**Title:** Community reporting database reveals rising coyote boldness and associated human concern in Edmonton, Canada

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**ABSTRACT**

In cities throughout North America, sightings of coyotes (*Canis latrans*) have become common. Reports of human-coyote conflict are rising, as is the public demand for proactive management to prevent negative human-coyote interactions. Effective and proactive management can be informed by the direct observations of community members, who can report their interactions with coyotes and describe the situation or context that led to that interaction. To assess the predictors of human-coyote conflict, we used a web-based reporting system to collect *N* = 9,134 community science reports of coyotes in Edmonton, Canada, between January 2012 and December 2021. We used a standardized ordinal ranking system to score each report on two indicators of human-coyote conflict: the actual risk of negative interactions, as indicated by coyote boldness, and the perceived risk of such interactions, reflected in human concern about coyotes. Using ordered logistic regression and chi-square tests, we then identified spatial, temporal and contextual covariates associated with conflict and assessed changes in conflict over time. Our analysis found that coyotes were bolder in less developed open areas and during the pup rearing season, but human concern was highest in residential areas and the dispersal season. Reports that mentioned pets or children were more likely to describe greater human-coyote conflict. Coyote boldness and human concern both increased over the 10 years of reporting. Our results highlight the differences and similarities between the factors that affect boldness and concern, and emphasize the need for the effective allocation of proactive management actions to improve coexistence between humans and urban coyotes.

**Keywords:** Human-coyote conflict, community science, *Canis latrans*, urban

**INTRODUCTION**

Coyotes (*Canis latrans*) are a common example of an urban-adapted species, and one of the few urban-dwelling large carnivores in North America (Schell et al. 2020). They survive in urban areas largely by avoiding interactions with humans (Mowry et al. 2020, Drake et al. 2021) while benefitting from reduced competition with other predators (Prugh et al. 2009), less human persecution in urban compared to rural areas (Collins and Kays 2011), and the abundant urban food resources available to them in the form of rodents, garbage, compost and fruit trees (Fedriani et al. 2001, Murray et al. 2015a, Sugden et al. 2021). Coyotes in urban areas can improve human quality of life by regulating rodent and smaller predator populations (Crooks and Soule 1999) and providing the feelings of connection with nature and aesthetic enjoyment that are often inherent in seeing wild animals (Soulsbury and White 2015, Cox and Gaston 2018). As such, many people living in cities tolerate, and even appreciate, urban coyotes (Soulsbury and White 2015, Sponarski et al. 2018). However, the past two decades have been marked by an apparent increase in negative human-coyote interactions that are characteristic of human-wildlife conflict, as indicated by rising numbers of bold and aggressive interactions between urban coyotes and people (Baker and Timm 2017, Poessel et al. 2017). These negative interactions may challenge continued coexistence.

Understanding the consequences of more frequent negative human-coyote interactions requires considering two factors that can indicate the level of conflict between humans and coyotes: the actual risk posed by coyote behaviour and people’s perception of that risk. The actual risk that coyote behaviour presents to people or pets is often studied retroactively based on attacks (White and Gehrt 2009, Baker and Timm 2017). Coyote attacks on pets are mostly attributed to predation or the defense of territories or dens (Gehrt et al. 2013, Poessel et al. 2017, Nation and St. Clair 2019); attacks on humans, despite their rarity, typically generate substantial media attention and degrade public tolerance (Alexander and Quinn 2011, Draheim et al. 2019). Attacks are often preceded by increasingly bold or aggressive behaviour, which is frequently caused by increasing coyote habituation to people (Baker and Timm 2017). Assessing boldness, which refers to the tendency of coyotes to approach or interact with people or pets, can therefore provide insight to the actual risk of harm from a coyote interaction.

Conversely, perceived risk is the concern that people have of harm to themselves, children, or pets when they see or interact with a coyote. Although human perception of the risk posed by coyotes may not align with the actual risk of a coyote attack, it reflects public tolerance of coyotes, and, consequently, public attitudes towards various forms of wildlife management and policy (Sponarski et al. 2018; Draheim et al. 2019). Managers are often limited to reactive approaches, like culls or targeted lethal removals (Breck et al. 2017), that are implemented after reported attacks in areas where the risk of attacks is assumed to be more likely (Baker and Timm 2017, Draheim et al. 2019). Perceived risk is an important component of human-coyote conflict but often underappreciated relative to the actual risk posted by coyote behaviour. Thus, assessments of human concern about potentially dangerous human-coyote interactions could guide proactive, non-lethal management efforts to minimize potential conflict.

In addition, any effective management strategy must be informed by knowledge of the spatial, temporal and contextual factors associated with coyote boldness and human concern. Identifying high-conflict areas for management action requires insight into the spatial variables that predict negative interactions between humans and wildlife (Delsink et al. 2013, van Bommel et al. 2020). For example, knowing which areas have low, moderate or high probabilities of interactions between humans and black bears (*Ursus americanus*) allows for management resources to be more efficiently allocated to improve coexistence (Merkle et al. 2011). Likewise, wildlife management can be further improved by knowledge of the diel, monthly, and inter-annual scales at which perceived or real negative encounters are most likely to occur (Morehouse and Boyce 2017, Soulsbury 2020). Furthermore, contextual variables that can increase actual or perceived risk, and thus conflict, include the presence of pets or children, off-leash dogs, and poor health of individual animals (Poessel et al. 2013, Olson et al. 2015).

To assess the importance of these variables for coexistence, large datasets of human-coyote interactions are imperative, and over the past decade, public reports of coyote sightings and interactions have emerged as an invaluable source of information. Community reporting databases allow researchers to conduct otherwise difficult long-term studies over large geographic areas while simultaneously engaging and educating members of the public (Weckel et al. 2010, Frigerio et al. 2018). Previous studies have collected voluntary reports of coyote activity using websites (Wine et al. 2015, Mowry et al. 2020), city reporting databases (Lukasik and Alexander 2011, Poessel et al. 2013), public surveys (Weckel et al. 2010), and apps (Mueller et al. 2019, Drake et al. 2021). Analyses of these datasets have largely focused on broad patterns in reports (Weckel et al. 2010, Poessel et al. 2013, Wine et al. 2015, Mowry et al. 2020), demonstrating that reporting varies across development levels and land cover types, coyote seasons, and with household income and education. Lukasik and Alexander (2011) and Drake, Dubay and Allen (2021) demonstrated that bold coyote behaviour was most prominent in the coyote pup rearing season. These studies also found more negative interactions in areas where coyotes consume more anthropogenic food (Lukasik and Alexander 2011). Despite these advancements, we are not aware of any study that has comparatively assessed the factors that drive changes in both coyote boldness and human concern, or that has investigated changes in the nature of human-coyote interactions over time.

In this study, we used community science reports collected over 10 years from a website in Edmonton, Canada to investigate two indicators of human-coyote conflict: coyote boldness towards people or pets and people’s concern about coyotes. First, we sought to determine the environmental settings and times of day or year that were more strongly associated with coyote boldness, and consequently, a higher risk of negative human-coyote interactions. Second, we aimed to identify the analogous suite of spatiotemporal predictors of increased human concern about coyotes, as these factors can also reveal important targets for urban wildlife management. Lastly, we assessed whether various contextual variables affected coyote boldness and human concern. To our knowledge, our study represents the largest and longest-term community science-based study on human-coyote interactions. Our data provides insight on the factors associated with real or perceived negative human-coyote interactions, with the goal of improving proactive urban coyote management and facilitating coexistence.

**METHODS**

**Study area**

Our study area was Edmonton, Alberta, Canada (53.54728oN, 113.50068oW), a city that is large in both area (684 km2) and population (976,223 in 2019 census; City of Edmonton 2019). Edmonton has warm summers (Jun-Aug daily average = 16.7°C) and cold winters (Dec-Mar daily average = -9.7°C; Environment and Climate Change Canada 2018). The city is bisected by the North Saskatchewan River valley and several large ravines, which form a network of minimally developed natural areas that provide abundant habitat for coyotes and other wildlife (Figure 1).

**Report collection**

Members of the public were able to voluntarily report coyote sightings or encounters through a

web-based platform launched in September 2010 on the Edmonton Urban Coyote Project website (<https://www.edmontonurbancoyotes.ca/reportsighting.php>). We promoted the website opportunistically during media interviews, public lectures, and social media posts, as well as through word of mouth, on labels attached to wildlife cameras in the city, and via a link on the City of Edmonton website (<https://www.edmonton.ca/residential_neighbourhoods/pets_wildlife/Coyotes.aspx>) that was added in 2019.

When submitting a report, reporters were asked to provide the date, time of day, and nearest intersection to the report location. Time of day was submitted by reporters using a drop-down menu with the option to select either hourly times between 5 AM and midnight, or a general time window (dawn, morning, afternoon, evening, or night). They were also asked to identify whether their report was a “sighting,” defined as an observation at a distance with no interaction, or “encounter,” defined as an interaction at close range. Reporters could optionally provide free-form comments, as well as their name and contact information. We included a map interface to allow reporters to precisely locate their report by placing a pin on the map. For the *N* = 3,366 reports that did not include map coordinates, we determined them *post hoc* based on the reported nearest street intersection and other information in the comments (e.g., if a specific park or building was named). To encourage participation, no registration or login was required.

**Extraction of response variables and contextual variables from reports**

Most reports (96.8 %, *N* = 8,859) included optional comments with further details about the human-coyote interaction including information on coyote boldness, human concern, and various contextual variables. We recruited a team of 30 volunteers and undergraduate students that read and classified the comments in each report following a standardized protocol (Figure 1, Text 1 in Appendix 1). For reports with comments that described coyote behaviour, volunteers assigned the behaviour a “boldness score” on an ordinal scale from one to nine. We later simplified these categories into a four-point scale of ranging from avoidance (e.g., ran away) to aggressive behaviour (e.g., made physical contact; Table 1). Human concern was classified on a three-point ordinal scale based on the explicit presence of words that directly reflect human concern. The three categories ranged from positive (e.g., beautiful), to neutral (e.g., curious or not scared), to negative (e.g., scared) emotional responses or perceptions (Table 2).

The five contextual variables that we determined from report comments were (1) the human activity occurring at the time of the report (e.g., walking, cycling, driving), (2); the presence or mention of vulnerable individuals (children, dogs or cats), (3); if dogs present were leashed or off leash, (4); the number of coyotes observed; and (5) the reporter’s interpretation of coyote health. To assess the repeatability between report classifiers, J. Farr randomly selected and re-classified 100 reports. For each variable that was extracted from the reports, we then calculated the percentage of reports where that variable was classified the same between reporters.

**Spatial and temporal variable collection**

To quantify the geospatial setting of each report, we imported report locations into ArcGIS Pro v2.7 (Figure 1). We excluded reports that were located outside of Edmonton city limits or in recently annexed but undeveloped rural land, and we identified our study area by generating a minimum convex polygon around the remaining report locations. Land cover types within our study area were classified using geospatial data from the City of Edmonton Urban Planning Land and Vegetation Inventory (uPLVI) database, a high-resolution database that uses remotely sensed imagery and Softcopy photogrammetry to identify land cover types for urban land use decisions (City of Edmonton 2018). For our study, we binned uPLVI land cover classifications into six land cover types representing various degrees of human development and coyote habitat quality. These land cover types are comparable to those used in similar studies (Table 3; Weckel et al. 2010, Poessel et al. 2013, Mowry et al. 2020).

Because coyote boldness and human concern may be affected by a combination of site-specific conditions (van Bommel et al. 2020) and broader landscape characteristics (Murray et al. 2015b, Wine et al. 2015), we measured land cover at five different scales: within 100, 200, 400, 800 and 1600 m radii of each report. Land cover was calculated as the proportional area of each land cover type within the circular area defined at each scale. Proportional land cover measurements were then centered log-ratio transformed to minimize autocorrelation (Quinn et al. 2019). To compare the distribution of reports across different land cover types (see below), we also assigned a single land cover category to each report based on the category with the greatest proportional area within a 100-meter radius of the report.

Building density and road distance have previously been associated with human-coyote encounters (Wine et al. 2015, Drake et al. 2021); therefore, we determined building density based on the proportional area of building footprints within each of the five scales around each report (Statistics Canada 2019). We also measured the distance from each report to the nearest road from the City of Edmonton single line street network geospatial database. For road distance, we applied an exponential distance decay function (*e*-*0.002d*, where d = meters to the nearest road) to confine values between zero (far from road) and one (on road; Nielsen et al. 2009). All spatial variables were measured in raster format with a 10 x 10-meter cell size.

We also measured changes in reporting, coyote boldness, and human concern across years, months, and time of day, as well as across the coyote breeding, pup rearing and dispersal seasons. We manually categorized time of day into either day (after sunrise and before sunset) or night (before sunrise or after sunset). Sunrise and sunset times were specific to Edmonton and were adjusted for intra-annual variation. Biologically defined seasons were classified based on the month in which the report was submitted (Morey et al. 2007): breeding (January 1 – April 30), pup rearing (May 1 – August 31), or dispersal (September 1 – December 31).

**Statistical methods**

We first assessed spatial, temporal and contextual patterns in report submissions. For land cover types, we estimated the expected number of reports based on the total proportion of that land cover type within the study area. We then applied Pearson’s chi square test to test whether reports occurred more or less frequently than expected in each land cover type. To assess how reporting varied over time, we summarized the number of reports in each of the biological coyote seasons for each year from 2012 to 2021, the percentage of reports during each month, and the number of reports from day and nighttime. For each contextual variable we determined the number of reports assigned to each variable category.

To identify the best spatial and temporal predictors of coyote boldness and human concern, we used ordered logistic regression with the *clm* function in the R package ordinal (Christensen 2019). Time of day and contextual variables were strongly correlated with each other (Table 1 in Appendix 3), as we might expect (e.g., more dogs are outside during the day), so we excluded these variables from our models and examined them separately (see below). We first used a pseudo-optimized multiple scale approach (Mcgarigal et al. 2016) to select which of the five measurement scales for each land cover variable and building density was the best-fit scale for a multivariate model. In brief, this approach involved conducting univariate models for each variable and then retaining the scale with the lowest Akaike’s information criterion value (AIC; Burnham and Anderson 2004; Table 2 in Appendix 3). The optimal scale for each variable was identified separately for coyote boldness and human concern. If a variable’s best-fit scale did not improve on the AIC of the null model, we excluded that variable from further analyses. We then assessed correlations between the remaining variables using Spearman’s rank correlation coefficient (Table 3 and 4 in Appendix 3), and for any pairs of variables where r > 0.6, we removed the variable that produced a higher AIC value in univariate models. All numerical variables were mean centered and scaled.

For each of coyote boldness and human concern, we constructed global models (Table 5 in Appendix 3) that included each of the non-correlated spatial variables, year, and coyote biological season (using breeding season as the reference) as additive effects. We included interaction terms between year and each of the spatial variables to test if temporal changes in the response variables were associated with specific spatial factors in the urban environment. In models of coyote boldness, we also included interaction terms between biological season and each of natural and modified open area to test for seasonal changes in coyote behaviour that might be associated with denning in these less-developed areas (Dodge and Kashian 2013). We used AIC-based model selection with the *dredge* function from the package MuMIn (Barton 2020) to identify the variables and interactions that were retained in the top models (ΔAIC < 2). Because year was a significant predictor of both boldness and concern (see below, results), we explored this relationship in more detail using linear regressions predicting the percentage of reports within each of the ordinal scores as a function of year.

To determine if boldness and concern scores significantly differed based on time of day or contextual factors, we used Pearson’s chi square tests of independence (Weckel et al. 2010), followed by *post hoc* tests (chisq.posthoc.test.package; Ebbert 2019) to determine which levels of each factor were most strongly associated with boldness or concern. For these analyses, we included reports for which each contextual variable could not be determined because this “unknown” category serves as a reference category and could potentially be informative for some variables (e.g., vulnerable individuals or dog leash status). We also used chi square tests to test whether reports that identified bolder coyote behaviour also expressed more human concern. Alpha values for each residual test were adjusted with Holm’s correction for multiple comparisons (Macdonald and Gardner 2000). We conducted all statistical analyses in R version 4.1.3 (R Core Team 2022) and considered effects to be significant if 95% confidence intervals did not overlap zero or if p values < 0.05.

**RESULTS**

**Reporting patterns**

From September 2, 2010, to December 31, 2021, *N* = 11,239 reports were submitted on the Edmonton Urban Coyote project website. Of these, we removed *N* = 1,722 spam or duplicate reports, *N* = 256 reports that were outside of Edmonton city limits, and *N* = 127 reports from 2010 and 2011 because of limited reporting in these years. The final dataset included *N* = 9,134 unique and spatially explicit coyote reports between January 1, 2012, and December 31, 2021. Of the 100 reports that were re-classified to assess classification repeatability, inter-rater agreement for each variable ranged from 85-96% (Table 1 in Appendix 1).

Reports were widely distributed across the city and unevenly spread across land cover types (χ24 = 1,564, p < 0.001; Figure 1). Based on the proportion of each land cover type within our study area, we received more reports than expected in residential (59.1%, *N =* 5,396), mowed grass (12.2%, *N =* 1,111), and natural land cover (10.9 %, *N =* 997) areas and fewer than expected in commercial (11.1%, *N*=1,016) and modified open areas (6.7%, *N*=614). Reporting increased over time, and was consistently higher in the breeding and dispersal seasons (Figure 2A, 2B). Reports were also more common during the day than at night (Figure 2C). Human activity was discernable in 48.1% (*N* = 4,405) of reports and mostly involved walking (19.1%), being in a home or yard (18.4%) or driving (9.1%; Figure 3). Vulnerable individuals (mostly dogs) were present or mentioned in 30.8% (*N* = 2,816) of reports, and a subset of those reports identified dogs as leashed (11.7%) or off-leash (9.4%). Most reports involved a single coyote (59.4%), and a small subset of reports identified coyote health as healthy (13.9%) or unhealthy (6.0%).

Coyotes were most commonly reported as avoidant or indifferent, followed by bold and aggressive (Table 1), though measures of human concern indicated that negativity towards coyotes was much more common than neutral or positive responses. Reports that mentioned physical contact between people or pets and coyotes consisted mostly of dog attacks (*N* = 85), followed by cat depredations (*N* = 50); only in one report did a coyote contact a human while attempting to take a sled from a child. Among the reports for which both boldness and human concern could be classified, the two variables were significantly related (χ26 = 56.3, p < 0.001), with reports of bold or aggressive behaviour being more likely to express negative perceptions of coyotes (Figure 1 in Appendix 2).

**Spatiotemporal predictors of coyote boldness and human concern**

Ordered logistic regression analysis revealed a suite of spatial and temporal variables that predicted coyote boldness and human concern (Figure 4). Because there was little variation among coefficient and confidence estimates within the full set of top-ranked models for each of boldness and human concern (ΔAICc < 2; Tables 6 and 7 in Appendix 3), we only present results for the single best model for each response variable (Figure 4). The top model predicting coyote boldness indicated that the log odds likelihood of bolder behaviour was higher during the pup rearing season and in areas with higher proportions of mowed land cover (within a 100 m radius), but lower closer to roads and in areas with greater building density (within 200 m). The significant interaction term in this model indicated that boldness was higher during the pup rearing season in areas with more modified open land cover (400 m buffer size, Figure 1 in Appendix 3). The top model for human concern indicated that a higher likelihood of human concern was associated with increases in the proportion of residential area (within 800 m) and modified open land cover (within 1600 m), as well as with the dispersal season (Figure 4)

Both the coyote boldness and human concern models indicated a significant increase in the likelihood of human-coyote conflict over time (Figure 4). None of the interaction terms with year were significant when we only considered the single best model for each response variable (Table 6, Table 7 in Appendix 3); however, for models predicting human concern, we noted that the interaction term between residential area and year was retained in 19 of 20 top models, was significant in 13 of these, and was consistently negative (Table 7 in Appendix 3). This interaction indicated that concern was generally higher in residential areas at the beginning of the reporting period, but increasing levels of concern in non-residential areas reduced the magnitude of this ‘residential area’ effect over time (Figure 2 in Appendix 3). While several other variables and interaction terms appeared in some of the top models (ΔAICc < 2) for boldness and concern, their effects were not significant in any of these (Tables 6 and 7 in Appendix 3).

Given our model’s indication that both boldness and human concern had increased over the reporting period, we examined these temporal changes in greater detail by evaluating the percentage of reports within each of the ordinal scores each year (Figure 5). Specifically, the percentage of reports describing bold behaviour increased significantly (β = 2.19, p < 0.001) while avoidance behaviour decreased (β = -1.82, p < 0.001), though the percentage of reports describing indifferent (β = -0.71, p = 0.21) and aggressive behaviour (β = 0.24, p = 0.16) did not change. Similarly, negative perceptions about coyotes became more common among the reports (β = 1.07, p = 0.072) and positive perceptions became less common (β = -1.07, p = 0.005), with no change in the proportion of neutral perceptions (β = 0.002, p = 0.997).

Analysis of diel patterns in coyote boldness showed that indifferent behaviour was significantly more common during the day and avoidance behaviour was significantly more common at night (χ22 = 30.1, P < 0.001; Figure 2 in Appendix 2). However, human concern did not differ between day and night (χ22 = 1.09, P = 0.58).

**Contextual influences on boldness and concern**

All the contextual variables, which could help identify situations more likely to lead to dangerous interactions, were significantly related to coyote boldness (Figure 6, Table 3 in Appendix 2). Aggressive coyote behaviour was reported more frequently than expected when cats or dogs were mentioned, when dogs were off-leash, and when two or more than three coyotes were observed. Bold behaviour, which is less of a direct threat to human or pet safety but still presents an actual risk, was more frequent when reporters were walking, when dogs were mentioned, and when two or three coyotes were present. The least threatening coyote behaviours, avoidance and indifference, occurred mostly in reports when people were driving, cycling, or in their home or yard, when only one coyote was observed, and when coyotes were perceived as healthy.

Most contextual variables were related to human concern, demonstrating that they are important factors affecting the perceived risk presented by coyotes (Figure 6, Table 3 in Appendix 2). Concern was more frequently reported when dogs, children, or multiple vulnerable individuals were mentioned; conversely, reports that didn’t mention any vulnerable individuals expressed less concern. Perceptions were more likely to be positive when only one coyote was observed and when the coyote(s) were described as healthy

**DISCUSSION**

Human-coyote conflict is increasing in urban areas throughout North America (White and Gehrt 2009, Baker and Timm 2017), creating a need to better understand the spatial, temporal, and contextual factors that predict coyote boldness and human concern as these factors are essential for informing future management strategies. We used our community science data to demonstrate that coyotes are bolder in areas with more mowed grass, but less bold closer to roads and in areas with higher building density. We also found that, during the pup rearing season, reports of boldness were more frequent in areas with higher amounts of modified open land cover. Human concern was greater in areas with more residential land cover and areas with more modified open land cover, as well as during the dispersal season. Most notably, boldness and human concern both increased significantly from 2012 to 2021. Lastly, we identified several contextual variables that were strongly related to human-coyote conflict. Aggressive coyote behaviour was more frequent when reports mentioned free-roaming cats and off-leash dogs, and while the presence of children was not related to coyote boldness, the level of human concern was greatest when reports mentioned children and/or dogs.

**Spatiotemporal patterns in coyote boldness**

We found that coyote boldness was higher in less-developed areas that were not naturally vegetated. Poessel et al. (2013) have similarly reported increased conflict-indicating interactions in open areas relative to natural areas of Denver, Colorado, and Wine et al. (2015) found that coyote encounters were more likely in managed clearings in Mecklenburg County, North Carolina. These results collectively suggest that human-coyote conflict in cities is most prominent in spaces that are at the interface of natural and developed urban areas, and thus more similar to the peri-urban or rural environments where human-wildlife conflicts are generally most common (König et al. 2020). This pattern may arise because coyotes in open areas are visible for longer, and may thus appear to be bolder; alternatively, bolder animals may be more likely to occupy areas with less vegetation cover, as has been reported for brown bears (*Ursus arctos*; Bombieri et al. 2021). We also found that our spatial variables were most explanatory of boldness when measured at smaller spatial scales (≤ 400 m radii from reports; Table 2 in Appendix 3), suggesting that boldness is more strongly driven by site-specific factors like the proximity to vegetation cover, territorial boundaries, or dens during the pup rearing season.

Boldness was also significantly more likely during the summer pup rearing season, which is consistent with other studies (White and Gehrt 2009, Lukasik and Alexander 2011). Of note, fewer reports were submitted during this period, indicating that coyotes likely avoid humans and pets most strongly during this season but behave more aggressively when interactions do occur. Aggression during the pup rearing season presumably reflects coyotes defending their young from perceived threats posed by humans or dogs (Bombieri et al. 2018). There were also more reports of cat depredations during the pup rearing season (29 of 50 total), probably caused by a combination of coyotes seeking food for their pups and generally greater numbers of free-roaming cats in the summer (Nation and St. Clair 2019).

Boldness during the pup rearing season was particularly associated with modified open areas, which we attribute to the denning behaviour of coyotes in these areas. Dens in modified open areas have less vegetative cover than dens in natural areas; less vegetative cover provides less opportunity for avoidant behaviour, so coyotes denning in these areas may become more aggressive. Indeed, reports from natural areas were more likely to describe avoidance (28.9%) than aggression (12.9 %) relative to reports from modified open areas (20.3% avoidance and 20.7% aggression; Table 1 in Appendix 2). An alternative hypothesis is that coyotes denning in more disturbed modified open areas may be more prone to boldness because of repeated exposure to humans and their pets in these areas (Young et al. 2019). In either case, our study shows that coyote behaviour in modified open areas during the pup rearing season may often present a risk to the safety of humans and their pets.

We additionally found that coyote boldness increased over the 10-year reporting period, in agreement with previous observations of increasing human-coyote conflict across North America (White and Gehrt 2009, Baker and Timm 2017). Our findings align with recent animal behaviour studies that have identified higher boldness in urban coyotes, possibly due to a reduction in human persecution, repeated benign interactions with humans, and an increase in access to anthropogenic food (Breck et al. 2019, Young et al. 2019, Brooks et al. 2020). There is also evidence that coyote boldness towards humans is passed from parents to offspring (Schell et al. 2018), which could increase coyote boldness over time and thereby accelerate the increase in boldness-driven conflict. Furthermore, higher coyote population density within cities may lead to intraspecific competition that favours bolder individuals (Bateman and Fleming 2012). Our top ordinal regression models did not include any interactions between spatial variables and year, suggesting that these changes in boldness were relatively consistent across the urban environment. Of note, we found that aggressive behaviour did not increase over time, possibly because aggressive individuals were targeted for removal by city managers. We believe that our study is the first to measure an increase in coyote boldness using indirect methods (i.e., public reports of coyote behaviours) rather than evaluations of coyote attacks (Baker and Timm 2017).

**Spatiotemporal patterns in human concern**

We evaluated perceived risk in addition to coyote boldness and found that reporters expressed more concern about coyotes as the amount of residential area within 800 m of the report increased. This observation is consistent with previous findings that people are less tolerant of coyotes near their homes despite being generally tolerant of coyotes in cities (Bonnell and Breck 2017, Drake et al. 2020). This effect also highlights how human concern may not align with the actual risk of a coyote behaving boldly or aggressively: concern was higher in residential areas, but boldness was negatively associated with building density and road proximity (which, based on our tests for multicollinearity, serve as effective proxies for residential area; see Table 3 in Appendix 3).

Human concern was also higher in areas with more modified open land cover, where bold interactions were more likely during the pup rearing season. Although reports of bolder coyotes were more likely to express greater concern, we also suspect that this could be due to people reporting from areas with more modified open areas having greater awareness of the bold or aggressive coyote interactions that are more common in those areas. This is likely reflected in the higher concern expressed near modified open areas, because awareness of negative human-coyote interactions has previously been shown to increase people’s perceived risk of coyotes (Sponarski et al. 2018, Draheim et al. 2019). We lastly found that concern was significantly higher in the dispersal season than the breeding season; we also received more reports during the dispersal season and increased coyote sightings and interactions may cause reporters to be more concerned. Both residential and modified open land cover were most explanatory at larger scales (≥ 800 m radii; Table 2 in Appendix 3), indicating that broader landscape characteristics were more important for human concern than the site-specific factors, that predicted coyote boldness.

Like boldness, human concern about coyotes increased over the 10-year reporting period (Figure 4, 5). This runs contrary to previous predictions that public acceptance of coyote presence in cities will grow over time even if bold and aggressive encounter continue to occur (Lawrence and Krausman 2011, Jackman and Rutberg 2015). Instead, our findings suggest that increased coyote boldness, alongside public awareness of the rising risk that bold urban coyotes present to people and pets, may prevent public tolerance from growing over time. Indeed, while concern was higher in residential areas during the first few years of report collection, this effect was reduced over time due to growing human concern across all land cover types.

**Contextual factors affect coyote boldness and human concern**

While boldness and concern were predicted by several spatiotemporal variables, we also found that contextual variables had a strong effect on the type of human-coyote interaction that was reported. We found evidence that the presence or mention of vulnerable individuals was strongly correlated with increased coyote boldness and human concern. Dogs and cats were associated with bolder and more aggressive coyote behaviour, supporting the findings of others that human-coyote interactions involving pets are more likely to cause conflict (Poessel et al. 2013, Baker and Timm 2017). Coyotes were described as “aggressive” less often when dogs were leashed (14.6%) compared to off leash (32.5%; Table 1 in Appendix 2), but bold behaviour was more common when dogs were leashed (39.2%) than off leash (22.3%), suggesting that leashed dogs may still engender conflict-indicative coyote behaviour even if they are less likely to be attacked than when off leash. Although coyote attacks on children are well-publicized and can lead to serious injury (Carbyn 1989, White and Gehrt 2009, Alexander and Quinn 2011), we did not find a significant relationship between the presence or mention of children and coyote boldness or aggression. However, human concern was significantly higher when reports mentioned dogs, children, or multiple vulnerable individuals. This demonstrates a higher perceived risk of coyote attacks on pet and children, which likely drives a lower tolerance for coyotes in cities (Draheim et al. 2019).

With respect to other contextual variables, coyotes were bolder when they were observed with other coyotes and when people were walking; human concern was lower when people were driving or when only a single coyote was mentioned. These results provide evidence that people perceive less risk from coyotes in situations where they presumably feel safer. Although coyotes in poor health may be more conflict-prone (Murray et al. 2015b), we found no evidence for this; however, coyotes that were perceived to be healthy were more likely to be avoidant or indifferent. We expect this could be caused by reporting bias, as reporters may be less likely to notice and characterise a coyote’s health in encounters where coyotes are behaving boldly or aggressively.

**Limitations**

Our study had several limitations. First, reports were collected non-randomly and non-independently, which introduces the potential biases inherent to community reporting databases (Poessel et al. 2013, Sullivan et al. 2014): repeat reporting by some residents but not others, uneven advertising of the reporting database across neighborhoods or over years, potentially higher reporting from affluent neighborhoods with higher education levels (Wine et al. 2015, Mowry et al. 2020), and varying visibility of coyotes across seasons, time of day or land cover types due to differences in vegetative cover, human activity and daylight (Quinn 1995, Poessel et al. 2013). While these sources of bias likely affect the spatial and temporal distribution of reports, our analyses mitigated these effects by focusing on measures of coyote boldness and human concern rather than spatiotemporal influences on the number or distribution of reports.

Second, reports were spatially and temporally autocorrelated, but we used large sample sizes and verified modelling results with chi-square tests to minimize Type I error (Table 3 in Appendix 2). Third, our post-hoc method of quantifying coyote boldness and human concern from a community reporting database does not provide data that can be compared to empirical behavioural observations of animals (e.g., Breck et al. 2019) or randomized public surveys (e.g., Drake et al. 2020) because of the biases inherent in community reporting data (see above). Despite their limitations, our findings demonstrate that further resources and research are needed to mitigate the increase in coyote boldness and human concern identified in our study and others (White and Gehrt 2009, Baker and Timm 2017, Poessel et al. 2017), and we join others in suggesting that community science can provide valuable information about human-coyote interactions (Weckel et al. 2010, Drake et al. 2021).

**Management implications**

Our findings can be applied to increase the efficiency of several of the management actions that are already being implemented in our study area and elsewhere. Coyote boldness, and thus the risk to humans and pets, was generally higher in less-developed and open areas (Poessel et al. 2013, Wine et al. 2015); managers might therefore target these areas for public education about keeping dogs on-leash and containing smaller pets with coyote-proof fencing (Draheim et al. 2019). Managers could also increase their monitoring of urban coyote activity in these higher-risk, human use areas, areas and train community members to haze coyotes that behave boldly (Bonnell and Breck 2017). Additionally, community hazing programs that target these areas during the breeding season prior to den site selection may prevent denning in these areas and proactively prevent negative interactions (Bonnell and Breck 2017). Other management actions that could be applied before and during the pup rearing season to limit risks to humans and pets may include seasonal closures of open areas with high numbers of bold or aggressive interactions.

To prevent coyotes from becoming bolder and decrease human concern in residential areas, managers can implement proactive management practices that limit coyote use of these areas. Such approaches can include attractant management to reduce coyote access to anthropogenic food sources (Murray and St. Clair 2017), aversive conditioning programs, and possibly even targeted removal of bold or aggressive individuals (Breck et al. 2017). The different scale at which spatial factors affect actual and perceived risk from coyote interactions also presents an important consideration for managers; actions targeted at addressing bold coyote behaviour might be most effective at specific within localized areas (e.g., areas where people walk dogs off leash or schoolyards), whereas actions to reduce human concern may be more successful if targeted at larger scales (e.g., neighborhoods). If management actions are informed by knowledge of the spatiotemporal and contextual predictors of conflict, they will be more efficient and effective at promoting human-coyote coexistence in cities across North America.

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