps), facilitating data collection over greater geographical and temporal scales than may otherwise be possible with resources and funding available to scientists (Lepczyk *et al.* 2004; Cohn 2008). This method also encourages community involvement and can simultaneously educate the public on environmental issues (Evans *et al.* 2005). In addition, citizens can provide data from sites often inaccessible to researchers, such as private properties (Lepczyk *et al.* 2004; Cohn 2008). More critically, citizens who live near coyotes may have supplementary insight into behavioural nuances and recognize changes in, or abnormal, conduct. In our experience, citizens have also observed behaviours that are previously undocumented in research publications (e.g., a coyote climbing a property owner's apple tree to feed) (Alexander 2015). Combined, the many anecdotal observations contributed by citizens can yield vital data that may even eclipse that gained through more traditional animal/researcher-centered studies. At the very least, previous research such as that conducted by Weckel *et al.* (2010) in New York found that results from citizen data concurred with those from traditional methods to understand habitat use and distribution of coyotes. Some researchers have still argued that citizen science is plagued by too many issues to be useful, including: lack of operational budgets, user fatigue, and challenges for data reliability (McKelvey *et al.* 2008; Devictor *et al.* 2010). Issues with data reliability can include: reporter bias, poor sampling design, incorrect identification, and methodological inconsistencies (McKelvey *et al.* 2008; Devictor *et al.* 2010). Hence, there continues to be a need to do comparative analysis of the strengths and limitations of citizen science tools and resulting data.

To contribute to this understanding, we analyzed data collected from the *Living with Coyotes* web-based GIS tool (a server- and client-sided citizen science tool). We then compared our results to those found previously using a phone-in reporting system (a server-sided tool) for the same study area. We label the phone-in system as server-sided because its sole purpose is to collect data for use by the agency. Alternatively, web-GIS can be designed to serve the client by providing summary feedback in map form that can empower the user while providing a database to researchers or administrators.

MATERIAL AND METHODS

The study area, City of Calgary, Alberta sits approximately 1,200 m above sea level (Foley 2006) and covers 848 km^2, with a population in 2012 of 1,120,225 (Alberta Municipal Affairs 2017). Abundant parks and greenspaces are located throughout the city, as well as rivers, lakes, wetlands, and reservoirs (Foley 2006).

Data collection

Voluntary reports submitted by citizens to the *Living with Coyotes* web-GIS program between January 2010 and December 2012 were analyzed. *Living with Coyotes* was operational between 2009 and 2013; however, we only used the subset of data that provided full annum coverage. The mapping tool used Google maps as a platform, required users to register an account (to mitigate fraudulent activity), and allowed users to pan, zoom, point, and click on a site to submit a coyote encounter. Users were able to zoom down to street level, track their individual submissions over time (plot on a map), and view all other observations on community level displays.

When a site for an encounter was selected on the map with the point/click tool, a pop-up data sheet prompted submission of behavioural and statistical data. A georeferenced location (UTM) was automatically generated into the citizen's report. The datasheet included closed- and open-ended questions, such as: time of observation, number of animals observed, whether the animal was vocalizing, what type of vocalization (from a menu of options), presence of pups, how many pups, and a drop-down menu describing coyote behaviour. An example of questions asked to describe behaviour is "How was the coyote behaving when you first observed it?: walking, running, hunting, resting, other." In addition, the tool requested that users provide a narrative description of the location and encounter. We used the narrative description in combination with the other question responses to categorize the event type, while attempting to minimize differences in user perception/comprehension of encounters. Some questions were designed specifically to track changes in coyote behaviour, or incidences of aggression, over time by researchers (e.g., "How did the coyote behave in response to you?: run away, approach, follow, howl, growl, bite, other".)

The Living with Coyotes tool automatically populated data into a spreadsheet, which could then be downloaded. We screened 843 submissions between January 2010 and December 2012, removing observations that were reported outside of the study area boundary (n=47), with no date (n=13), or that were not encounters (n=2 were old den site locations). A total of 781 reports remained for analysis. Each report counted as 1 encounter, regardless of the number of coyotes, humans, or pets involved.

Data coding and analysis

Individual encounters were coded to a 'Type' using methods from Lukasik and Alexander (2011) who evaluated phone-in reports (Calgary 311, Coyote Hotline). 'Type' was assigned a value of 1 through 5, which corresponds to increasing levels of aggression or 'risky' behaviour by coyotes (Lukasik and Alexander 2011) (Table 1). This coding allowed comparisons across the 2 different data collection methods. We consider Type 1 to be non-conflict behaviour as there was no indication of aggression or attack. Types 4 and 5 are considered conflict because a coyote reportedly displayed aggressive behaviour or attacked a person or pet. Although Type 2 and 3 encounters are technically 'sightings' and non-conflict, they are importantly distinguished because they represent behaviour that could elevate the risk of conflict. In particular, coyotes eating bird seed, outdoor pet food, or garbage (Type 2) can result in food conditioning, which as previously mentioned is considered a key precursor to conflict (Fox and Papouchis 2005; Schmidt and Timm 2007). Type 3 encounters (following/stalking) also may indicate increased risk, but actual risk depends on the interpretation of the coyote's behaviour. Type 3 narratives typically described curiosity, escorting behaviour (e.g., coyote pushing a human or dog out of a den area to ensure they do not pose a threat to their young), or simply a coyote walking the same direction.

We used RStudio statistical software – version 1.0c (R Foundation 2017). RStudio is free, open-source programming software available through the Internet. Results with a P value <0.05 were considered significant.

Encounter types

We tested for significant difference in the frequency of encounters across Types (Types 1-5, Types 2-5, and aggregated groups of Types 2/3 versus 4/5), using Pearson's chi-square test (Whitlock and Schluter 2015). The chi-square

Table 1. Encounter type and description.

Type	Class	Description
1	Non-Conflict	Sightings only
2	Non-Conflict	Being fed or eating garbage
3	Non-Conflict	Following or “stalking” pets or people
4	Conflict	Aggressive behaviour towards humans or pets *(includes both defensive and predatory behaviour)*
5	Conflict	Attacks *(i.e., physical contact with humans or pets)*

test can be used on categorical data to determine the probability that differences between categories occurred by chance (i.e., tests for significant difference between the categories) (Chernoff and Lehmann 1954). Since 91% of reports were Type 1 (sightings only), we were concerned about overwhelming the dataset with Type 1 encounters and missing patterns across Types 2 through 5. Additionally, it is possible that some Type 1 encounters are the same coyote seen by multiple individuals (which is also conceivable for other encounter types, but we assume is most likely for sightings). In consideration of these concerns, we re-tested for significant differences across Types 2 to 5. We were also concerned whether sample size might confound results, so we aggregated Types 2 and 3 into ‘non-conflict’ events and tested against frequency of Types 4 and 5 ‘conflict’ events.

Temporal analyses: biological season and time of day

Encounters were coded to 1 of 3 biological seasons: Breeding from January through April, Pup-Rearing from May through August, and Dispersal from September through December (Morey *et al.* 2007; Lukasik and Alexander 2011). The Pearson’s chi-square test (Whitlock and Schluter 2015) was used to determine if the frequency of encounters (all combined) varied by season. We used Fisher’s 2-tailed exact test (Whitlock and Schluter 2015) to evaluate if there was a relationship between the types of encounters reported and biological seasons. Fisher’s 2-tailed exact test was used because >20% of the expected cell frequencies were too low to use chi-square approximation (Whitlock and Schluter 2015). Pearson’s chi-square test (Whitlock and Schluter 2015) was also used on each encounter type across seasons to see if they differed significantly compared to random chance, including testing ‘conflicts’ (Types 4 and 5 together) across seasons.

The time of day that each encounter occurred was coded using the following categories: Dawn, Daylight, Dusk, and Dark (Appendix). March and November have 2 different time spans due to daylight savings changes in the Mountain Time Zone (Appendix). We used the earliest start and latest end of a time period in each month as the time range since exact time of dawn, dusk, etc. varies slightly each day (Timeanddate.com 2017). To determine the probability that timing of encounters was random, we tested for differences in frequency among time categories using Pearson’s chi-square test (Whitlock and Schluter 2015). We then used Fisher’s 2-tailed exact test (Whitlock and Schluter 2015) to see if there was a relationship between encounter types and time categories.

Spatial analyses: city quadrant and park area

The web-GIS provided a unique UTM coordinate (georeference) for each data point, which allowed for spatial analysis. The data submitted also included contextual details (e.g., in proximity to greenspaces). Each encounter was coded to 1 of 4 Calgary municipal quadrants - Northeast (NE), Northwest (NW), Southeast (SE), and Southwest (SW). Quadrants were chosen for ease since they are predefined by the City of Calgary. These predefined quadrants also cover a similarly sized area, except for the SE which is larger but comparable in area when industrial regions are omitted (City of Calgary 2012). We used Pearson’s chi-square (Whitlock and Schluter 2015) to test for differences in frequency of the total number of reports by quadrant. We then used Fisher’s 2-tailed exact test (Whitlock and Schluter 2015) to examine dependence between encounter type and quadrant.

Table 2. Park area (km^2) in Calgary, Alberta in 2012 – including natural and maintained parks (Alberta Parks 2017; City of Calgary personal communication 2017). Only park space owned by the City of Calgary and Province of Alberta are included (excludes community or other owned parks due to difficulty obtaining such data).

Quadrant	City Park Area (km^2) †	Provincial Park Area (km^2) ‡	TOTAL
NE	5.59	0	**5.59**
NW	22.02	0	**22.02**
SE	7.49	10.17	**17.66**
SW	10.73	3.39	**14.12**
TOTAL	**45.83**	**13.56§**	**59.39**

†2012 data ‡ unchanged since 2012 § Breakdown between SE and SW is estimate

Finally, we used Pearson's chi-square (Whitlock and Schluter 2015) to test for significant differences between the amount of park space available (Alberta Parks 2017; City of Calgary 2017, personal communication) and encounters reported in each quadrant. Park space includes both natural and maintained spaces owned by the City of Calgary or Province of Alberta and is reported in square kilometers (Table 2). Fish Creek Provincial Park spans the SE and SW quadrants so we estimated 75% as part of the SE and 25% as part of the SW based on visual inspection of city maps (visual estimate only because no official information on this park's split between SE and SW could be obtained).

RESULTS

Encounter type

Encounter Type 1 made up 91% of all reports, whereas encounter Type 5 accounted for just 1% (Figure 1). Upon removing Type 1, we found a significant difference across Types 2 through 5 (χ^2=10, df: 3, P<0.05). Type 3 was most frequent at 41% and Type 5 was least frequent at 16% (Figure 2). We also found a significant difference between 'non-conflict' (Types 2 and 3) and 'conflict' (Types 4 and 5) groupings (χ^2=4.8, df: 1, P<0.05). 'Non-conflict' encounters made up 63% (n=43) of these reports (n=25 were 'conflict' encounters).

Temporal analyses: biological season and time of day

We found a significant difference in the frequency of reports by season (χ^2=170.5, df: 2, P<0.001). There were 402 encounters reported in Dispersal season (52%), followed by 274 in Breeding season (35%) and 105 in Pup-Rearing season (13%). We also found a significant difference between the types of encounters reported and biological seasons (Fisher's test, P=0.02) (Figure 3). When analyzing each type separately, Type 1 and 2 encounters were statistically different across seasons (χ^2=167.8, df: 2, P<0.001 and χ^2=8.4, df: 2, P<0.025, respectively), with most encounters occurring during the Dispersal season: 52% of Type 1 and 60% of Type 2 (Figure 3). Types 3 and 4 were not statistically different across seasons (χ^2=1.1, df: 2, P>0.05 and χ^2=3.6, df: 2, P>0.05, respectively) (Figure 3). There were 45% of Type 5 encounters reported during Pup-Rearing season, but this was not significantly higher than reported in other seasons (χ^2=1.2, df: 2, P>0.05) (Figure 3). Even though 44% of 'conflict' reports (Types 4 and 5) occurred during Dispersal season, there was no statistical difference across seasons found in this analysis either (χ^2=1.5, df: 2, P>0.05) (Figure 4). We also mapped encounters by biological seasons (Figure 5). Plotting the encounters facilitates visualization of changes in behaviour that may be important to the development of conflict with people. For instance, our map shows more clustered encounters reported during Breeding and Pup-Rearing seasons, and less clustered during Dispersal season.

We found a significant difference in encounter frequency by time of day (χ^2=225.1, df: 3, P<0.001). Most reports were during the Daylight category (47%, n=369), followed by Dawn (22%, n=167), Dark (20%, n=157), and Dusk (11%, n=88). We did not, however, find a difference in encounter type by time of day (Fisher's test, P=0.08)

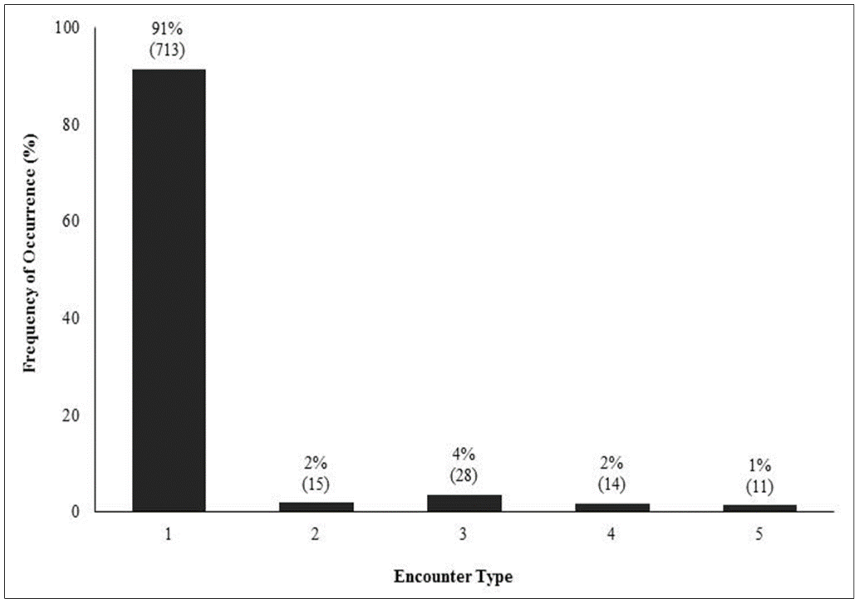

Figure 1. Percent (%) frequency of coyote encounters by type (n=781) reported by citizens in Calgary, Alberta – 2010 to 2012. There was a significant difference in frequency of encounters by type (P<0.001). Value in brackets equals number of reports.

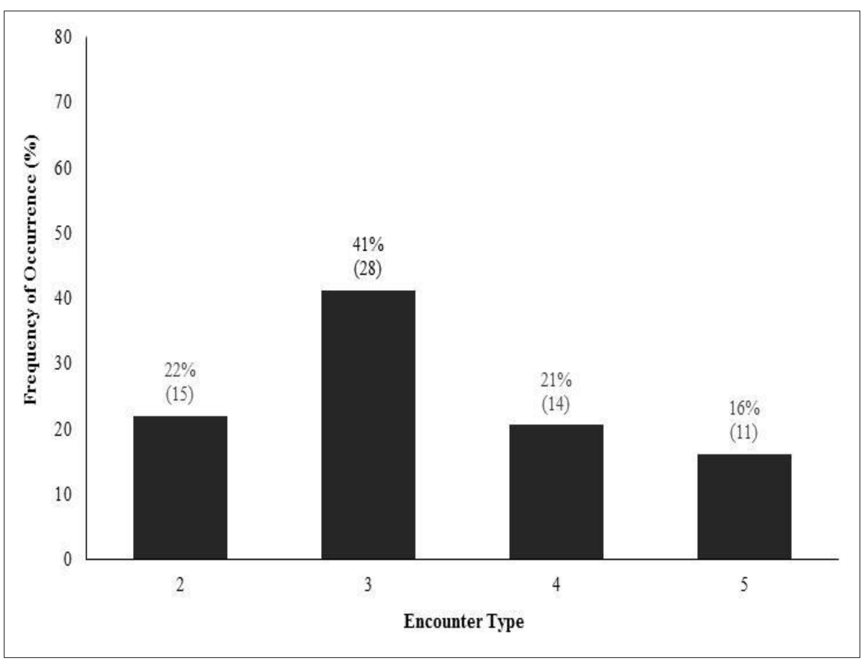

Figure 2. Percent (%) frequency of coyote encounter Types 2 through 5 (n =68) reported by citizens in Calgary, Alberta – 2010 to 2012. There was a significant difference in frequency of encounters (P<0.05). Value in brackets equals number of reports.

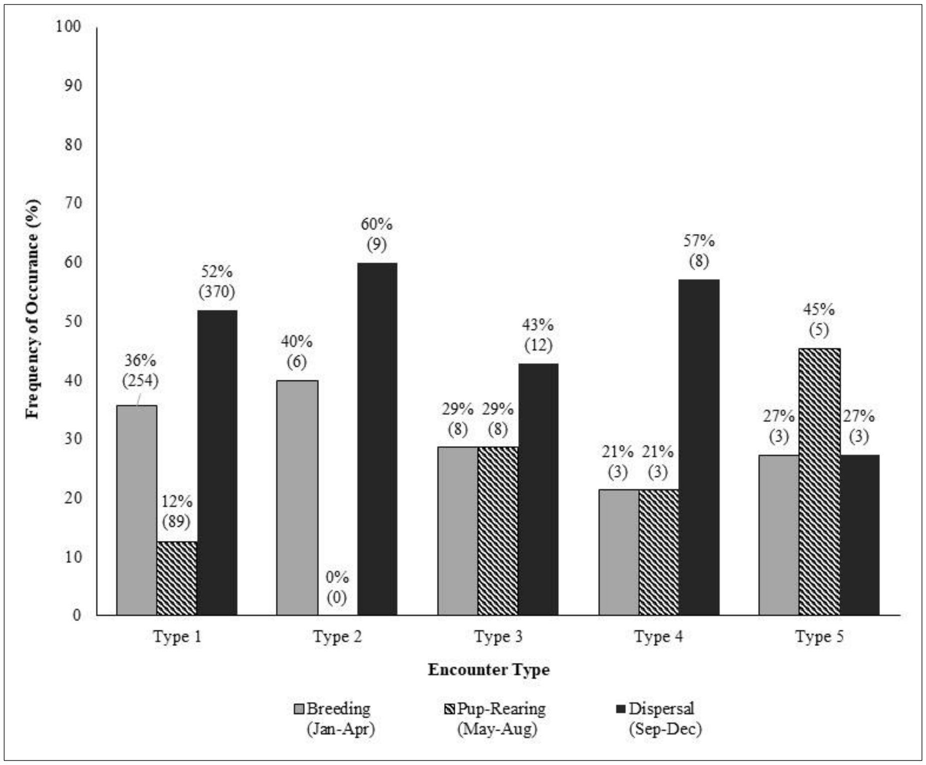

Figure 3. Percent (%) frequency of coyote encounters (n =781) by Type (1-5) and biological season in Calgary, Alberta – 2010 to 2012. There was a significant difference between the types of encounters reported and biological seasons (Fisher's test, P=0.02). Types 1 and 2 were significantly different (P<0.05 and P<0.025, respectively). Value in brackets equals number of reports. Percentages are calculated within Type, and are rounded to nearest integer.

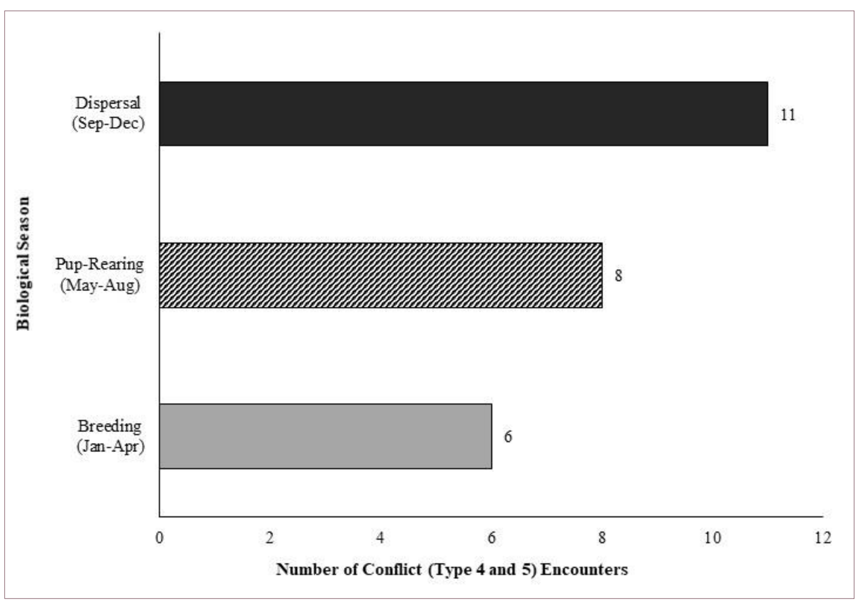

Figure 4. Number of coyote conflict reports (n=25) by biological season of coyotes in Calgary, Alberta – 2010 to 2012. Although the highest number of 'conflict 'encounters were reported in Dispersal season, there was no statistically significant difference between seasons (P>0.05).

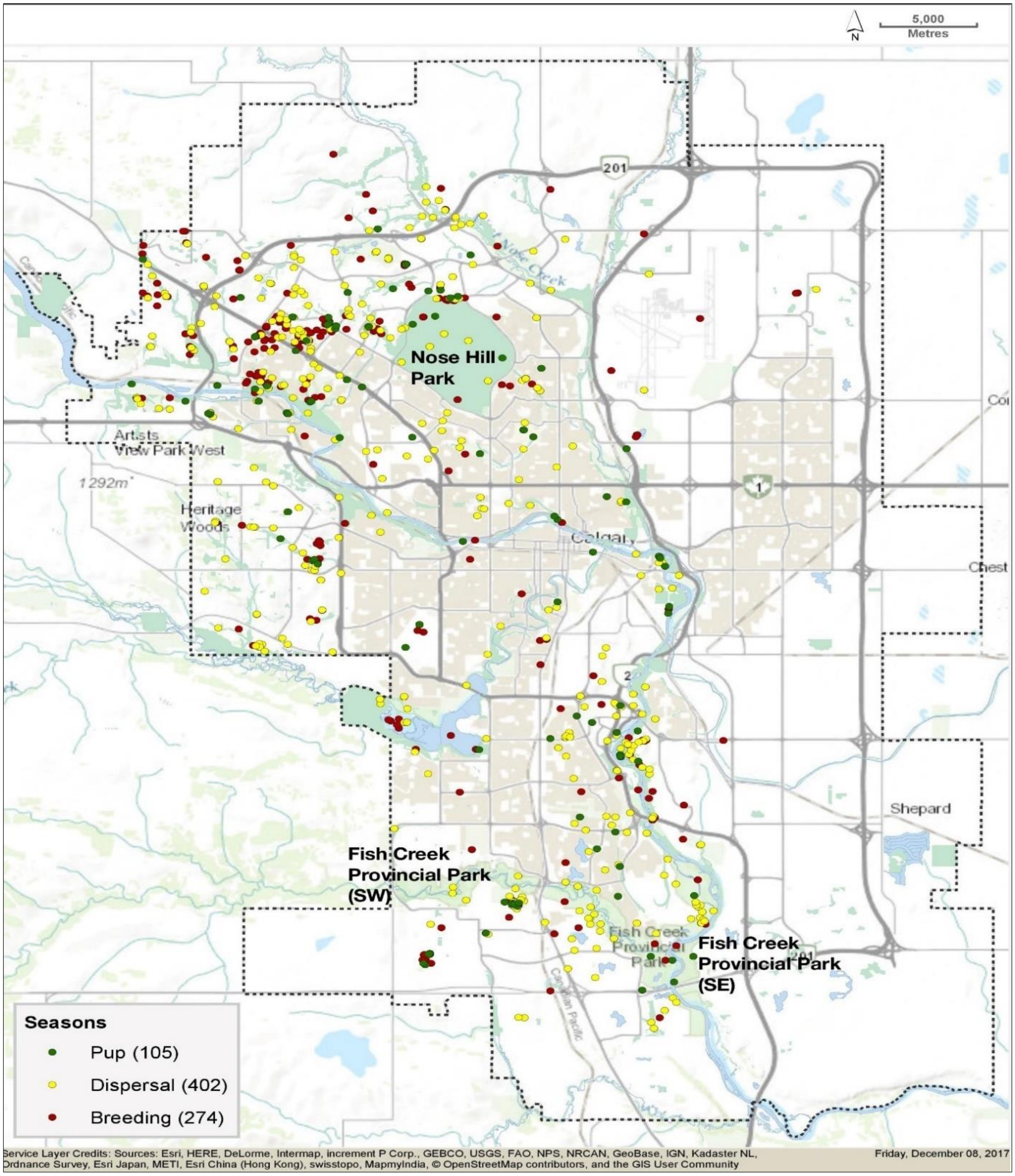

Figure 5. Map of coyote encounters (*n*=781) in Calgary, Alberta by biological season of coyotes – 2010 to 2012. Calgary's largest parks are labelled: Fish Creek Provincial Park is 13.56 km^2 (Alberta Parks 2017) and Nose Hill Park is 11.29 km^2 (City of Calgary 2017). Mapping in ArcGIS by Spatial and Numeric Data Services (SANDS), University of Calgary.

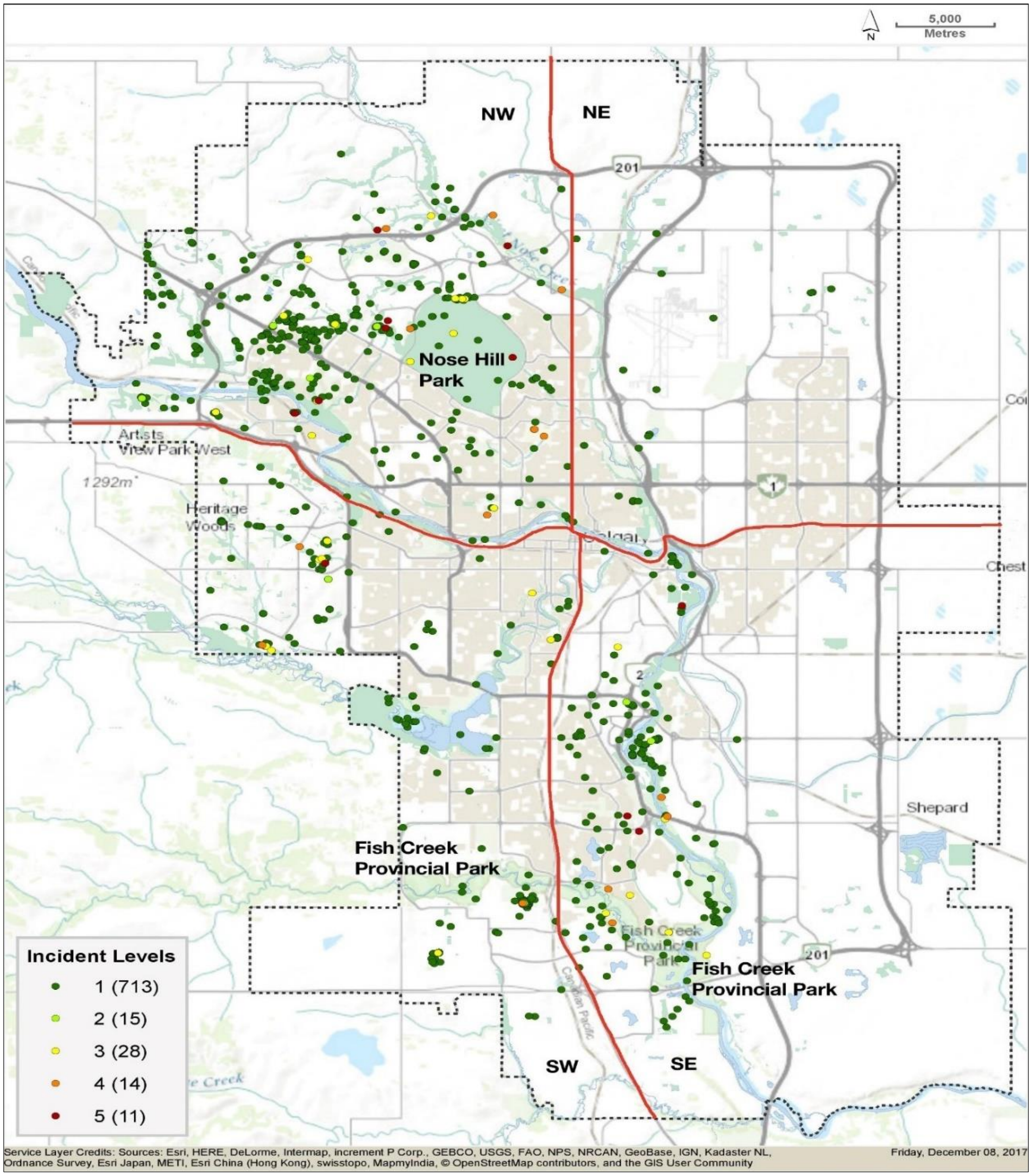

Figure 6. Map of coyote encounter types (n=781) by City of Calgary municipal quadrants (NW-NE-SW-SE) – 2010 to 2012. Red lines indicate approximate boundaries of quadrants. Calgary's largest parks are labelled: Fish Creek Provincial Park is 13.56 km^2 (Alberta Parks 2017) and Nose Hill Park is 11.29 km^2 (City of Calgary 2017). Mapping in ArcGIS by Spatial and Numeric Data Services (SANDS), University of Calgary.

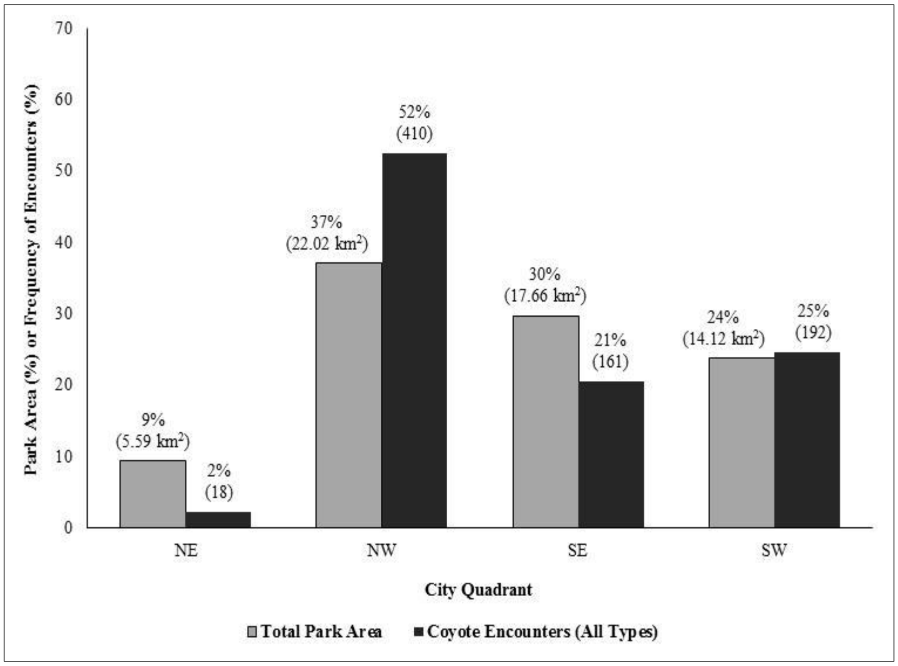

Figure 7. Total estimated percent (%) park area (km^2) in 2012 and percent (%) frequency of coyote encounters (n=781) by City of Calgary quadrant – 2010 to 2012. By quadrant, the frequency of encounters and amount of park area were significantly different (P<0.001 and P<0.025, respectively). There was no relationship, however, between encounter type and quadrant (Fisher's test = 0.99). Values in brackets pertaining to Coyote Encounters are number of encounters per quadrant.

Spatial analyses: city quadrant and park area

We mapped encounters by quadrant (Figure 6) and found a significant difference (χ^2=403.2, df: 3, P<0.001). The NW had 52% of all reports, followed by the SW at 25% and SE at 21% (Figure 7). The NE only recorded 2% of all reports (Figure 7). The contingency test determined that there was no relationship between encounter type and quadrant (Fisher's test, P=0.99). The amount of park area (km^2) in each quadrant was significantly different (χ^2=9.8, df: 3, P<0.025). The NW had the most park space (37%), which coincides with highest encounters, and the NE had the least park space (9%) with least encounters (Figure 7). The SE had more park space than the SW, but less encounters reported (Figure 7).

At the community scale, the NW had 6 neighbourhoods with at least 20 reports, whereas the SE had 3 and the SW had 1. The NE, however, had no communities with greater than 20 reports. Ranchlands (NW) and Shawnee Slopes (SW) reported the most encounters (n=66 and n=53, respectively). In the SE, Fish Creek Provincial Park reported the most (n=35).

With respect to the location of encounters (topographic feature), 68% (n=17) of 'conflicts' occurred in greenspaces, whereas 28% (n=7) occurred in yards and 4% (n=1) occurred on a non-highway road (Figure 8). For sightings, 70% (n=502) occurred in greenspaces, followed by 19% (n=138) on non-highway roads, and 6% (n=42) in yards (Figure 8).

DISCUSSION

Encounter types

Sightings dominated the coyote encounters reported by Calgary citizens (Figure 1) and echo prior findings of Lukasik and Alexander (2011). Poessel *et al.* (2013) also found that 87% of the 2003 to 2010 coyote encounters in the Denver Metropolitan Area were non-conflict occurrences (sightings and other evidence of coyotes). The multitude of Type 1 (sightings) may reflect polarized sentiments about whether coyotes belong in urban settings: 1) positive – that the presence of a coyote is interesting, and worth reporting and monitoring; 2) negative – that coyotes are perceived to be 'out of place' in the city, and potentially a threat (Alexander and Lukasik 2016). We cannot, however, evaluate these varying attitudes from the information garnered in this study.

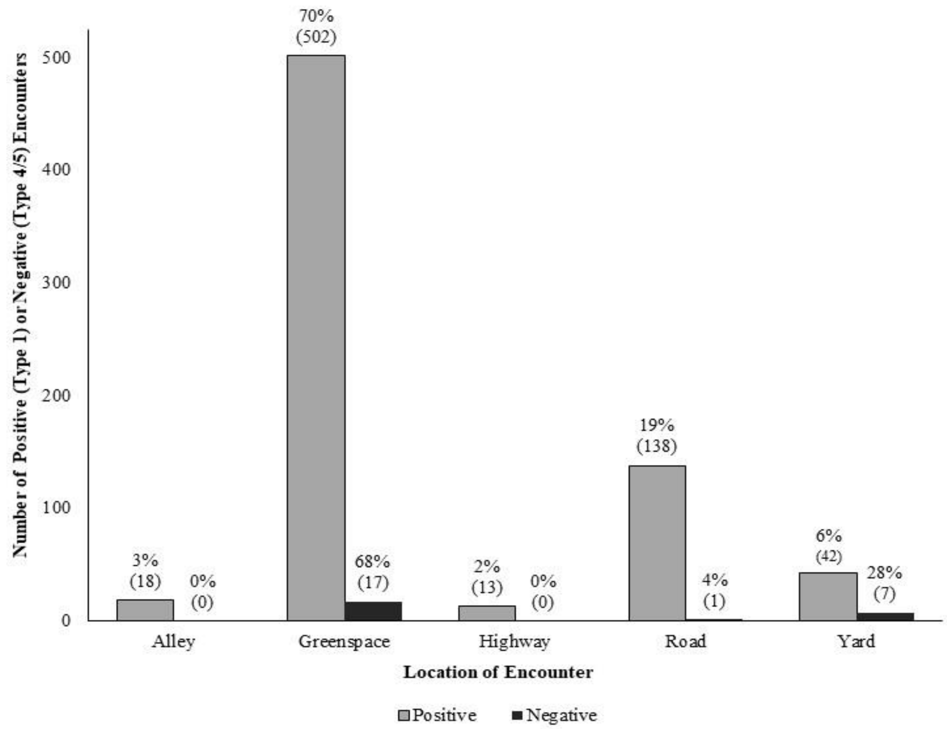

Figure 8. Location (topographic feature) and percent (%) frequency of coyote sightings (Type 1, *n*=713) and 'conflicts' (Types 4 and 5, *n*=25) in Calgary, Alberta – 2010 to 2012. Value in brackets equals number of reports.

Type 5 (attacks) represent just over 1% (*n*=11) of all reported encounters and involved dogs only (Figure 1). Likewise, Lukasik and Alexander (2011) found that Type 5 encounters comprised only a very small segment of their data, at just 2% (*n*=38) of 1684 reports (with no attacks on humans, only pets). Elsewhere, Poessel *et al.* (2013) concluded that only 12% (*n*=484) of 4,006 coyote encounters reported between 2003 and 2010 in Denver were attacks. Of those, 97% (*n*=471) were attacks on pets. Poessel *et al.* (2013) also noted that attacks by dogs (on other dogs) are considerably more common than attacks by coyotes. In Calgary, between 2010 and 2012, there were 11 reported coyote-on-dog attacks compared to 1,154 reported dog-on-dog attacks (City of Calgary personal communication 2017). Moreover, there were no reports of coyotes attacking humans during this time, but there were 211 incidents of dogs injuring people (City of Calgary 2017, personal communication).

'Conflicts' (Types 4 and 5) occurred most often in greenspaces (17 of 25 reports), followed by yards (7 of 25 reports) (Figure 8). Similarly, Lukasik and Alexander (2011) and Alexander and Quinn (2011) found that human-coyote conflicts primarily occurred in green/natural spaces (often associated with an off-leash dog) or in the vicinity of yards bordering greenspaces. We saw consistency across reporting methods (phone-in versus web-GIS) and found ongoing evidence that conflicts (at least between coyotes and dogs in Calgary) are related to human behaviour and domestic animal husbandry.

When we aggregated data, excluding sightings (Type 1), 'non-conflict' encounters (Types 2 and 3) outnumbered 'conflict' encounters (Types 4 and 5) by almost 2:1. In Calgary, coyotes regularly use human infrastructure (e.g., trails, roads, paved walkways) for movement (Lukasik and Alexander 2011), and hence there is an ongoing chance of encounters in these spaces. There is also a propensity by the general public to view the coyote as being in a 'human' landscape and therefore behaving inappropriately (Alexander and Lukasik 2016). From a management standpoint, Type 2 and 3 encounters require more nuanced review – at the very least an evaluation of the narrative collected and possibly a site visit or follow up interview to better comprehend any increased risk. An important element to a tool like *Living with Coyotes* or a phone-in system would be to include precise questions that adequately capture the actual behaviour of the coyote versus people's interpretation of the behaviour. We recommend that any similar tools request contact information to allow follow up. It is difficult to mandate the provision of personal information, but the inclusion of a registration protocol, as used in *Living with Coyotes*, can help in this regard.

Temporal differences: biological seasons and time of day

The frequency of all encounters combined – as well as sightings (Type 1) and being fed or eating garbage (Type 2) – were highest in Dispersal season, followed by Breeding season (Figure 3). This is expected based on typical increase in movement of coyotes during these periods (Andelt and Gibson 1979). There were, however, relatively few reports of coyotes being fed or eating garbage (Type 2; Figure 1), despite anthropogenic food sources often being cited as attractants in urban environments (Schmidt and Timm 2007; White and Gehrt 2009; Alexander and Quinn 2011) (Figure 9). Since most observations occurred during daylight when coyotes are visible and people venture outside more, this study may have overlooked access to garbage during darkness. Prior research examining diet in Calgary (Lukasik and Alexander 2012) found that ≤14% of coyote scats contained evidence of garbage. Although coyotes being fed or eating garbage was reported in Dispersal and Breeding seasons, none were reported during Pup-Rearing (Figure 3). Dispersal season is a time when coyotes – including juveniles leaving the natal home range – increase movement about the landscape, often in search of a new territory (Fox and Papouchis 2005; Lukasik and Alexander 2012). As such, animals may be more prone to eating garbage/human-sourced foods at this time – an easy resource in unfamiliar territory. As eating anthropogenically-sourced foods has been found to increase risk of conflict (Fox and Papouchis 2005; Schmidt and Timm 2007), greater vigilance with garbage/other food-related attractants (by citizens and agencies/municipalities) is warranted during Dispersal season.

Following/stalking (Type 3) and aggressive behaviour (Type 4) were also most numerous during the Dispersal season (Figure 3), but not statistically greater. Attacks (Type 5) were most frequent during the Pup-Rearing season, but again not significantly so (Figure 3). We also found that although 'conflict' encounters (Types 4 and 5 combined) were not statistically different across seasons, they were numerically higher during Dispersal (Figure 4). It is possible that some Type 3 encounters during the Dispersal season were predatory (e.g., stalking prey) or precursors to aggressive behaviour (i.e., could be categorized as 'conflict' encounters) that were not recognized by the person reporting the event. Even though Types 3 through 5 and 'conflict'

Figure 9: Urban coyote playing with garbage in a remnant greenspace that it used for denning, September 2018. Photo © S. M. Alexander.

encounters were not significantly different across seasons, these results may indicate potential to find significance in future similar studies.

Biologically, the observed trends are sensible. During Pup-Rearing season, 1 or both parents may remain close to the den or be more reclusive in activity, thereby reducing detectability and resulting in fewer sightings compared with other seasons. Den incursions by humans and dogs, as well as higher resource demands, may also intersect at this time to increase attacks. The previous could explain the higher number of attacks reported during Pup-Rearing season. Although aggressive behaviour reported during Dispersal season was not significantly higher than in other seasons, some studies have found that during dispersal periods, juvenile animals (especially males) have been disproportionately involved in conflict with humans (Saberwal *et al.* 1994; Teichman *et al.* 2016). At that time, juveniles may be more frightened, defensive, and/or inexperienced lending to increased attacks. They might also seek convenient opportunities for food (Timm *et al.* 2004), and prey upon pets, scavenge in garbage, or eat food left for other animals (e.g., bird seed). Evaluating the association between coyote age class and encounter type was, however, beyond the scope of this study. When mapping reports by season, we saw that encounters were more clumped during Breeding and Pup-Rearing than during Dispersal (Figure 5). This demonstrates how Dispersal encounters tend to occur in increasingly varied locations across the landscape.

In contrast, the earlier analysis by Lukasik and Alexander (2011) in the same area showed an increase in Type 5 encounters during Breeding season. They noted that foliage is greatly reduced during this period in Calgary, which plausibly increases visibility of coyotes by humans or dogs. This could result in greater insecurity by coyotes and increased chasing by dogs. The coyote's breeding season in Calgary overlaps with shorter days and sub-zero temperatures when people are less often outside. This may result in habitat that is usually used by people becoming more inviting to coyotes. When people return to these places (e.g., walking trails by rivers), risk of conflict could increase. There may be a cause for the variation in when attacks seemed to predominate between this and Lukasik and Alexander's (2011) study, but our data was not fine-detailed enough to explore this. In a Denver area study from 2003 to 2010, attacks on pets increased during winter months (Poessel *et al.* 2013). Interestingly, however, White and Gehrt (2009) found no relationship between season and attack, based on analysis of coyote attacks on humans in Canada and the United States from 1960 to 2006. The inherent differences across literature suggests that geographic context and concomitant variation in season date ranges, attractants, human behaviour, coyote density, coyote behaviour, numbers of observations, daylight hours, etc., may be linked to the disparity seen in results.

We found that encounter frequency varied by time of day. Daylight observations were expected to be more frequent due to enhanced visibility of coyotes by people (which concurs with our results). We do not, however, believe this indicates a change in activity specific to urban context. Coyotes are often considered to be crepuscular (predominately active in twilight), especially in rural areas (Andelt and Gibson 1979; Fox and Papouchis 2005), but >3 years observation of rural and urban coyotes shows activity throughout the day, with more detectability at dawn/dusk due to vocalizations (Alexander, unpublished data). Some researchers have found that in urban environments, activity tends to shift towards semi-dark to dark periods, plausibly to avoid humans (Andelt and Gibson 1979; Fox and Papouchis 2005; Grubbs and Krausman 2009). For instance, in Tucson, Arizona coyotes used golf courses and medium-density residential areas in the evenings when there is less human activity (Grubbs and Krausman 2009). Grubbs and Krausman (2009) found that coyote activity increased later at night, which was accompanied by movements into high-density neighbourhoods. Coyotes then returned to resting sites during dawn.

Some research has suggested that increasing urban coyote activity during the day may signal increased tolerance to humans, which could be a precursor to conflict where humans and coyotes overlap (White and Gerht 2009). While the previous finding may hold true elsewhere, and for individual coyotes in Calgary, we do not believe it ubiquitously relates to higher conflict risk. Elevated risk is more likely a result of elevated co-occurrence of humans and coyotes in space. Moreover, in Calgary and surrounding areas, movement and hunting by coyotes is reported at all times of the day, with and without conflict. Arguably, it is not the presence of coyotes during daylight, but changes in the specific behaviour of an individual coyote during this time (e.g., presence or lack of flight behaviour) that is a key indicator of elevated conflict risk.

City quadrants and park area

The frequency of human-coyote encounters varied by quadrant. Additionally, the distribution of observations suggests there is a correlation between frequency of encounters and amount of park/green space. The amount or type of park space may influence the kind of people who live in an area, but also, the kind of people may influence how local greenspaces are regularly used (Özgüner 2011). Differences in gender, education, culture, and experience with wildlife have been associated with how greenspaces are used (which may increase or decrease wildlife sightings) as well as how different groups perceive wildlife (Loyd and Miller 2010; Özgüner 2011). For instance, NE Calgary has a larger proportion of citizens for whom English is a second language and less population familiar with English relative to other parts of Calgary (Statistics Canada 2011). This may have resulted in lower reporting rates even if coyotes were present since the reporting tool was in English only. In addition to potential variation in use of greenspaces (and therefore reporting rates), it is important for future web-based tools to consider "access constraints" when designing, marketing, and analyzing data. Possible considerations include whether language barriers, knowledge of reporting need, ability to identify the species, or available time – among other challenges – affect reporting rates. If so, some neighbourhoods may be biased towards lower reports as a result.

Considering park space and the frequency of encounters reported, the SE of Calgary had relatively more park area but less reported encounters than the SW. This finding points to the need to consider dynamics and intersection of habitat with developed environment. For example, Fish Creek Provincial Park in Calgary is split between the SE and SW and therefore might be expected to similarly affect encounter rate. The entire park (which makes up about 60% of the park space in the SE), however, is west of Calgary's busiest and widest roadway – Deerfoot Trail – which conceivably acts as a barrier to the remainder of the SE quadrant. Also, since the SE has more industrial areas than the SW, there may be more greenspaces in the SE that have low human occupancy (i.e., open grassy fields that are awaiting development, which are common in Calgary industrial sites).

While the interaction between the amount of greenspace and coyote encounters is not linear in the present study, it warrants further attention. Lukasik and Alexander (2011) concluded that conflicts occurred more often where parks, greenspaces, or riparian habitat were near residential areas with higher human population densities. In addition, Poessel *et al.* (2017) also determined that more developed urban areas with limited natural space had higher conflicts. They suggest that urban areas designed with ample natural space provide refuge for coyotes and reduce risk of negative encounters. A conclusion might be that higher human population density and lack of greenspace intersect to increase attacks. We, however, found the opposite occurred. In this study, the SW community of Lower Mount Royal had the highest population density of 10,600 people per km^2 (City of Calgary 2012) and minimal greenspace, but no human-coyote conflicts reported during the period of this study (only 1 Type 1 encounter). The NW community of Edgemont had 3 conflict reports (most occurring in the same area) and a population density of 2,409 people per km^2, which makes Edgemont 1 of the lower-density communities in Calgary (City of Calgary 2012). Edgemont also borders Calgary's second largest park (Nose Hill Park) and contains considerable greenspace within the community.

A key explanatory factor in potential for attacks that we could not measure here is food conditioning. Lukasik and Alexander's (2012) scat analyses found a trend towards higher attack rates with higher percent garbage content. Morey *et al.* (2007) found that <2% of coyote scat tested in Chicago between 2000 and 2002 contained human-sourced food, and up until this time attacks were not reported (or were rare) even though the coyote population was apparently large (White and Gehrt 2009). In contrast, southern California is considered to have a large concentration of coyote attacks (White and Gehrt 2009), and Fedriani *et al.* (2001) found that ≤25% of coyote diets contained anthropogenic food, especially in high human-density areas. While our web-GIS tool yielded scant evidence of food conditioning (Type 2), it would be important in future to modify the emphasis of the website to ask for details on garbage/human-sourced food consumption by coyotes (perhaps with specific questions). Moreover, it may be critical to acknowledge that the tool cannot address this issue if observations tend to be daytime and garbage consumption is at night when less people are outside (we do not know the answer to the latter).

CONCLUSION

We found that human-coyote conflicts in Calgary, Alberta are infrequent and sightings make up the overwhelming volume of encounters reported. This concurs with earlier research by Lukasik and Alexander (2011). Coyotes were most often reported during the Dispersal season, followed by Breeding season. The highest number of attacks was reported in Pup-Rearing season, but not significantly so as to definitively connect propensity of attacks to this period. The highest number of 'conflict' encounters were reported during Dispersal season, but again not significantly enough to make a conclusive connection between human-coyote conflicts and this period. Most encounters were reported during daylight, which is expected considering when people are outside most often, and when better able see fine details and at a distance. We could not, however, make a connection between time of day and type of encounters reported. A link was found between amount of park area and frequency of encounters, at least with respect to the extremes. The NW quadrant of Calgary had the most park space and most encounters whereas the NE had the least of both. There may, however, be more than just percentage of park space involved in explaining why we found a variation in reports between areas of Calgary (e.g., demographic differences).

Lastly, there were very few reports of coyotes utilizing human-sourced foods (garbage, food left out for other animals, etc.); however, we expect that this occurred much more often than seen or reported. We conclude, in consensus with other researchers, that coyotes pose relatively low risk to humans or pets in urban environments, especially when compared to other threats such as injuries or attacks from dogs on other dogs or on humans.

We also argue that the web-GIS tool *Living with Coyotes* was comparably effective in recording encounter types and examining temporal trends, while providing insights into coyote behaviour beyond those derived from phone-in reporting (e.g., Calgary 311). The ability for users to reasonably pin-point the location of their coyote encounter can help to create more accurate maps than phone-in systems. Mapping of higher-risk encounter areas can help direct management efforts to further reduce risks to humans/pets and coyotes. For instance, it can be used to identify target neighbourhoods for education campaigns or those sites where more invasive tactics, such as hazing, may be required. Adding the option for follow up interviews into future similar studies could improve interpretation and accuracy of coyote behaviours reported by citizens. In addition, asking specific questions in the pop-up datasheet about food consumption by coyotes (e.g., if seen eating and, if so, what type of food was being consumed) could yield greater insight on this topic. Questions that measure perception changes or education gained by citizen users would also help evaluate the efficacy of future web-based tools. Lastly, considering ways to mediate potential reporting bias between areas due to differences in language, subject knowledge, time-constraints, etc., could assist in increasing the accuracy of results.

HUMAN-COYOTE MANAGEMENT CONSIDERATIONS

Although human-coyote conflicts are rare, implementing regulations to reduce interactions can plausibly diminish the small margin of risk even further. Strategies recommended are: 1) increased use of warning signs (Poessel *et al.* 2017); 2) restricting public access in presence of persistent coyote activity and known denning sites (Lukasik and Alexander 2011); 3) promoting and enforcing adherence to leash laws for dogs when in coyote territory (Bounds and Shaw 1994; Alexander and Quinn 2011); 4) building fenced off-leash areas within less desirable coyote habitat; 5) increased use of public education and media outreach programs to notify citizens of areas with high or regular coyote activity (e.g., door-to-door, mail inserts, social media, and television broadcasting); 6) development of humane hazing protocols (Fox and Papouchis 2005; Lukasik and Alexander 2011); 7) implementation of measures to reduce access to garbage and other food-related attractants (Fox and Papouchis 2005; Alexander and Quinn 2011; Poessel *et al.* 2017). In addition, emphasizing the ecological role of coyotes, and relaying positive messages to foster coexistence, will optimistically increase their acceptance by citizens.

Research into effects of hazing coyotes is relatively new and requires more attention. Bonnell and Breck (2017) employed citizen science to assist with their hazing trials and found positive effects in reducing coyote presence. They found that community-level hazing programs can be effective (e.g., to discourage coyote presence in an area) and immediate in the short-term, but long-term effectiveness needs further evaluation. While successful hazing techniques have been shown to be effective and humane, the recent emergence of untested approaches (e.g., paint-balling) raises significant concerns about the welfare of coyotes that are hazed.

Enacting and enforcing regulations to reduce coyote access to garbage and other human-associated food sources (such as bird seed and pet feeders) should further reduce risk of conflicts (Fox and Papouchis 2005; Alexander and Quinn 2011; Poessel *et al.* 2017). Some municipalities have implemented bylaws and changes to procedures to minimize human-wildlife conflicts. Examples from Nelson, BC, Revelstoke, BC, and Canmore, Alberta are bylaws including: no fruit permitted to collect on trees, bushes, or the ground; when and where bird feeders can be placed; garbage must be stored within a building or in a wildlife resistant container; outdoor cooking appliances/accessories (e.g., barbeques) must be clean and odour free; outdoor food storage (e.g., refrigerators or freezers) must not be accessible to wildlife; and no outdoor composting of meat or large amounts of fruit. Another example of measures to reduce access to garbage is in Coquitlam, BC where the city revised its curbside collection times so that garbage is picked up first (and early in the day) in high-wildlife use areas. We are hopeful that more and more communities will implement measures to reduce human-wildlife conflict in support of coexistence.

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APPENDIX

Time categories by month using 24-h clock. March and November have 2 time-spans due to daylight savings in Mountain Time Zone. Earliest and latest time used per category, per month since time adjusts slightly each day. Information provided by Timeanddate.com (2017).

Time Category / **Month**	**Dark**	**Dawn**	**Daylight**	**Dusk**
January	18:00 - 07:39	07:40 - 08:39	08:40 - 16:39	16:40 - 17:59
February	18:50 - 06:49	06:48 - 08:13	08:14 - 17:27	17:28 - 18:49
March *(pre-time change)*	19:07 - 06:26	06:27 - 07:20	07:21 - 18:18	18:18 - 19:06
March *(post-time change)*	20:43 - 06:38	06:39 - 07:58	07:59 - 19:34	19:35 - 20:42
April	21:36 - 05:31	05:32 - 07:09	07:10 - 20:10	20:11 - 21:35
May	22:27 - 04:42	04:42 - 06:06	06:07 - 20:59	21:00 - 22:26
June	22:41 - 04:38	04:39 - 05:25	05:26 - 21:45	21:46 - 22:40
July	22:39 - 04:39	04:40 - 05:59	06:00 - 21:24	21:25 - 22:39
August	22:02 - 05:21	05:22 - 06:47	06:48 - 20:22	20:23 - 22:01
September	20:55 - 06:15	06:16 - 07:35	07:36 - 19:15	19:16 - 20:54
October	19:46 - 07:03	07:04 - 08:27	08:28 - 18:11	18:12 - 19:45
November *(pre-time change)*	18:45 - 07:53	07:54 - 08:31	08:31 - 18:05	18:05 - 18:44
November *(post-time change)*	17:40 - 06:59	06:59 - 08:16	08:17 - 16:32	16:33 - 17:39
December	17:20 - 07:38	07:39 - 08:39	08:40 - 16:29	16:30 - 17:19