**Rising coyote boldness and human concern of coyotes over 10-years from a community reporting database 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, which can be informed by the direct observations of citizens who may report both coyote behaviour and their perceptions of their interactions with coyotes. We used a web-based reporting system to collect *N* = 9,134 reports of coyotes that were voluntarily submitted in the city of Edmonton, Canada, between January 2012 and December 2021 to assess the spatial, temporal and contextual correlates of conflict, whether it had changed over time, and whether any temporal changes were related to other variables. We developed a standardized classification method to categorize two indicators of human-coyote conflict: coyote boldness and human concern. We used ordered logistic regression analysis and χ2 tests to identify the covariates associated with conflict and to assess changes over time. We found that while coyote boldness was more likely in less-developed open areas and during the pup rearing season, human concern was highest in residential areas and during the dispersal season. Reports that mentioned pets or children were more likely to describe negative interactions. Over the 10 years of reporting boldness and concern both increased, but there was some evidence of rising human tolerance of coyotes in residential neighborhoods. Our results inform proactive management actions that seek to prevent conflict, including public education about protecting pets, preventing the anthropogenic food-conditioning of urban coyotes, and using aversive conditioning to increase wariness of coyotes in residential areas.

**INTRODUCTION**

Urban landscapes are inhospitable for many animal species, yet some can thrive even in the midst of human society (Schell et al., 2020). These synanthropes are highly adaptable and many have undergone population expansions despite the displacement and diminishment of biodiversity as a result of urbanization across the globe (McKinney, 2006, Foley et al., 2005). Among the displaced species 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 (Drake et al., 2021, Mowry et al., 2020), while benefitting from the predator refuge (Prugh et al., 2009), reduced human persecution (Collins and Kays, 2011), and abundant natural and anthropogenic food resources provided by cities (Fedriani et al., 2001, Murray et al., 2015a). Coyote presence with minimal interactions is often tolerated and even appreciated by the majority of city-dwellers (Sponarski et al., 2018, Soulsbury and White, 2015), many of whom appreciate the benefits that coyotes provide to society by controlling rodent populations (Crooks and Soule, 1999), scavenging (Fox, 2006), and providing aesthetic enjoyment (Soulsbury and White, 2015). However, over the past two decades there has been an apparent increase in negative interactions between people and urban coyotes (Baker and Timm, 2017, Poessel et al., 2017), which may challenge their continued coexistence.

Understanding interactions between humans and coyotes requires consideration of both the actual risk posed by coyote behaviour towards people and the perceived risk indicated by the level of human concern towards coyotes. The actual risk that coyote behaviour presents to people or pets is often studied retroactively by examining pet or human attacks (White and Gehrt, 2009, Baker and Timm, 2017). Coyote attacks on pets most are mostly attributed to predatory attacks or attacks in defense of territories or dens (Nation and St. Clair, 2019, Gehrt et al., 2013, Poessel et al., 2017), and despite the rarity of direct coyote attacks on humans they generate substantial media attention and degrade public tolerance (Alexander and Quinn 2011, Draheim et al., 2019). Equally important to actual boldness or aggression of coyotes is the risk people perceive of injury to themselves, children, or pets when they see or interact with a coyote. Although human concern of coyotes may not align with the actual risk of an attack based on coyote behaviour, it describes public tolerance towards coyotes, and, subsequently, acceptance of various forms of wildlife management and policy (Sponarski et al. 2018; Draheim et al. 2019). While managers are often limited to reactive action after attacks or instances of extremely high human concern of coyotes (Baker and Timm, 2017, Draheim et al., 2019), understanding more subtle changes in coyote boldness and human concern, as well as the factors associated with these, can enable proactive management.

To facilitate human-coyote coexistence, knowledge of the spatial, temporal and contextual variables that are associated with real or perceived negative interactions is essential. Identifying spatial variables that predict negative interactions between humans and wildlife can help identify high-risk areas for managers (van Bommel et al., 2020, Delsink et al., 2013). For example, understanding which areas have low, moderate or high probabilities of interactions between humans and black bears (*Ursus americanus*) enables the effective allocation of resources to improve coexistence (Merkle et al., 2011). Likewise, understanding when perceived or real negative encounters are most likely to occur at diel, monthly, and inter-annual scales, is imperative for further increasing the efficacy of wildlife and people management (Soulsbury, 2020, Morehouse and Boyce, 2017). Contextual variables that can influence the occurrence and severity conflict include the presence of pets or children, the number of coyotes, and the health status of individual animals (Olson et al., 2015, Poessel et al., 2013). Large datasets of human-coyote interactions are needed to assess the importance of these variables for coexistence, and over the past decade, public reports of coyote sightings and encounters have emerged as an invaluable source of information.

Community reporting databases allows 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). Voluntary reports of coyote activity have been collected through websites (Mowry et al., 2020, Wine et al., 2015), 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). Studies resulting from analyses of these datasets have focused largely on the broad patterns in reports and have identified temporal trends in reporting as well as socioeconomic and landscape factors associated with coyote reports (Wine et al., 2015, Mowry et al., 2020, Weckel et al., 2010). To date, no study to our knowledge has examined the factors associated with changes in both boldness of coyote behaviour and human concern of coyotes or investigated changes in human-coyote interactions over time.

In this study, we used reports collected over 10 years from an online website in Edmonton, Canada to investigate two indicators of human-coyote conflict: the boldness of coyote behaviour towards people and the human concern of coyotes. First, we aimed to determine which spatial, temporal and contextual factors were associated with more bold coyote behaviour and stronger human concern of coyotes. We predicted that coyote boldness would increase in less-developed areas (Poessel et al., 2013, Wine et al., 2015), during the pup rearing season (White and Gehrt, 2009, Lukasik and Alexander, 2011), and when pets are present (Baker and Timm, 2017), while human concern would be highest in residential neighborhoods and when children were mentioned because of elevated perceived risk (Draheim et al., 2019, Sponarski et al., 2018). Second, we assessed whether coyote boldness or human perceptions had changed over the duration of report collection and if any specific variables were associated with these changes. We expected for coyote boldness to increase because of coyote urban adaptation towards bolder behaviour (Schell et al., 2018, Breck et al., 2019), but for human concern to decrease because of shifting public perceptions towards tolerance of coyotes (Jackman and Rutberg, 2015, George et al., 2016).

**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). Edmonton is located within the central parkland natural subregion, which is an area composed of productive agricultural lands interspersed with wetlands and mixed forests of aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), and spruce trees (Picea spp; Natural Regions Committee, 2006). The city is bisected by the North Saskatchewan River valley and several large ravines, which form a network of minimally developed natural areas (Figure 1).

**Report collection and classification**

We used a web-based platform launched in September 2010 to collect voluntarily submitted reports of coyotes from members of the general public 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, through word of mouth, on labels attached to wildlife cameras in the city, and via a link to the website on the City of Edmonton website (<https://www.edmonton.ca/residential_neighbourhoods/pets_wildlife/Coyotes.aspx>) that was added in 2019. Fields that the reporter filled out included the date, time of day, type of report, nearest intersection to the report location, additional comments, and the reporter’s name and contact information. We also included a map interface with a prompt for the reporter to precisely locate the report by placing a pin on the map, and if coordinates were missing, we assigned them post-hoc based on the reported nearest street intersection and information in the comments (i.e., if a specific park or building was named). To encourage participation, no registration or login was required.

When submitting a report, users were asked to indicate whether the type of report was a sighting defined as an observation at a distance with no interaction, or encounter, defined as an interaction at close range. Most reports (96.8 %, *N* = 8,859) included optional comments with further details about the human-coyote interaction, so we developed a classification form to categorize coyote boldness towards people and human concern of coyotes (Appendix 1). We classified coyote boldness into nine coyote response categories that we binned into a four-point ordinal scale ranging from avoidance (e.g., ran away) to aggressive behaviour (e.g., made physical contact, Table 1). For human concern, we classified reports on 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 (Table 2). With the classification form we also identified five contextual variables: the human activity occurring at the time of the report (e.g., walking, cycling, driving), the presence of vulnerable individuals (children, dogs or cats), if dogs present were leashed or off leash, the number of coyotes, and coyote health. We assessed the repeatability of report classification between classifiers by randomly selecting and re-classifying five subsets of twenty reports and calculating the percentage of reports that differed between observers.

**Spatial and temporal variables**

To measure spatial variables associated with reports, we first mapped report locations using ArcGIS Pro v2.7 (Figure 1). We excluded reports that were located outside of Edmonton city limits or located in recently annexed but undeveloped land outside of the city, and identified our study area by generating a minimum convex polygon around remaining report locations. We categorized land cover types 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). We categorized six land cover types representing various degrees of human development and coyote habitat quality (Table A1, A2 in Appendix 1). These land cover types were measured at five scales as the proportional area within a 100, 200, 400, 800 and 1600 m radius circular neighborhood of reports. We measured multiple 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 (1600m radius; Murray et al., 2015b, Wine et al., 2015). We applied a centered log-ratio transformation to the compositional land cover variables (Quinn et al., 2019). We also assigned a discrete land cover category to each report based on the category with the greatest proportional area within a 100-meter radius of the report. We determined the distance of reports to roads using the City of Edmonton single line street network geospatial database and applied an exponential distance decay function (*e*-*ad*, d = distance to roads, a = 0.002) to transform values exceeding a few hundred meters to zero and confine all values to be between zero (far from road) and one (on road; Nielsen et al., 2009). Lastly, we determined building density based on the proportional area of building footprints within each of the five scales (Statistics Canada, 2019). All spatial variables were measured in raster format with a 10 x 10-meter cell size.

We measured temporal variables at the scale of years, months and within a day. Annual trends were assessed based on the year in which the report occurred excluding 2010 and 2011 which had minimal reporting. Within years, we used the report date to identify the month and the biological season of coyotes (Morey et al. 2007): breeding (January 1 – April 30), pup rearing (May 1 – August 31), or dispersal (September 1 – December 31). 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. 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).

**Statistical methods**

We first assessed spatial, temporal and contextual patterns in coyote reporting based on the distribution of reports across land cover types (as categories), years, months, night or day, and contextual variables. For land cover types, we estimated the expected number of reports based on the area of that land cover type within the study area. We then applied Pearson’s chi square test to assess differences between the observed and expected number of reports.

We visualized trends in coyote boldness and human concern over time using only the reports where comments provided sufficient information to classify either variable. Within these subsets, we calculated the percentage of reports pertaining to each ordinal category for each year. For additional information to support our statistical inferences we calculated these percentages, and also used chi square tests to examine the distribution of boldness and concern within each of the land cover classes, across coyote seasons, months, and diurnal temporal scales, and for each of the contextual independent variables (Tables A1, A2, A3 in Appendix 3).

To model the variables that were associated with 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 exhibited numerous correlations with other categorical variables (Table 1 in Appendix 4), we excluded them from these models and examined them separately (see below). We used a pseudo-optimized multiple scale approach (Mcgarigal et al., 2016) to select the best-fit scale for land cover variables and building density by conducting univariate models and choosing the scale for each variable with the lowest Akaike’s information criterion value (AIC; Burnham and Anderson, 2004; Table 2 in Appendix 4). If a variable’s best-fit scale had a higher AIC value than the null model, we excluded that variable from further analyses. We assessed correlations between retained scale-optimized variables with Spearman’s rank correlation coefficient (R > 0.6; Table 3 and 4 in Appendix 4), and removed the less explanatory of the correlated variables (higher AIC value). All spatial variables and year were then mean centered and scaled. We created base models that included each of the spatial variables and coyote biological season (categorical variable, breeding season as reference) as additive effects, as well as interaction terms between season and each of the land cover types (Table 5 in Appendix 4). We used AIC model selection with the *dredge* function from the package MuMIn (Barton, 2020) to identify the variables and interactions that were retained in the top base models (ΔAIC < 2). We then constructed a global model with the variables from the top models and year as an additive variable. We also included interactions between year and each term with a significant effect in the top base models to determine if specific landscape variables were associated with changes over time (Table 5 in Appendix 4). Again, we applied the *dredge* function to the global model to identify our final set of models (ΔAIC < 2) and the spatial and temporal variables associated with coyote boldness and human concern.

To determine if the distribution of boldness and concern ordinal scale values were significantly different across time of day and contextual variable categories, we used Pearson’s chi square tests of independence (Weckel et al., 2010). If chi square test results were significant, we used the *chisq.posthoc.test* function from the chisq.posthoc.test package (Ebbert, 2019) to determine the most strongly related categories from Pearson’s residuals (rij = (Oij-Eij) / where ij = ith column and jth row in chi-square matrix, E = expected count, O = observed count), and we adjusted alpha values with Holm’s correction for multiple comparisons (Macdonald and Gardner, 2000). We also used this method to assess the relationship between coyote boldness and human concern, and between contextual variables and year, season and land cover types to assess if contextual variables may relate to the spatial and temporal variables affecting coyote boldness and human perceptions (Figures 1-3 in Appendix 4). 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 2021, 2021, *N* = 11,239 reports were made to 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. Coordinates were assigned to *N* = 3,366 reports (36.7%). The final dataset of classified reports included *N* = 9,134 unique and spatially explicit coyote reports between January 1, 2012, and December 31, 2021. The mean total repeatability of report classification was 92%, and for coyote boldness and human concern categories repeatability was 84% and 96%, respectively.

**Reporting patterns**

Reports were widely distributed across the city but were unevenly spread across land cover types (χ24 = 1,564, P < 0.001, Figure 1). The abundance of reports in land cover types was greater than expected in residential (59.1%, *N =* 5,396), mowed grass (12.2%, *N =* 1,111), and natural land cover (10.9 %, *N =* 997) but not commercial (11.1%, *N*=1,016) or modified open areas (6.7%, *N*=614) based on their availability in the study area. Reporting increased over time, and was consistently higher in the breeding and dispersal seasons (Figure 2A). October to March had high numbers of reports (69.9% of reports over 6 months) while reporting was lower from April to September (30.1% of reports, Figure 2B). Reports were more common during the day than at night (Figure 2C). Of the contextual variables (Figure 3), we were able to determine human activity in 48.1% (*N* = 4,405) of reports, vulnerable individuals were present or mentioned in 30.8% (*N* = 2,816), dog leash status in 21.1% (*N* = 415) of reports that mentioned dogs, the number of coyotes in 83.9% (*N* = 7,668), and coyote health in 19.9% of reports (*N* = 1,819). Reporters were primarily walking (19.1%), in home/yard (18.4%), or driving (8.1%) but also mentioned various outdoor activities (1.7%) and cycling (0.8%). Dogs were the most common vulnerable individual mentioned (20.9%) but reports also mentioned cats (1.9%), children (4.8%), and multiple vulnerable individuals (3.2%). When dogs were present, they were mostly leashed (11.7%) but were often off-leash (9.4%). The majority of reports involved a single coyote (59.4%), but some mentioned pairs (15.5%), groups of three (5.0%) or more (4.0%). A small number of reports identified coyote health as healthy (13.9%) or unhealthy (6.0%).

**Coyote boldness and human concern**

Coyote boldness could not be determined in the majority of reports (52.2%, *N* = 4,770) because these reports were sightings where no human-coyote interaction took place (Table 1). The most common coyote boldness categories were avoidance and indifference followed by bold and aggressive behaviour. Reports where physical contact was reported between people 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. When human concern could be determined, reports expressed predominantly negative responses, although some reports did express neutral or positive perceptions indicating low concern of coyotes (Table 2). Among the reports that permitted classification of both boldness and human concern, the two were significantly related (χ26 = 56.3, P < 0.001) with reports expressing negative perceptions of coyotes more likely to identify bold or aggressive behavior (Figure 1 in Appendix 3).

Examining the distribution of coyote boldness and human concern categories over time revealed apparent increases in human-coyote conflict from 2012 to 2021 (Figure 4). The percentage of reports indicating bold behaviour increased significantly while avoidance behaviour decreased, but indifferent and aggressive behaviour did not significantly change. Similarly, within the reports where human concern was determined there was an increase in negative perceptions and a decrease in positive perceptions, but no change in neutral perceptions.

Ordered logistic regression analysis of coyote boldness and human concern revealed 20 top models (ΔAICc < 2) for each response variable (Tables 6 and 7 in Appendix 4). The top model for 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 100m, and in areas with more modified open land cover within 400m during the pup rearing season (Figure 5). Lower coyote boldness was predicted by closer proximity to roads and greater building density within 200m (both of which were correlated with proportion of residential area, which was excluded from these models). The top model for human concern indicated that a higher likelihood of more human concern of coyotes was associated with increases in the proportion of residential area within 800m and modified open land cover (within 1600m), and the dispersal season (Figure 5). The top models for both coyote boldness and human concern of coyotes indicated a significant increase in the likelihood of human-coyote conflict over time (Figure 5). 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), but in models of human concern the interaction term between residential area and year was negative, indicating decreased human concern of coyotes in residential areas over time (Table 7 in Appendix 4). Although this effect was marginally insignificant in the top model (Figure 5), it was retained in 19 of 20 top models, was significant in 13 of these, and was consistently negative. While several other variables and interaction terms did appeared intermittently in the top models of boldness and concern, their effects were not strongly directional or consistently significant (Tables 6 and 7 in Appendix 4).

Analysis of diel patterns showed that time of day was significantly related to coyote boldness (χ22 = 30.1, P < 0.001) with indifferent behaviour more common during the day and avoidance behaviour more common at night (Figure 2 in Appendix 3). However, human concern did not differ between day and night (χ22 = 1.09, P = 0.58).

All contextual variables were significantly related to coyote boldness (Figure 6, Table 3 in Appendix 3). Bold coyote behaviour was significantly more frequent when reporters were walking and significantly less so when cycling, driving, or in a home/yard. When reports mentioned cats there was a strong positive correlation with aggressive behaviour, and dogs were significantly related to both bold and aggressive behaviour in coyotes. Coyote boldness was not significantly related to the presence or mention of children or multiple vulnerable individuals. Off-leash dogs were more frequently associated with aggressive coyote behaviour. Reports with only one coyote were negatively related with bold and aggressive behaviour, and more frequently involved avoidance, and bold coyote behaviour was significantly more prevalent in reports with two or three coyotes. When reporters mentioned more than three coyotes, aggressive behaviour was more frequently mentioned. Healthy coyotes were less frequently bold or aggressive, and positively related to avoidance and indifference.

Human concern was significantly related to all contextual variables except dog leash status (Figure 6, Table 3 in Appendix 3). When reporters were walking, they more frequently had greater concern of coyotes and they had fewer negative perceptions when driving. The presence or mention of dogs, children, or multiple vulnerable individuals were all strongly positively correlated to higher human concern as indicated by more frequent negative responses. Lower human concern as indicated by positive perceptions was more common in reports where no vulnerable individuals were mentioned. Human concern was lower when only one coyote was reported. Additionally, reports of healthy coyotes were significantly positively correlated with lower human concern.

**DISCUSSION**

Human-coyote conflict is increasing in urban areas throughout North America (Poessel et al., 2017, Baker and Timm, 2017), creating a need to better understand the correlates of conflict that may result from spatial, temporal, and contextual variables that can inform future mitigation strategies. We approached this goal using over 9,000 reports collected over 10 years on a website-based community reporting database in Edmonton, Canada. By classifying report comments to describe coyote boldness and human concern (Table 1, 2), we identified an increase in reports with bold coyote behaviour and negative perceptions of coyotes from 2012 to 2021 (Figure 4). Using ordered logistic regression, we also found that coyote boldness was associated with increases in mowed areas and in modified open areas during the pup rearing season, while declining closer to roads and in areas with higher building density. Human concern was greater in areas with more residential land cover but also areas with more modified open land cover and during the dispersal season. We also identified statistical support for the aforementioned rise in human-coyote conflict over years (Figure 5), but found evidence, although marginally non-significant, that concern of coyotes in residential areas is decreasing over time. Lastly, we found that contextual variables were strongly related to human-coyote conflict (Figure 6). Aggressive coyote behaviour was more frequent when reports mentioned free-roaming cats and off-leash dogs, and while children were not related to coyote boldness, the level of human concern was greatest when children or dogs were mentioned in reports.

**Spatiotemporal patterns in coyote boldness and human concern**

We predicted that coyotes would exhibit bolder behaviour in natural or open areas because they are more likely to have territories and dens in these areas (Dodge and Kashian, 2013, Gehrt et al., 2009). We found partial support for this prediction; natural land cover was excluded from our top models and instead, the inverse relationship between boldness and higher building density and road proximity suggested that less developed open areas are where coyotes behave most antagonistically. This relationship is further supported by the positive effect of mowed land cover on boldness. Poessel et al. (2013) also reported increased negative encounters in open but not natural areas in Denver, Colorado, and Wine et al. (2015) found that coyote encounters were more likely in managed clearings in Mecklenburg County, North Carolina. This pattern may occur because coyotes are visible for longer, thus appearing to be bolder, in open areas or because bolder animals are more likely to occupy areas with less vegetation cover, as has been reported in brown bears (Ursus arctos; Bombieri et al., 2021). The higher explanatory value of smaller scales (Table 2 in Appendix 4) further suggests that boldness is 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 pup rearing season, which supports our initial hypothesis and the findings of similar studies (White and Gehrt, 2009, Lukasik and Alexander, 2011), especially in modified open areas. Of note, reporting was lowest during this period (Figure 2), indicating that coyotes likely avoid humans and pets most strongly during this season but behave more aggressively when interactions do occur. The increased probability of boldness when human-coyote interactions occur is likely attributed to defense of young from perceived threats posed by humans or dogs (Bombieri et al., 2018). During this season, reporters were more frequently walking (Figure 1 in Appendix 4), which also may have contributed to higher boldness (Figure 5). There were also more reports of cat depredations during the pup rearing season (29 of 50 total), probably caused by both greater numbers of free-roaming cats in this season and provisioning behaviour of coyotes (Nation and St. Clair, 2019). Modified open areas were strongly related to higher boldness during the pup rearing season (Figure 5), suggesting that the denning behaviour of coyotes in these areas is especially problematic for human-coyote coexistence. We attribute this to lower levels of vegetative cover for dens in modified open areas compared to natural areas, which may predispose coyotes in these areas toward aggression rather than avoidance behaviour. This is supported by reports in natural areas containing more avoidance (28.9%) and less aggressive behaviour (12.9 %) compared to modified open areas (20.3% avoidance and 20.7% aggression), despite off-leash dogs being frequent in both areas (Figure 2 in Appendix 4). Alternatively, coyotes denning in more disturbed modified open areas may be more prone to bold behaviour because of repeated exposure to humans and their pets in these areas (Young et al., 2019).

We found that human concern of coyotes was stronger in residential areas (Figure 5), which supported our initial prediction that human tolerance for coyotes would be lowest in this context. This result supports similar findings by others that people are less tolerant of urban coyotes near their homes although tolerant of their broader presence in cities (Drake et al., 2020, Bonnell and Breck, 2017). This effect also highlights how human concern may not align with the actual probability of bold or aggressive coyote behaviour, which was negatively associated with building density and road proximity (which are correlated with residential area). However, human concern was also related to modified open land cover (Figure 5), where bold interactions were more common during the pup rearing season. We surmise that this could be because reports of more bold coyote behaviour are also likely to have more human concern (Figure 1 in Appendix 3), and because people reporting from areas within the vicinity of modified open areas are aware of bold or aggressive encounters occurring nearby, causing higher perceived risk of coyotes that can decrease tolerance (Sponarski et al., 2018, Draheim et al., 2019). We also expect that higher perceived risk was indicated by the elevated total number of reports in the dispersal season and residential areas, as these both accumulated more reports than expected (Figure 1, 2), and had higher human concern despite having lower associated probabilities of coyote boldness (Figure 5). Both residential and modified open land cover were most explanatory at larger scales (Appendix 2 in Appendix 4), indicating that broader landscape characteristics were more important for human concern than site specific factors.

**Increases in coyote boldness and human concern over time**

Over the 10 years in which we collected reports, coyote boldness increased as we expected (Figure 4, 5), supporting conclusions by others that human-coyote conflict is increasing across North America (Baker and Timm, 2017, White and Gehrt, 2009). The top models did not include any interactions between land cover and years, suggesting that changes in boldness were most likely attributed to changes in urban coyote behaviour. These findings align with recent studies that have identified greater boldness in urban coyotes compared to rural conspecifics, possibly because of 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 further accelerate the increase in boldness-driven conflict. Furthermore, higher coyote population density within cities may cause more intraspecific competition that favours bolder individuals (Bateman and Fleming, 2012). Of note, we found that aggressive behaviour towards humans and pets did not exhibit the same 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 coyotes.

Human concern of coyotes also increased over the duration of report collection in opposition to our expectations (Figure 4, 5). We propose that the overall increase in human concern was connected to the rise in bold coyote behaviour and also to increased awareness of bold or aggressive interactions experienced by others, as previous work has shown that tolerance may be degraded by stronger perceived risk from knowledge of pet and human attacks (Sponarski et al., 2018, Draheim et al., 2019), or sensationalized media reports (Alexander and Quinn 2011). Others have predicted that public acceptance of coyote presence in cities will grow over time even if bold and aggressive encounter continue to occur (Jackman and Rutberg, 2015, Lawrence and Krausman, 2011), but our findings suggest that increased coyote boldness and public awareness of this trend may mitigate this effect.

In contrast to the overall increase in concern, we found evidence that public tolerance in coyotes in residential areas had increased over time (Figure 5). Although this effect was marginally insignificant in the top model, it was retained in 19 of 20 top models and was significant in 13 of these, and was consistently negative (Table 7 in Appendix 4). We propose that the reduced concern of coyotes in urban neighborhoods has occurred because the majority of human-coyote interactions in residential areas involve avoidant (30.4%) or indifferent (44.6%) coyote behaviour. As long as coyote boldness remains inversely related with building density and road proximity (i.e., outside of residential areas), we expect that human concern of coyotes in these areas will continue to decrease. This relationship in residential neighborhoods may be similar to one described in brown bears where both humans and bears are capable to habituating to the presence of the other (Smith et al., 2005). Our study demonstrates that even if tolerance of coyotes in residential neighborhoods increases over time, rising boldness in less-developed areas of the urban environment may prevent improvements in the public tolerance of urban coyotes.

**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 (Figure 6). Dogs and cats were associated with more bold and aggressive coyote behaviour, supporting our predictions and the findings of others that more negative human-coyote interactions involve pets (Poessel et al., 2013, Baker and Timm, 2017). Aggressive coyote behaviour occurred in 32.5% of reports with off leash dogs, but bold behaviour remained common when dogs were leashed (33.5% of reports), suggesting that leashed dogs may still be subject to antagonistic coyote behaviour, but they are less likely to be attacked. Although predatory coyote attacks on children are well-publicized and can lead to serious injury (Carbyn, 1989, Alexander and Quinn 2011, White and Gehrt, 2009), we did not find a significant relationship between the presence or mention of children and coyote boldness or aggression. In contrast, human concern was significantly higher when dogs, children, or multiple vulnerable individuals were mentioned in reports. Again, this demonstrates that a higher perceived risk of coyote attacks on pet and children likely leads to lower tolerance of coyote presence in cities (Draheim et al., 2019).

Other contextual variables showed that coyotes exhibited bolder behaviour when people were walking and when more coyotes were observed, and that human concern was lower in reports when people were driving or when a single coyote was mentioned. These results further provide evidence that people were less worried about coyotes in situations where they logically felt more secure. Although coyotes in poor health may be more conflict-prone (Murray et al., 2015b), this was not demonstrated in our study even though healthy coyotes were correlated with avoidance and indifference (Figure 6). We expect this could be caused by reporting bias as reporters may be more likely to notice and characterise a coyote’s health in encounters where they are not preoccupied with potential risk (i.e., when coyotes were not behaving boldly or aggressively).

**Limitations**

Our study had several limitations that are important to note when interpreting our results. First, public reports were non-randomly and non-independently collected, which introduces potential bias commonly associated with community reporting databases (Dickinson et al., 2010, Sullivan et al., 2014, Poessel et al., 2013). Sources of bias include 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 strongly effect the spatial and temporal distribution of reports, our analyses mitigated these effects by testing relative differences within subsets of reports where coyote boldness and human concern were determined. Second, the descriptions of coyote behavioural responses in our reports were not independent of human perceptions of those same behaviours and we interpreted our results accordingly. Third, we recognize the correlated nature of reports over space and time, but used large sample sizes and verified modelling results with chi-square tests to minimize Type I error (Appendix 2, Table 4). Fourth, we acknowledge that our post-hoc quantification of coyote boldness and human concern from a community reporting database does not provide comparable information to empirical behavioural observations of animals (e.g., Breck et al., 2019) or randomized public surveys (e.g., Drake et al., 2020) and should be interpreted accordingly. Despite these limitations, we join others in suggesting that community reporting databases provide much valuable information about human-coyote interactions and conflict (Weckel et al., 2010), but that subsequent investigations would benefit from prompting reporters to provide more specific information in reports to support analyses that are anticipated a priori by research teams that include biologists, social scientists, and wildlife managers.

**Management implications**

Our findings support several of the management actions that are already being implemented in our study area and elsewhere to reduce conflict between humans and coyotes. If coyote boldness is generally higher in open areas presenting greater risk to human and pet safety (Poessel et al., 2013, Wine et al., 2015), management might target these areas for public education about keeping dogs on-leash in high risk areas to avoid aggressive encounters, containing smaller pets with coyote-proof fencing (Draheim et al., 2019), and training citizens to haze coyotes that behave boldly in human-use areas (Bonnell and Breck, 2017). Proactive management should also aim to further limit coyote use of residential areas to prevent coyotes from becoming bolder in neighborhoods, which is likely needed to ensure that human tolerance continues to improve in these areas. Attractant management to reduce coyote access to anthropogenic food sources (Murray and St. Clair, 2017), as well as aversive conditioning programs and possibly even targeted removal of problem individuals should be considered (Breck et al., 2017). Management efforts should also be increased before and during the pup-rearing season. These might include seasonal closures of open areas with high numbers of bold or aggressive interactions to limit risks to human and pet safety and also prevent further habituation of adult or young coyotes. Additionally, aversive conditioning programs that target these higher-risk 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). Our findings also demonstrate that further resources and research are needed to mitigate the increase in coyote boldness and human concern that we identified in our study. These actions are likely to increase opportunities for coexistence by coyotes and people in cities across North America.

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