**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, and reports of human-coyote conflict are rising. Also increasing is the public demand for proactive management to prevent negative interactions. Effective and proactive management can be informed by the direct observations of community members who can report their interactions with coyotes and the factors surrounding them. 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: coyote boldness and human concern about coyotes. Using ordered logistic regression and chi-square tests we 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 conflict-indicative interactions. 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 increasing 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**

Urban landscapes are inhospitable for many animal species, yet some species can thrive in developed areas (Schell et al. 2020). City-dwelling species are highly adaptable, and many have increased in abundance despite the general diminishment of biodiversity as a result of urbanization across the globe (Foley et al. 2005, McKinney 2006). Among the species displaced by urban expansion are most large carnivores, which are often unable to coexist with high densities of humans (Woodroffe 2000). Coyotes (*Canis latrans*) are an exception to this pattern. Since the 1800s, coyotes have expanded out of the Great Plains across North America, including into densely populated cities and suburbs where they are constantly near humans (Bateman and Fleming 2012, Hody and Kays 2018).

Urban coyotes largely avoid interactions with humans (Mowry et al. 2020, Drake et al. 2021), while benefitting from the refuge that cities provide from larger predators (Prugh et al. 2009), reduced human persecution in urban compared to rural areas (Collins and Kays 2011), and abundant urban food resources available to them from high rodent populations, garbage, compost and fruit trees (Fedriani et al. 2001, Murray et al. 2015a). Many people living in urban areas tolerate, and even appreciate, having coyotes in the city (Soulsbury and White 2015, Sponarski et al. 2018). For example, coyotes can improve human quality of life by regulating rodent and smaller predator populations (Crooks and Soule 1999), and providing a sense of nature connectedness and aesthetic enjoyment that is often inherent in seeing wild animals (Soulsbury and White 2015, Cox and Gaston 2018). However, the past two decades have also been marked by an apparent increase in human-coyote conflict as indicated by rising bold and aggressive interactions between people and urban coyotes (Baker and Timm 2017, Poessel et al. 2017), which may challenge continued coexistence.

Understanding the consequences of more frequent 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 towards people 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). Often preceding attacks are shifts in coyote behaviour towards boldness and aggression, which are frequently caused by increasing coyote habituation to people (Baker and Timm 2017). Assessing coyote boldness, which refers to their tendency to approach or interact with people or pets, can 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), after attacks or instances of extremely high degrees of human concern about coyotes (Baker and Timm 2017, Draheim et al. 2019). However, increased understanding of more subtle changes in coyote boldness and human concern, and the factors associated with these, can better enable proactive management efforts to minimize human-coyote conflict like aversive conditioning programs, reduction of food attractants, and public education campaigns (Breck et al. 2017).

Any effective proactive urban coyote management strategy must be informed by knowledge of the spatiotemporal and contextual factors associated with coyote boldness and human concern. Identifying high-conflict areas for management action requires insight to 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 efficacy can be further improved by understanding when perceived or real negative encounters are most likely to occur at diel, monthly, and inter-annual scales (Morehouse and Boyce 2017, Soulsbury 2020). 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). In order to assess the importance of these variables for coexistence, large datasets of human-coyote interactions are imperative.

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 focused largely 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, is often highest during the coyote dispersal and breeding seasons, and is associated with areas of higher household income and education levels. Lukasik and Alexander (2011) and Drake, Dubay and Allen (2021) have quantified the variables associated with different coyote behaviours towards people, demonstrating a strong seasonal trend with bold coyote behaviour most prominent in the coyote pup rearing season. These studies have also found more negative interactions in areas where coyotes consume more anthropogenic food (Lukasik and Alexander 2011), and that humans and coyotes are generally closer to each other when interactions occur farther from roads (Drake et al. 2021). To our knowledge, no study has yet comparatively assessed the factors that drive changes in both coyote boldness and human concern, or investigated changes in the nature of human-coyote interactions over time.

In this study, we used 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 spatiotemporal predictors of higher actual risk of conflict-indicative human-coyote interactions based on coyote boldness. Second, we aimed to identify the spatiotemporal predictors of increased perceived risk of human-coyote interactions that indicate conflict based on people’s concern about coyotes. Lastly, we assessed the effect of various contextual variables on coyote boldness and human concern. In addressing these three objectives, we aim to provide insight on the factors associated with real or perceived negative human-interactions in order to improve proactive urban coyote management and facilitate 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>). Because of minimal reporting in 2010 and 2011 (*N* = 127 reports), we excluded reports from these years from all analyses. We promoted the website opportunistically during media interviews, public lectures, and social media posts, 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. Reporters were asked to optionally 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 hourly times between 5 AM and midnight, or one of the following categories: 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, and 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 using a Google Form and following a standardized protocol (Figure 1, Text 1 in Appendix 1). For reports with comments that provided insight on coyote behaviour, volunteers assigned one of nine coyote response categories that we simplified into a four-point ordinal scale of coyote boldness ranging from avoidance (e.g., ran away) to aggressive behaviour (e.g., made physical contact, Table 1). Human concern was classified into a three-point ordinal scale from positive (e.g., beautiful), to neutral (e.g., curious or not scared), to negative (e.g., scared) emotional responses or perceptions based on the explicit presence of words that directly relate to human concern about coyotes (Table 2). The five contextual variables that we also determined from report comments were the human activity occurring at the time of the report (e.g., walking, cycling, driving), the presence or mention of vulnerable individuals (children, dogs or cats), if dogs present were leashed or off leash, the number of coyotes observed, and the reporter’s interpretation of coyote health. To assess the repeatability between report classifiers, J. Farr randomly selected and re-classified 100 reports. We then calculated the percentage of reports where boldness and concern were classified the same between reporters, as well as the percentage of reports classified the same for each of the contextual variables.

**Spatial and temporal variable collection**

To measure the spatial variables associated with reports, we imported report locations into ArcGIS Pro v2.7 (Figure 1). We excluded reports that were located outside of Edmonton city limits or located in recently annexed but undeveloped rural land outside of the city, 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 that were comparable to those previously used in similar studies (Table 1 in Appendix 2; Weckel et al. 2010, Poessel et al. 2013, Mowry et al. 2020).

We then calculated the proportional area of each land cover type within 100, 200, 400, 800 and 1600 m radii of each report. We measured land cover at these five different scales because coyote boldness and human concern may be more strongly affected by site-specific conditions (100, 200, 400 and 800m radii; van Bommel et al. 2020) or broader landscape conditions at the approximate scale of urban coyote territories or urban neighborhoods (1600m radius; Murray et al. 2015b, Wine et al. 2015). Proportional land cover measurements were 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 been previously 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), and 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). Multiplying distances by 0.002 minimizes the effect of roads outside of the home range of coyotes (>1600 m; Nielsen et al. 2009, Wine et al. 2015). 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 biological coyote seasons. We manually categorized time of day into either day (morning, afternoon or any hourly times after sunrise and before sunset) or night (dawn, night, or any times before sunrise or after sunset). Sunrise and sunset times were specific to Edmonton and were adjusted for intra-annual variation. Biological 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 coyote reporting. 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. We also assessed trends in coyote boldness and human concern over space, time and context. For this analysis, we used chi square tests to test for differences in the distribution of boldness and concern scores within each of the land cover classes, across coyote seasons, and diurnal temporal scales, and for the categories within each of the contextual variables (Tables 1, 2, 3 in Appendix 3).

To identify the best spatiotemporal predictors of increased coyote boldness and human concern, we used ordered logistic regression with the *clm* function in the R package ordinal (Christensen 2019). Because time of day and contextual variables were strongly and expectedly correlated with each other (Table 1 in Appendix 4), we excluded them from these models and examined them separately (see below). We then 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 (i.e., 100, 200, 400, 800 or 1600 m radii) was the best-fit scale for a multivariate model. In brief, this approach involved conducting univariate models for each variable, with one model per scale, and then retaining the scale with the lowest Akaike’s information criterion value (AIC; Burnham and Anderson 2004; Table 2 in Appendix 4). The optimal scale for each variable was identified separately for coyote boldness and human concern. If a variable’s best-fit scale had a higher AIC than 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 4), and for any pairs of variables where r > 0.6, we removed the variable that produced a higher AIC value in univariate models. All spatial variables and year were mean centered and scaled.

For each of coyote boldness and human concern, we constructed global models (Table 5 in Appendix 4) that included each of the non-correlated spatial variables, coyote biological season (categorical variable, breeding season as reference), and year as additive effects. We also included interaction terms between year and each of the spatial variables to test if temporal changes in coyote boldness or human concern were associated with specific spatial factors in the urban environment. In models of coyote boldness, we further added interaction terms between biological season and both natural and modified open land cover types to test for seasonal changes in coyote behaviour that could be associated with denning in these less-developed areas (Dodge and Kashian 2013). We used AIC model selection with the *dredge* function from the package MuMIn (Barton 2022) to identify the variables and interactions that were retained in the top models (ΔAIC < 2). We used the *Effect* function from the package effects (Fox and Hong 2009) to visualize interaction plots for significant interaction terms in the top models. To evaluate the effect of spatiotemporal predictors on boldness and concern, we plotted the coefficients and 95% confidence intervals from the top model for each response variable. We further tested whether coyote boldness and human concern had changed over time using a linear regression model with the percentage of annual 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). If the chi square test results were significant, we used the *chisq.posthoc.test* function from the chisq.posthoc.test package (Ebbert 2019) to determine which levels of each factor were most strongly associated with boldness or concern based on Pearson’s residuals. The “unknown” category of contextual variables provided a reference category of when the contextual variable was not mentioned in these reports, and because this is potentially informative for some of the contextual variables (e.g., vulnerable individuals or dog leash status) it was retained in all chi square tests and residual visualizations. We also used chi square tests to test whether reports that identified bolder coyote behaviour also expressed more human concern, and to determine if contextual variables were correlated with the spatiotemporal variables that predict changes in coyote boldness and human perceptions (Figures 1-3 in Appendix 4). 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**

**Data collection**

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, boldness was the same in 85%, concern in 96%, human activity in 87%, the presence or mention of vulnerable individuals in 97%, dog leash status in 85%, number of observed coyotes in 92%, and perceived coyote health in 89%.

**Reporting patterns**

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 were present or mentioned in 30.8% (*N* = 2,816) of reports, were mostly dogs, and in a few of these dogs could be identified as leashed (11.7%) or off-leash (9.4%). The majority of all reports involved a single coyote (59.4%), and a small subset of reports identified coyote health as healthy (13.9%) or unhealthy (6.0%).

While coyote behaviour was not bold or aggressive in the vast majority of reports (Table 1), the human concern about coyotes indicated that negativity towards coyotes was much more common than neutral or positive responses (Table 2). Coyotes were most commonly reported as avoidant or indifferent, followed by bold and aggressive. Reports that mentioned physical contact between people or pets and coyotes consisted mostly of dog attacks (*N* = 85), followed by cat depredations (*N* = 50), and only in one report did a coyote contact a human while attempting to take a sled from a child. Among the reports of 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 3).

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

Ordered logistic regression analysis revealed a suite of spatial and temporal variables that strongly predicted coyote boldness and human concern (Figure 4). Model selection revealed 12 top models for boldness and 20 for human concern (ΔAICc < 2). We present and discuss the effect of spatiotemporal predictors based on their values in the top models of concern and boldness (Figure 4), because within the full set of top models there was little variation between coefficient and confidence estimates (Tables 6 and 7 in Appendix 4). The top model of coyote boldness indicated a significantly higher log odds likelihood of bolder behaviour during the pup rearing season, in areas with higher proportions of mowed land cover (within a 100 m radius), and, during the pup rearing season, in areas with more modified open land cover within 400 m (Figure 4 in Appendix 4). Boldness scores were generally lower closer to roads and in areas with greater building density within a 200 m radius (both of which were correlated with the proportion of residential area within 100 m, which was excluded from the global boldness model). 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 coyote boldness and human concern models indicated a significant increase in the likelihood of human-coyote conflict over time (Figure 4). Changes in boldness over time were not linked to any specific spatial variables, as none of the interaction terms with year were significant in the top models (Table 6 in Appendix 4). However, the interaction term between residential area and year was negative in models predicting human concern. Although this effect was marginally non-significant in the top model (Figure 4), it was retained in 19 of 20 top models, was significant in 13 of these, and was consistently negative (Table 7 in Appendix 4). This was due to human concern being more likely in areas with more residential area in early years, but as concern became stronger overall in later years the effect of residential area as a predictor was reduced (Figure 5 in Appendix 4). While several other variables and interaction terms appeared in some of the top models (ΔAICc < 2) for boldness and concern, their effects were marginal (Tables 6 and 7 in Appendix 4).

The percentage of annual reports within each of the ordinal scores further indicated that coyote boldness and human concern had increased over the reporting period (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 3). However, human concern did not differ between day and night (χ22 = 1.09, P = 0.58).

**Contextual Variables**

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 3). 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 presents 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 3). A greater sense of human concern was much more frequently reported when dogs, children, or multiple vulnerable individuals were mentioned, and reports that didn’t mention any vulnerable individuals were less concerned. Low human concern based on more frequent positive perceptions of coyotes occurred 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 about coyotes in order to inform future mitigation strategies. Using ordered logistic regression, we demonstrated that coyote boldness was more likely with increases in the amount of nearby mowed areas, but declined closer to roads and in areas with higher building density. We also found that during the pup rearing season reports from areas with higher amounts of modified open land cover were much more likely to report higher boldness. 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. From 2012 to 2021, both coyote boldness and human concern indicated rising human-coyote conflict in Edmonton. Lastly, we found that contextual variables 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, dogs, or both children and pets.

**Spatiotemporal patterns in coyote boldness**

We found that coyote boldness was higher in less-developed areas that were not naturally vegetated, but rather mowed areas and, during the pup rearing season, modified open areas. Similarly, Poessel et al. (2013) reported increased conflict-indicating interactions in open areas but not in 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. Together with our results, these studies 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 occur 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 in brown bears (Ursus arctos; Bombieri et al. 2021). We also found that variables were most explanatory of boldness when measured within smaller spatial scales (≤ 400 m distance from reports; Table 2 in Appendix 4), suggesting that boldness is most strongly driven by site-specific factors like the proximity to vegetation cover, territorial boundaries, or dens during the pup rearing season.

Boldness was 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, presumably to defend 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 coyotes seeking food for their pups, as well as greater numbers of free-roaming cats in this season (Nation and St. Clair 2019). Boldness during the pup rearing season was particularly associated with modified open areas, suggesting that the denning behaviour of coyotes in these areas is especially challenging for human-coyote coexistence. We attribute this to lower levels of vegetative cover for dens in modified open areas compared to natural areas; less vegetative cover provides less opportunity for avoidant behaviour so coyotes may therefore become more aggressive instead. 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). Alternatively, coyotes denning in more disturbed modified open areas like agricultural fields and school grounds rather than natural areas may be more prone to boldness because of repeated exposure to humans and their pets in these areas (Young et al. 2019).

Coyote boldness increased over the 10 years in which we collected reports, in agreement with previous observations of increasing human-coyote conflict across North America (White and Gehrt 2009, Baker and Timm 2017). Our top ordinal regression models did not include any interactions between spatial variables and years, suggesting that changes in boldness were relatively consistent across the urban environment. 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). 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 without focusing explicitly on attacks (Baker and Timm 2017), but rather indirectly through public reports of coyote behaviours.

**Spatiotemporal patterns in human concern**

We found that reporters expressed more concern about coyotes as the amount of residential area within 800 m of the report increased, which 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, which was negatively associated with building density and road proximity (which are correlated with residential area). However, human concern was also higher in areas with more modified open land cover, which is 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 people reporting from the vicinity of modified open areas may be more aware of bold or aggressive encounters occurring nearby, thus increasing their perceived risk of coyotes (Sponarski et al. 2018, Draheim et al. 2019). We also found that concern was significantly higher in the dispersal season than the breeding season, and this may be linked to the abrupt increase in coyote reports during this season compared to the preceding pup rearing 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; Table 2 in Appendix 4), indicating that broader landscape characteristics were more important for human concern than site specific factors, which were more important for coyote boldness.

Human concern also indicated growing human-coyote conflict in Edmonton, possibly because of its association with coyote boldness. This was contrary to the predictions of others 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 may demonstrate that increased coyote boldness and public awareness of the rising risk that bold urban coyotes present to people and pets may prevent public tolerance from growing over time. The interaction between residential area and year indicated that concern was higher in areas with more residential land cover during the first few years of report collection, but over time this effect was reduced by growing human concern across all areas.

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

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%; Appendix 3, Table 1), but bold behaviour was more common when dogs were leashed (39.2%) than off leash (22.3%), suggesting that leashed dogs may still be subject to high amounts of 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 and this demonstrates a higher perceived risk of coyote attacks on pet and children, which likely leads to lower tolerance of coyote presence in cities (Draheim et al. 2019).

With respect to other contextual variables, coyotes were bolder when people were walking and when more coyotes were observed, and human concern was lower when people were driving or when only a single coyote was mentioned. These results provide further 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 potential biases commonly associated with 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 coyote boldness and human concern. 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 3). Third, our post-hoc method of quantifying of 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 reporting databases provide valuable information about human-coyote interactions.

**Management implications**

Our findings provide information on the spatial, temporal and contextual factors associated with human-coyote conflict that 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, is generally higher in less-developed and open areas (Poessel et al. 2013, Wine et al. 2015), and management might target these areas for public education about keeping dogs on-leash to avoid aggressive encounters and containing smaller pets with coyote-proof fencing (Draheim et al. 2019). Managers could also increase monitoring of urban coyote activity in these areas and train community members to haze coyotes that behave boldly in these higher-risk, human use areas (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 human and pet safety may include seasonal closures of modified open areas with high numbers of bold or aggressive interactions. To prevent coyotes from becoming bolder and decrease human concern of their presence in neighborhoods, managers can implement proactive management practices that limit coyote use of residential areas, including 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 scales at which spatial factors affect actual and perceived risk from coyote interactions also present an important consideration for managers; actions targeted at addressing bold coyote behaviour may be most effective within localized areas (e.g., near dens or where people walk dogs off leash), whereas actions to reduce concern of coyotes may be more successful if targeted at larger scales (e.g., neighborhoods). If these actions are informed by knowledge of the spatiotemporal and contextual predictors of conflict, they will be more efficiently and effectively applied to promote human-coyote coexistence in cities across North America.

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