



# Coyotes access diverse anthropogenic attractants at the ecotone between natural and residential urban areas

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## Abstract

Natural areas in cities are important refugia for wildlife, but some species also use developed areas. Such adaptation may be facilitated at the ecotone between natural and residential areas where wildlife encounter anthropogenic resources. We quantified human activities and objects that potentially attract coyotes (*Canis latrans*) by providing shelter, food, prey habitat, and novelty items where backyards back onto natural areas in Edmonton, Canada. We related attractant abundance and human demographic variables to coyote access to backyards, scat abundance, and the number and nature of reports detailing interactions with coyotes near the ecotone. Among 468 surveyed backyards, 31% were accessed by coyotes, and we detected 2055 instances of attractants. Coyotes selectively accessed unfenced backyards with food and novelty items, and backyard access was most common along transects where fences were infrequent, and shelter was abundant. Evidence of deer on transects was weakly correlated with increased prevalence of scats. Public reports describing conflict with coyotes were more frequent in areas with more coyote access to backyards, fewer fences, and more shelter. Weak evidence indicated that food abundance, scat prevalence, and backyard access were higher in areas with larger houses and more university-educated and retired residents. These results suggest that coyotes frequently access attractants at the ecotone between natural and residential areas, which may promote habituation, food conditioning, and human-wildlife conflict. These effects could be reduced, and coexistence could be promoted with clearer boundaries separating natural and residential areas, opposing conventional recommendations for reserve design that encourage gradual transition zones.

**Keywords** Coexistence · Coyote · Ecotone · Habituation · Human-wildlife conflict · Urban green space

## Introduction

Increasing and accelerating global urbanization (McKinney 2002; United Nations 2018) renders natural areas in cities increasingly important for both humans (Jabbar et al. 2021; Semeraro et al. 2021; Reyes-Riveros et al. 2021) and wildlife (reviewed by Nielsen et al. 2014). Natural areas in cities, which we define as urban green spaces with natural vegetation, benefit human populations by providing spaces for recreation and relaxation (Reyes-Riveros et al. 2021), improving mental and physical health and well-being (reviewed by Jabbar et al. 2021), and providing ecosystem services (Semeraro et al. 2021). These spaces are important ecologically (Nielsen et al. 2014) because they retain the vegetative

structure, patterns, and processes of the native ecosystem that foster biodiversity (Matthies et al. 2017), provide connectivity for wildlife (Vergnes et al. 2013), and create important refugia and habitat for native species (Morrison et al. 2016). In some cities, urban natural areas are sufficiently extensive to serve as core areas (e.g., Shafer 1995; Volenec and Dobson 2020) that may be connected via corridors to support reserve systems over larger landscapes (Williams et al. 2005; Beier et al. 2008; Dickson et al. 2019)—a function that is increasingly recognized by both city planners and citizens (City of Edmonton 2007; Friends of the Chicago River 2020).

Establishment of large, connected patches of natural areas in urban landscapes address two of the most prevalent principles of reserve design (i.e., reserve size and reserve connectivity; Diamond 1975; Shafer 1994) that stemmed from Island Biogeography (MacArthur and Wilson 1967), but less attention has been paid to the establishment of buffers around core areas, which are transition zones between the core

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protected area and a matrix of lesser ecological value (Shafer 1994; Williams et al. 2005; Lovell and Sullivan 2006), where the detrimental effects of people can be moderated (Fattorini et al. 2018). The transition between adjacent ecosystems may be gradual (i.e., ecoclines), such as land cover that changes with latitude, or they may be abrupt and characterised by defined edges (i.e., ecotones; Kent et al. 1997). Buffers consisting of gradual transition zones are routinely recommended as part of traditional reserve planning (Shafer 1994, 1999; Hawkes et al. 1997) because they protect the core from edge effects (Hawkes et al. 1997; Mwampeta et al. 2021), prevent abrupt changes in habitat type (Shafer 1994, 1999), and complement core areas (Grant and Samways 2011). However, when buffer areas are used by large mammals or carnivores, they can also increase rates of human-wildlife conflict, and this challenge has been recognized at wildland-rural interfaces (Woodroffe and Ginsberg 1998; Gurung et al. 2008; Karanth et al. 2012; Siljander et al. 2020; Mwampeta et al. 2021).

Urban natural areas rarely have designated buffers, but the nature of the ecotone between these areas and adjacent residential land cover has ecological and societal implications. Many cities attempt to regulate human use of this space by prohibiting human encroachment into public natural areas adjacent to private residential yards, which has been documented in Canada (McWilliam et al. 2010, 2012, 2014), the United States (Matlack 1993), and Australia (Stenhouse 2004). Encroachment can degrade habitat via waste disposal, trail development, vegetation removal or modification, and erection of structures on public lands (McWilliam et al. 2010). Encroaching residents might also establish bird houses or feeders, plant gardens, modify vegetation, establish hammocks, fire pits, play structures or lawn furniture, store firewood or tools, and, especially, dump compost (Fors et al. 2018). Bylaws to prohibit encroachment are typically intended to prevent degradation of habitat and inconvenience to neighbours (McWilliam et al. 2010, 2014), but they may also be important tools for promoting coexistence with wildlife, particularly for urban-adapting carnivores.

One urban-adapted species that may respond to human influence and encroachment at the ecotone between urban natural areas and residential yards is the coyote (*Canis latrans*). Coyote range has expanded to include most of the continent and all major North American cities (Bekoff and Wells 1982; Gompfer 2002; Gehrt and Riley 2010; Poessel et al. 2017). Within cities, coyotes primarily occupy urban natural areas, however they also use the surrounding urban matrix (Grubbs and Krausman 2009; Gese et al. 2012; Dodge and Kashian 2013), including residential yards (Murray and St. Clair 2017). Urban coyotes present both benefits and risks for humans (Soulsbury and White 2015), with conflict stemming from physical attacks on people and pets (Lukasik and Alexander 2011) and their potential to act as vectors for

zoonotic disease, including the lethal tapeworm, *Echinococcus multilocularis* (Luong et al. 2020; Houston et al. 2021). Conflict rates typically increase outside urban natural areas (Lukasik and Alexander 2011; Poessel et al. 2017), especially when coyotes use residential areas (White and Gehrt 2009; Poessel et al. 2013; Farr et al. 2023), or when coyotes access anthropogenic food sources and become food-conditioned (White and Gehrt 2009; Murray et al. 2015, 2016). Food conditioning is especially likely following intentional wildlife feeding (Cox and Gaston 2018), which is more common among certain human demographics, such as seniors or high income individuals who can afford to purchase food for wildlife (Howard and Jones 2004; van Heezik and Hight 2017).

One means of reducing the potential for human-coyote conflict in residential areas is to better understand the nature of the ecotone between urban natural areas, where coyotes are more prevalent (Grubbs and Krausman 2009; Gese et al. 2012; Dodge and Kashian 2013), and adjacent residential yards where conflict may escalate (White and Gehrt 2009; Poessel et al. 2013). Coyotes are more likely to use residential yards that are unfenced (Thompson 1979; Murray and St. Clair 2017), offer hiding cover (Murray and St. Clair 2017) or shelter (Way 2009), or contain food resources, such as garbage, compost, fruit trees, and bird seed (Elliot et al. 2016; Murray and St. Clair 2017). Coyotes may also be attracted to residential yards that contain small pets (Elliot et al. 2016) or natural prey, which may use yard features (e.g., brush piles) as habitat (Hansen et al. 2020). Even inedible novelty items that can be chewed may attract wild canids in both urban (Windell et al. 2020; Raymond and St. Clair 2023) and rural environments (McNay 2002; Trapp 2004). Preventing access to these features could reduce the probability of food conditioning, raising pups in association with people, and transmitting zoonotic parasites—all circumstances that are known to increase conflict between humans and coyotes (Lukasik and Alexander 2011; Murray et al. 2015; Schell et al. 2018) and other carnivores (Herrero 1985; McNay 2002; Hopkins et al. 2010; Morales-Gonzalez et al. 2020). In recent years, new reports of coyote attacks on people and pets in urban areas have increased substantially, increasing the need to better understand and mitigate the circumstances that contribute to conflict.

The purpose of this study was to identify and quantify persistent human activities and objects that may attract coyotes to the ecotone between urban natural areas and backyards, and to relate these metrics to potential forms of human-coyote conflict. We had five specific objectives to better understand coyote and human use of urban ecotones. First, we quantified attractive features where backyards met urban natural areas. These attractive features fit into five non-overlapping categories, including the absence of physical barriers, support of perennial prey populations, and provision of shelter, food, and novel objects. Second,

we related the abundance of food, which we considered the most relevant attractant for human-wildlife conflict, to three metrics reflecting the human demographics of neighbourhoods. Third, we related the frequency with which these attractants and three human demographic predictors were associated with coyotes entering backyards, which we assessed using snow tracking. Fourth, we compared the presence of attractants and human demographics to the relative abundance of coyote scats, which represent zoonotic disease risk. Finally, we related attractant abundance to the prevalence of reports of coyotes submitted by the public, which represent the nature of human-coyote interactions. We aimed to describe human activities that are unregulated, but which may contribute significantly and ubiquitously to human-wildlife conflict in urban areas with a focus on the ecotone between natural areas and areas of human habitation. We also aimed to recommend management actions to mitigate the negative effects of these human activities and to integrate our findings into the larger framework of buffer areas in reserve design.

## Methods

### Study area

We conducted this study in Edmonton, Alberta, Canada, a northern city ~650 km<sup>2</sup> in size that is home to approximately one million people (City of Edmonton 2019), and which is characterized by extensive, ongoing, and increasing urban sprawl (Stan and Sanchez-Azofeifa 2017). We conducted field work for this study in March 2022 but used a database of reports of coyote activity submitted by members of the public from 2010 to 2020 to quantify reporting frequency. Edmonton includes extensive natural areas, most notably a network of ravines branching off the North Saskatchewan River Valley, which bisects the city. The river valley park network represents over 70 km<sup>2</sup> of natural area within Edmonton city limits (City of Edmonton 2022a) and represents sufficient regional ecological value that it is a candidate urban National Park (Upright 2022). Although the slopes surrounding the river valley and ravine were used by European settlers for several industrial purposes (e.g., coal mines, lumber yards, brick factories, garbage dumps) in the late 1800s and early 1900s, their topography and preservation as park lands have largely prevented their development (City of Edmonton 2022a). In the early 1900s, city planners located roadways at the tops of banks where ravine and river valley areas flattened to facilitate public observation of the river valley; older parts of the city therefore feature roads separating residential housing from adjacent natural areas (City of Edmonton 2022a). More recent developments frequently feature houses with backyards that back directly

on to the sloped natural areas below, potentially creating a more gradual ecotone between residential and natural areas that is also more difficult to monitor for potential sources of human-wildlife conflict.

### Data collection

We selected 19 areas in which to conduct transect surveys. Most transects occurred in different municipal neighbourhoods, but two that occurred in the same neighbourhood were separated by ~1300 m. Average distance to the closest transect was 1435 m (SD = 1005). Although the perimeters of some natural areas in Edmonton are characterised by uniformly fenced backyards and paved or otherwise improved trails adjacent to residential areas, we selected areas where backyards backed directly onto natural areas that were continuous with the river valley without separation by a roadway or improved trail. We selected transects on gentle slopes (< 10%) because steep slopes inhibited visual assessment of attractants at the edges of backyards. Transects ranged in length from 105 to 1590 m ( $\bar{x}$  = 531 m, SD = 311) and encompassed ten to 51 backyards ( $\bar{x}$  = 25.4, SD = 11.6), for a total of 484 yards.

We walked transects that were 2 – 10 m from the property line (visualized via GPS) parallel to the ecotone between private backyards and public natural areas. We recorded features on public land adjacent to backyards up to 15 m from the property line, which we could thoroughly survey. Because we could not enter private land, we recorded features in backyards when they were clearly visible from public land (as by Murray and St. Clair 2017). We eliminated from analyses backyards for which visual penetration was poor or topography forced us to be more than 10 m from the property line.

To assess access to backyards by coyotes, we recorded whether we detected coyote tracks in the snow indicating one or more coyotes had travelled into a backyard. Although we observed tracks suggesting coyote travel on public land parallel to property lines adjacent to most backyards, we classified a backyard as having been accessed by coyotes only when tracks crossed the property line and entered the backyard. We identified coyote tracks based on track size and shape and the presence of canine foot morphology, and we distinguished from domestic dog tracks based on gait, absence of splay between toes and the presence of sharp claws (Elbroch and MacFarland 2019). To support correct identification of tracks, the surveyor responsible for assessing tracks (S.R.) was certified in wildlife track and sign identification (<https://trackercertification.com/>) and used multiple criteria to determine species. We classified a backyard as having been accessed by coyotes only when we could confidently identify coyote tracks.

Within public land up to 15 m from property lines and visually observable private land (i.e., backyards), we categorized features that might attract coyotes into five non-overlapping groups: absence of barriers, and presence of shelter, food, prey habitat, and novelty objects. We defined barriers as a fence of metal, wood, brick, or plastic that completely encircled the backyard behind the house, including temporary fences (e.g., those made of rebar stakes and plastic mesh), but excluding those with an open gate. Although coyotes can cross wire fences up to 168 cm (5.5 feet), and overhangs and aprons are considered necessary for fences to preclude coyote access (Thompson 1979), our classification was based on ease of access, not whether access was possible. Shelter included decks and outbuildings with accessible foundations that coyotes could readily crawl under (Way 2009; Murray and St. Clair 2017). We counted the following food items: bird feeders, bird seed scattered on the ground, compost (bins or piles), discarded pumpkins, and garbage bags on the ground. We counted various features that represented potential habitat for coyote prey, including woody yard waste (i.e., branches), grass clippings, deciduous leaf litter, discarded Christmas trees, wood rounds, stacked wood, rock piles or permeable rock walls, stacks or piles of bricks, construction materials, concrete waste, and lumber. For novelty objects (i.e., human objects that did not offer coyotes a food or nutritional reward, such as clothing, plastic toys or objects, and damaged sports equipment), we counted the number of items that had been chewed by coyotes based on the presence of marks consistent with coyote dentition (Elbroch 2006). This approach may have led to inclusion of some items chewed by coyote-sized domestic dogs and exclusion of items chewed by coyote pups, and it prevented the inclusion of items that were located on private property that we could not examine for tooth marks. Most features were easily enumerated as count data, but we addressed items that were frequently deposited in piles of varying sizes (e.g., piles of branches, leaves, grass clippings, lumber, construction materials) by estimating the number of cubic meters of the attractant using a one-meter pole. Lastly, we recorded whether we detected deer (*Odocoileus virginianus* or *O. hemionus*) sign (i.e., pellets or tracks) during each transect. Deer presence likely represents a food source and reflects high-quality prey habitat, but this (categorical) information could not be combined with other (count) variables.

While conducting transect surveys, we visually identified coyote scats that were within 5 m of transects (Reed and Merenlender 2011). We distinguished coyote scats from those of domestic dogs by characteristic differences in shape and the presence of grain in dog scats (Reed and Merenlender 2011; Elbroch and MacFarland 2019). When we could not confidently identify a scat as belonging to a coyote, we did not include it in our analyses, which sometimes included scats that occurred on private property near transects. For each scat, we recorded its geographic location and, when possible, the presence or absence of five dietary

components that are easy to detect visually in scat: fruit, vegetation, natural prey (i.e., hair, bones or feathers), bird seed, and anthropogenic material, including garbage (e.g., Murray et al. 2015; Ogurtsov 2018).

## Data analysis

We summarised the abundance of attractants and scat along each transect using transect as the unit of replication because wildlife may respond more strongly to aggregated residential yard characteristics than to features of an individual yard (Belaire et al. 2014), and to support analysis of coyote reports in the adjacent area. To determine the influence of local human demographics on food abundance, frequency of access to backyards and scat abundance, we used three metrics. We used the building footprint layer available from the City of Edmonton's Open Data Portal to calculate the average footprint among houses located along each transect, which we used as an index for wealth, (City of Edmonton 2022b). We calculated the number of respondents that had acquired a university degree and the percent of respondents that reported being retired, both from Edmonton's 2016 census results measured at the scale of the adjacent neighborhood (City of Edmonton 2016). Because the two transects that occurred in the same neighbourhood had the same values for education and retirement metrics, we summed their constituent data when considering the influence of local human demographics, resulting in a sample size of 18 transects.

We determined the effects of local human demographics on food abundance by using regression to build a univariate model for each of house footprint, education, and retirement. For all regression models we tested global models for overdispersion (Burnham and Anderson 2002) and used a negative binomial distribution (if data were overdispersed) or a Poisson distribution (if data were not overdispersed; Cox et al. 2009). Because individual households are often responsible for feeding wildlife (Howard and Jones 2004), we included the number of houses along each transect as an offset term. We used univariate models to prevent overfitting (Harrell 2015) and reported confidence intervals (CI) and rate ratios (RR) to emphasize effect sizes (Nakagawa and Cuthill 2007), given risk of Type 1 error associated with conducting multiple univariate tests (Moran 2003; Nakagawa 2004) and risk of Type 2 error associated with small sample size. Because there is no consensus on the best pseudo  $R^2$  metric to assess the explanatory power of Poisson regression models (Cox et al. 2009), we reported two pseudo  $R^2$  metrics: McFadden's pseudo  $R^2$  is typically smaller than alternate pseudo  $R^2$  metrics (i.e., values of 0.2 – 0.4 indicate excellent fit, McFadden 1979), and Nagelkerke's pseudo  $R^2$  may result in values that are misleadingly high compared to  $R^2$  values for linear regression models (Veall and Zimmermann 1994). We compared models to null models using likelihood ratio tests.



To test the relationship between coyote access to backyards and the presence of attractive features, we first used student *t*-tests to compare the average number of attractive features among backyards that had been accessed by coyotes and those that had not, we used a chi square test to compare the number of accessed backyards among transects, and we used a Fisher's exact test to compare backyard access among fenced and unfenced backyards. For each transect, we developed predictors by calculating the percent of backyards with an intact fence and the number of instances of each attractant type per kilometre of transect. We then used Poisson regression to develop models that predicted the number of accessed backyards on each transect as a function of these predictors, including deer presence, offset by the total transect length (Coxe et al. 2009). To prevent overfitting, we limited the number of predictors in any given model to two (Harrell 2015). We did not allow correlated variables (Pearson's correlation value,  $r > 0.6$ ) to appear in the same model, and we used variance inflation factors (VIF) to confirm the absence of collinearity. We used Akaike information criterion weight adjusted for small sample sizes ( $AIC_c$ ) to compare models, and we considered models within two  $AIC_c$  to be equally predictive (Burnham and Anderson 2001). When multiple models were within two  $AIC_c$ , we averaged models using  $AIC_c$  weights, and we reported conditional average coefficients, which reduce Type 2 error (Grueber et al. 2011). To determine the effect of local human demographics on coyote access to backyards, we used negative binomial regression to develop three univariate models predicting the number of accessed backyards as a function of house footprint, education, and retirement, respectively. We evaluated the explanatory power of all models using both McFadden's and Nagelkerke's pseudo  $R^2$  metrics, and we compared to null models using likelihood ratio tests.

To relate scat abundance to the presence of attractants in backyards, we used ArcGIS to determine the distance from the property line of each backyard to the nearest scat. We first used a student *t*-test to compare this distance between backyards that had been accessed and those that had not been accessed. We then used negative binomial regression to assess the influence of the percent of backyards that had an intact fence, the abundance of each category of attractant per kilometre of transect, and the presence or absence of deer on the incidence of scat (i.e., scat count) at the transect level. Because we expected scat count to be proportional to transect length, we included transect length as an offset term. We used the approach previously described to prevent overfitting, to identify the most important predictors, and to assess model fit. To assess whether the predictors of scat abundance differed when scat predominantly contained anthropogenic material (a measure of greater access to human-provided attractants), we repeated this analysis for only the subset of scats that contained anthropogenic material, including garbage, compost, and birdseed. Lastly, we tested the influence of house footprint, education and retirement on scat abundance using three univariate negative binomial regression models.

To determine the effects of average attractant abundance in and adjacent to backyards on the abundance and nature of human-coyote interactions, we used reports submitted to a community reporting database administrated by the Edmonton Urban Coyote Project (Edmonton Urban Coyote Project 2022; Farr et al. 2023). Reports collected between 2010 and 2020 ( $n = 7887$  across the city) were attributed to a GPS location and various details about the event as described by Farr et al. (2023). We used ArcGIS to generate transect areas by developing a 300-m buffer around each transect. We chose a 300-m buffer because it was socially and ecologically relevant; reports within 300 m of the transect occurred within the same municipal neighbourhood as the transect and contained much of the green space adjacent to the transect, where we assumed coyotes that accessed ecotone attractants spent much of their time and accessed shelter and hiding cover. Six of the areas we generated overlapped, so we avoided pseudoreplication in this analysis by merging overlapping transects and summing their constituent data, resulting in a sample size of 16 transect areas, which ranged in size from 396000m<sup>2</sup> to 1691000m<sup>2</sup> ( $\bar{x} = 687000\text{m}^2$ ,  $SD = 331,000$ ). We associated reports ( $n = 618$ ) with transects when they occurred within the generated buffers. Reports were collected up to 12 years earlier than our quantification of attractants, but we tested for consistency of reporting among years by creating models that predicted the proportion of annual reports occurring in a given transect area as a function of year. From these reports, we generated five response variables: the total number of reports, the number of reports that occurred in a residential yard, the number of conflict reports (i.e., reports in which the coyote approached, followed, or attacked a human or pet), the number of reports where the reporter's perception of the coyote, or of coyotes generally, was negative, and the number of reports that involved an unhealthy animal. Further details on how this information was extracted from the reporting database can be found in Farr et al. 2023. For each response variable, we determined the influence of the percent of backyards with intact fences, the percent of backyards that were accessed, the presence or deer, and the abundance of each type of attractant using negative binomial regression, including the area of the buffer around the transect as an offset. To accommodate the small sample size ( $n = 16$ ), we tested only univariate models, but we otherwise used the modelling approach previously described. Owing to concerns that repeat reports by individuals could bias results, we repeated this analysis with a subset of reports in which we randomly selected a single report per person per year.

We used ArcGIS v 10.8.2 (ESRI 2022) to conduct spatial analyses, and we used R v 4.0.3 (R Core Team 2022) to conduct statistical analyses and to create figures. We used a significance level of 95% for all analyses. To mitigate Type I

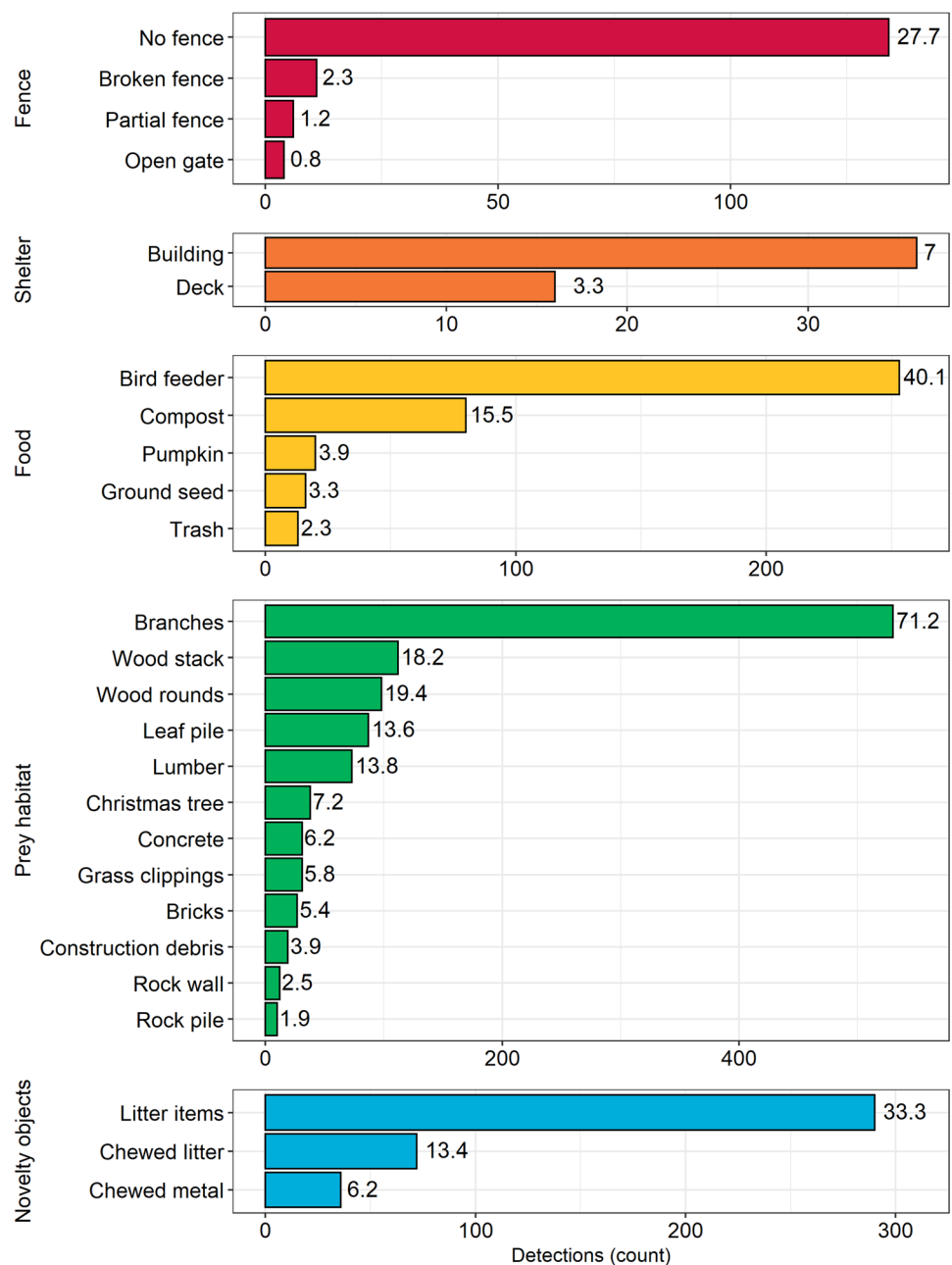
and Type 2 error, we emphasized effect sizes by reporting rate ratios and 95% confidence intervals for all beta coefficients (Moran 2003; Nakagawa 2004; Nakagawa and Cuthill 2007). We mean-centered and standardized (1 SD) beta coefficients.

## Results

Among 19 transects that traversed 484 backyards, we documented 2055 instances of potential attractants that were readily visible within backyards or deposited on public land adjacent to private property (Fig. 1, Table S1). Fences

were absent for 134 backyards (27.7%) and incomplete (e.g., broken, open gate) for another 21 (4.3%). Attractants related to shelter included outbuildings ( $n = 36$ ) and decks ( $n = 16$ ) with accessible foundations, which were cumulatively present in 10.3% of backyards. The most common food attractant was bird feeders, which we detected 253 times in or near 40.1% of backyards, followed by compost, which we detected 80 times in or near 15.5% of backyards. Every attractant that we categorized as food for coyotes likely also represented an attractant for coyote prey species. Where we detected accumulations of food on the ground (e.g., birdfeeders, compost on the

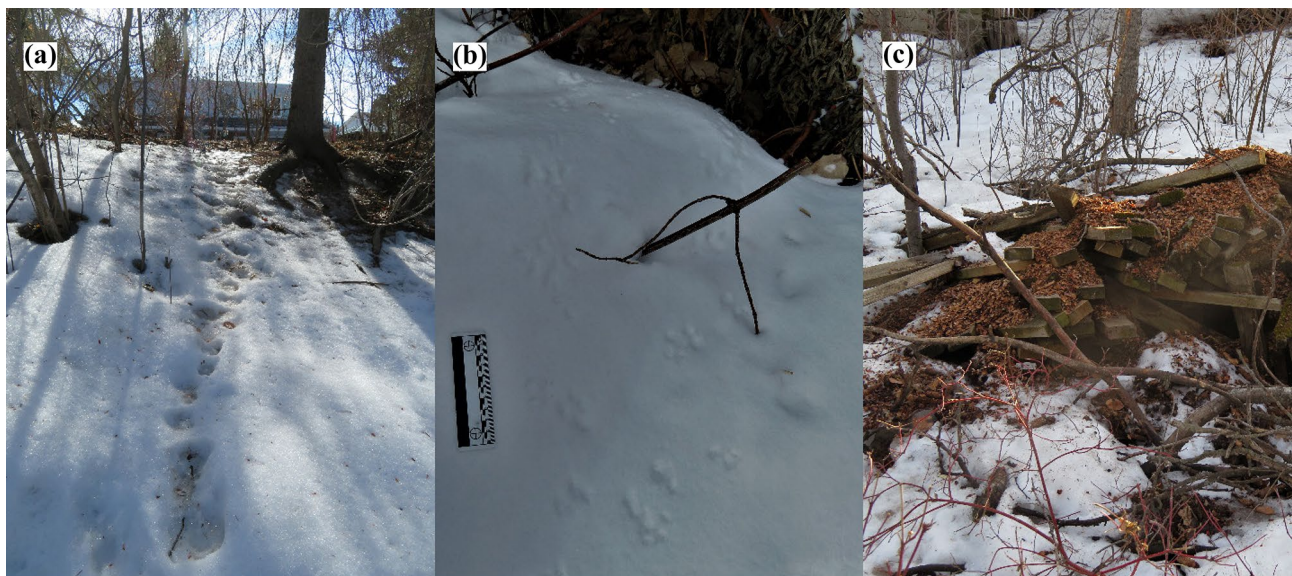
**Fig. 1** A summary of the major attractants quantified at the ecotone between 484 residential private properties and urban natural areas in Edmonton, Alberta, Canada, 2022. Bars represent the number of detections for each feature or attractant, and numerical labels indicate the percentage of backyards that contained or were adjacent to the feature or attractant. To facilitate analysis, we classified attractants into five non-overlapping categories, however some attractants likely represented multiple categories



ground), we frequently observed tracks of various species in the surrounding snow, including coyotes, deer, deer mice (*Peromyscus* sp.), voles (*Microtus* spp.), red squirrels (*Tamiasciurus hudsonicus*), hares (*Lepus americanus* or *L. townsendii*), and various birds, especially magpies (*Pica hudsonia*). The most common example of prey habitat was branches, which we detected 530 times in or near 71.5% of backyards, followed by wood stacks ( $n = 112$ , 18.2% of backyards) and wood rounds ( $n = 98$ , 19.4% of backyards). Other common types of prey habitat included lumber ( $n = 73$ , 13.8% of backyards) and deciduous leaf waste ( $n = 87$ , 13.6% of backyards; Fig. 2b, c). We frequently detected evidence that coyote prey used these features for habitat and recorded deer mouse, vole, red squirrel and snowshoe hare tracks entering accumulations of anthropogenic debris that we classified as prey habitat (Fig. 2b), and we detected squirrel middens in anthropogenic features, such as piles of lumber (Fig. 2c). We detected 290 small items of anthropogenic litter in or near 33.3% of backyards, and 72 of these items (25%) had been chewed or shredded by coyotes. We documented birdseed scattered on the ground where there were also tracks of coyotes, deer, birds, and rodents ( $n = 16$ ), food scraps or compost on the ground ( $n = 12$ ), garbage bags torn open and accessed by coyotes ( $n = 6$ ), salt licks for deer ( $n = 2$ ), piles of cat kibble ( $n = 2$ ), a chicken coop in association with animal bedding (e.g., straw, wood shavings,  $n = 1$ ), torn animal feedbags ( $n = 1$ ), and a deer feeder full of grain ( $n = 1$ ). Negative binomial models provided

weak support that there was greater abundance of food along transects associated with larger houses ( $\beta = 0.16$ ,  $P = 0.26$ ,  $CI = -0.1, 0.4$ ), more university-educated people ( $\beta = 0.20$ ,  $P = 0.16$ ,  $CI = -0.1, 0.5$ ), and more retired individuals ( $\beta = 0.18$ ,  $P = 0.20$ ,  $CI = -0.1, 0.5$ ), however the confidence intervals for all predictors overlapped zero, and likelihood ratio tests suggested that models failed to perform better than null models at  $P < 0.05$  (Table 1).

Of the 484 backyards we surveyed, we could visually assess whether or not backyards had been accessed by coyotes in 97% of backyards (Fig. 2a); in the remaining 16 backyards, snow accumulation or texture was insufficient to confidently detect or identify tracks, so we removed these backyards from our analysis. Among these 468 backyards, 145 (31%) showed evidence of access by coyotes. Among 19 transects, evidence of coyote access to individual backyards varied and ranged from 0% ( $n = 0$  of 44 backyards) to 78% ( $n = 18$  of 23 backyards;  $\chi^2 = 45.9$ ,  $df = 18$ ,  $P < 0.01$ ). Coyote access was significantly higher in backyards lacking an intact fence; 94% of backyards without intact fences were accessed by coyotes, and we did not detect a single instance of coyotes accessing a fenced backyard, regardless of fence height (Fisher's exact test,  $df = 1$ ,  $P < 0.01$ ). On average, backyards accessed by coyotes had 50% more instances of prey habitat ( $t = 4.37$ ,  $df = 466$ ,  $P < 0.01$ ), 59% more instances of food ( $t = 2.83$ ,  $df = 466$ ,  $P = 0.01$ ), 91% more instances of shelter ( $t = 2.51$ ,  $df = 466$ ,  $P = 0.01$ ), and 105% more instances of novelty items ( $t = 2.47$ ,  $df = 466$ ,  $P = 0.02$ ; Table S2, Fig. 3a). To separate the effects of fences



**Fig. 2** Examples of the ecotone between urban natural areas and residential areas in Edmonton, Alberta, Canada, 2022. **a** A coyote trail accessing an unfenced backyard adjacent to an urban natural area. **b** Deer mouse tracks accessing a pile of backyard waste deposited on

public land. The ruler is 10 cm long and shows 1-cm increments. **c** A red squirrel midden in a pile of discarded lumber in the natural area outside a backyard

**Table 1** The summary metrics for negative binomial models predicting food abundance, the number of backyards accessed by coyotes, and abundance of coyote scats based on local human demographics related to house footprint (an index of wealth), education (i.e., percent of individuals with a university degree), and lifestyle (i.e., percent of individuals who were retired) located at the ecotone between

natural and residential areas in Edmonton, Alberta, Canada, 2022. We reported standardized (1 SD) and mean-centered beta coefficients ( $\beta$ ), rate ratios (RR), 95% confidence intervals (CI), Nagelkerke's pseudo  $R^2$  metric ( $N R^2$ ), and McFadden's pseudo  $R^2$  ( $M R^2$ ). We compared model performance to a null model using likelihood ratio tests, and we report associated  $P$  values (Vs. null)

Predictor	B	CI ( $\beta$ )	$P$	$N R^2$	$M R^2$	RR	CI (RR)	Vs. null
Number of instances of food								
House footprint	0.16	-0.1, 0.4	0.26	0.06	0.01	1.00	1.0, 1.0	0.31
Education	0.20	-0.1, 0.5	0.16	0.09	0.01	1.01	1.0, 1.4	0.20
Retirement	0.18	-0.1, 0.5	0.20	0.08	0.01	1.04	1.0, 1.1	0.22
Number of backyards accessed by coyotes								
House footprint	0.25	0, 0.5	0.07	0.14	0.03	1.00	1.0, 1.0	0.09
Education	0.17	-0.1, 0.5	0.28	0.05	0.01	1.01	1.0, 1.0	0.31
Retirement	0.23	-0.1, 0.5	0.11	0.12	0.02	1.05	1.0, 1.1	0.13
Number of coyote scats								
House footprint	0.33	-0.1, 0.7	0.10	0.10	0.02	1.01	1.0, 1.0	0.16
Education	0.47	0.1, 0.9	0.02	0.23	0.04	1.03	1.0, 1.1	0.03
Retirement	0.04	-0.4, 0.4	0.83	0.00	0.0	1.01	0.9, 1.1	0.84

and attractants, we repeated this analysis using the subset of backyards that lacked an intact fence; among backyards without intact fences ( $n = 155$ ), accessed backyards had 140% more food attractants ( $t = 3.7$ ,  $df = 153$ ,  $P < 0.01$ ) and 197% more novelty objects ( $t = 2.7$ ,  $df = 153$ ,  $P = 0.01$ ), but they did not differ significantly with respect to abundance of shelter ( $t = 0.0$ ,  $df = 153$ ,  $P = 0.99$ ) or prey habitat ( $t = 0.9$ ,  $df = 153$ ,  $P = 0.41$ ; Table S3, Fig. 3b).

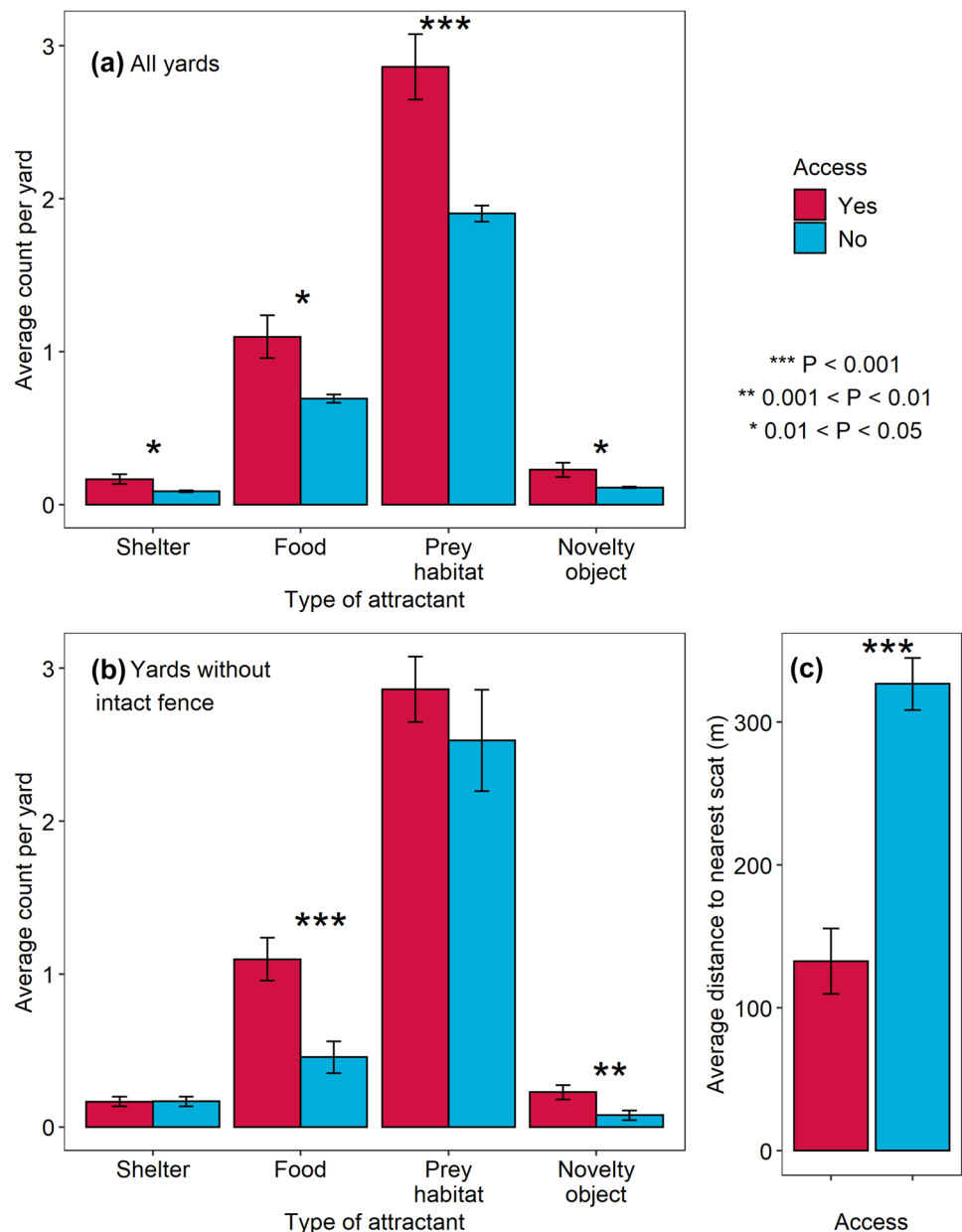
A global model predicting the number of accessed backyards along a transect resulted in two top models. The top model ( $AIC_c = 88.8$ ) indicated that fewer intact fences was the most important predictor of coyote access to backyards ( $\beta = -0.48$ ,  $P < 0.01$ ,  $CI = -0.62, -0.33$ ), and the second model ( $AIC_c = 89.9$ ) suggested that both few intact fences ( $\beta = -0.44$ ,  $P < 0.01$ ,  $CI = -0.61, -0.28$ ) and abundant shelter ( $\beta = 0.08$ ,  $P = 0.35$ ,  $CI = -0.09, 0.26$ ) increased coyote access to backyards. Model-averaged results indicated that for every additional percentage of backyards with intact fences, the number of backyards accessed by coyotes decreased by 2% ( $RR = 0.98$ ,  $CI = 0.97, 0.99$ ), and for every additional instance of shelter per kilometre, the number of backyards accessed increased by 3% ( $RR = 1.03$ ,  $CI = 0.97, 1.09$ ). The global model met the dispersion assumptions of Poisson regression (dispersion ratio = 0.855,  $P = 0.59$ ). The final models fit the data well (Nagelkerke pseudo  $R^2 = 0.85$  and 0.86; McFadden pseudo  $R^2 = 0.30, 0.31$ , for first and second model, respectively), showed little collinearity (maximum VIF = 1.20), and likelihood ratio tests indicated both models fit the data better than the null model ( $P < 0.01$ ). As with food abundance, negative binomial models indicated that the number of backyards accessed by coyotes along transects was weakly associated with larger houses ( $\beta = 0.25$ ,

$P = 0.07$ ,  $CI = 0, 0.5$ ), a higher percent of university-educated people ( $\beta = 0.17$ ,  $P = 0.28$ ,  $CI = -0.1, 0.5$ ), and a higher percent of retired individuals ( $\beta = 0.23$ ,  $P = 0.11$ ,  $CI = -0.1, 0.5$ ; Table 1). These models did not perform significantly better than null models.

We detected 192 coyote scats in or near backyards (i.e., within 5 m of transects). We detected 82 scats that contained anthropogenic material, including garbage (42.7%), 64 scats containing birdseed (33.3%), and 130 scats containing either anthropogenic material or birdseed (67.7%). Distance to the nearest scat was, on average, 194 m closer for backyards that were accessed by coyotes compared to backyards that were not ( $t = 4.7$ ,  $df = 466$ ,  $P < 0.01$ ; Fig. 3c). A global negative binomial model predicting the number of scats along a transect as a function of the abundance of the various attractants met the dispersion requirements for negative binomial regression (dispersion ratio = 1.14,  $P = 0.32$ ) and resulted in one model within 2  $AIC_c$ . This model ( $AIC_c = 130.3$ ) suggested that deer presence increased scat abundance by 2.43 times ( $RR = 2.43$ ,  $CI = 1.0, 5.8$ ; Table 2). However, the model failed to explain most of the variation in the data, and a likelihood ratio test suggested that it didn't fit the data better than the null model ( $P = 0.06$ ). When we repeated the modelling procedure for only those scats containing anthropogenic material, we obtained a similar result; deer presence was the strongest predictor of scats containing anthropogenic material and increased its abundance by 3.37 times ( $RR = 3.37$ ,  $CI = 1.4, 8.2$ ; Table 2), and a likelihood ratio test showed that this model performed better than the null model ( $P = 0.01$ ). As with the abundance of food and the number of backyards accessed by coyotes, scat abundance was weakly predicted by larger houses ( $\beta = 0.33$ ,  $P = 0.10$ ,  $CI = -0.1, 0.7$ ),



**Fig. 3** Average count of four categories of attractants found in or near all backyards (**a**,  $n=468$ ) and in or near backyards lacking an intact fence (**b**,  $n=155$ ) with differing access by coyotes in Edmonton, Alberta, Canada, 2022. **c** Average distance to the nearest scat among backyards with differing access by coyotes. Error bars represent standard error



a higher percent of university-educated people ( $\beta=0.47$ ,  $P=0.02$ ,  $CI=0.1, 0.9$ ), and a higher percent of retired individuals ( $\beta=0.04$ ,  $P=0.83$ ,  $CI=-0.4, 0.4$ ; Table 1). For these

analyses, only the model predicting scat based on percent of university educated people performed better than the null model according to likelihood ratio tests ( $P=0.03$ ).

**Table 2** The summary metrics for predictors of the abundance of (1) all scats ( $n=192$ ), and (2) scats containing anthropogenic material, including garbage, compost, and birdseed ( $n=130$ ) along transects at the ecotone between natural and residential areas in Edmonton, Alberta, Canada, 2022. We report only negative binomial models within 2  $AIC_c$  (i.e., the top models) with standardized

(1 SD) and mean-centered  $\beta$  values, 95% confidence intervals (CI), and rate ratios (RR). We used Nagelkerke's pseudo  $R^2$  metric ( $N R^2$ ) and McFadden's pseudo  $R^2$  ( $M R^2$ ) to evaluate the model's predictive power, and we assessed model performance by comparing to null models using  $P$ -values from likelihood ratio tests (Vs. null)

Scat content	Predictor	$\beta$	CI ( $\beta$ )	$P$	$N R^2$	$M R^2$	RR	CI (RR)	Vs. null
Any content	Deer	0.89	0.0, 1.8	0.01	0.18	0.03	2.43	1.0, 5.8	0.06
Anthropogenic material	Deer	1.22	0.3, 2.1	0.01	0.28	0.05	3.37	1.4, 8.2	0.01

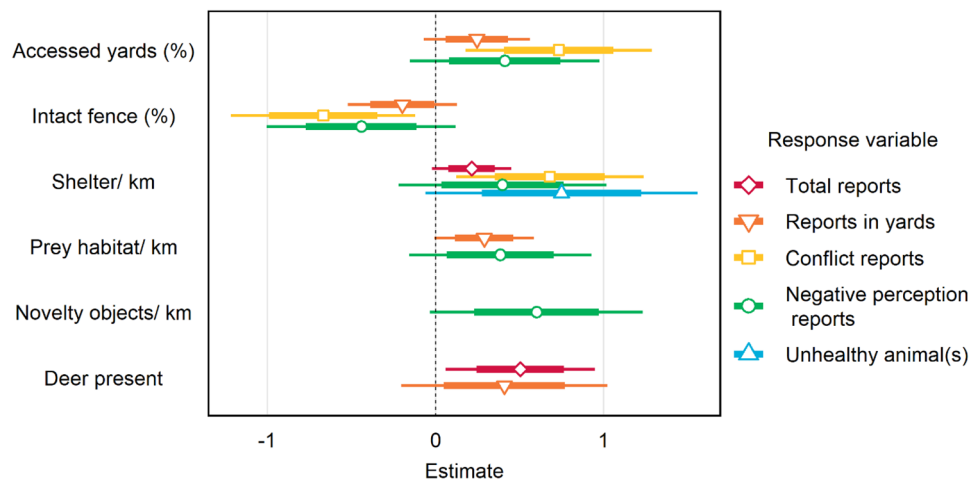
Of the 618 reports of coyotes that occurred in areas within 300 m of transects ( $n=16$ ), 132 (21.4%) were classified as occurring within a backyard and 71 (11.5%) were classified as conflict encounters (i.e., coyotes approached, followed, or attacked a human or pet). The reporter's perception of the encounter was negative in 33 (5.3%) cases and 46 (7.4%) reports specified that the coyote was unhealthy. Univariate models for each of these five response variables suggested that attractants influenced the number and nature of reports of coyote activity. The total number of reports increased by 1.66 times if deer were present, and by 8% per additional instance of shelter, but the confidence intervals associated with shelter overlapped zero, whereas those associated with deer presence did not (Table 3, Fig. 4). Although the number of reports occurring in backyards was increased by the abundance of accessed backyards, prey habitat, and deer presence, and decreased by abundance of intact fences, the confidence intervals for all predictors overlapped zero, and none of these models performed better than the null model according to likelihood ratio tests (Table 3, Fig. 4). The number of reports characterised by conflict increased by 28% per additional

shelter per kilometre, by 4% per percent increase in accessed backyards along a transect, and decreased by 3% for each percent increase in fenced backyards. Reports in which the reporter expressed negative sentiments towards coyotes were increased by the abundance of novelty objects, accessed backyards, prey habitat, and shelter, and decreased by abundance of intact fences, but these predictors were associated with wide confidence intervals, and likelihood ratio tests suggested that models did not perform significantly better than the null model (Table 3, Fig. 4). Lastly, reports of unhealthy animals increased by 32% per unit increase in shelter abundance per kilometre (Table 3, Fig. 4), and, although the 95% CI slightly overlapped 0, likelihood ratio testing suggested this model performed better than the null model. Patterns of reporting among transect areas were similar among years; for all models predicting the proportion of annual reports occurring in a given transect area, year was associated with a large  $P$ -value and wide confidence intervals. When we repeated the analysis omitting reports submitted by the same individual within the same calendar year ( $n=207$ ), the direction of the effects was the same for all models ( $n=15$ , Table S4).

**Table 3** The summary metrics for predictors of five different response variables derived from reports of coyote activity submitted by members of the public in Edmonton, Alberta, Canada ( $n=618$ ). Reports were submitted between 2010 and 2020, and predictors were quantified in 2022. All results represent univariate negative binomial regression models, offset by the area in which reports occurred. We report only models within 2 AIC<sub>c</sub> of each other (i.e., the top mod-

els) with standardized (1 SD) and mean-centered  $\beta$  values, 95% confidence intervals (CI), and rate ratios (RR). We used Nagelkerke's pseudo  $R^2$  metric ( $N R^2$ ) and McFadden's pseudo  $R^2$  ( $M R^2$ ) to evaluate model predictive power, and we assessed model performance by comparing to null models using  $P$ -values from likelihood ratio tests (Vs. null). For each response variable, predictors are listed by ascending AIC<sub>c</sub>

Predictor	B	CI ( $\beta$ )	$P$	$N R^2$	$M R^2$	RR	CI (RR)	Vs. null
Total reports								
Deer	0.50	0.1, 0.9	0.03	0.24	0.03	1.66	1.1, 2.6	0.04
Shelter	0.21	0.0, 0.5	0.07	0.17	0.02	1.08	1.0, 1.2	0.08
Reports in backyards								
Prey habitat	0.30	0.0, 0.6	0.05	0.19	0.04	1.01	1.0, 1.0	0.07
Accessed backyards	0.25	-0.1, 0.6	0.13	0.13	0.03	1.01	1.0, 1.0	0.13
Deer	0.41	-0.2, 1.0	0.19	0.10	0.02	1.51	0.8, 2.8	0.21
Intact fence	-0.20	-0.5, 0.1	0.23	0.09	0.02	0.99	1.0, 1.0	0.23
Conflict reports								
Shelter	0.68	0.1, 1.2	0.02	0.26	0.06	1.28	1.0, 1.6	0.03
Accessed backyards	0.73	0.2, 1.3	0.01	0.25	0.06	1.04	1.0, 1.1	0.03
Intact fence	-0.67	-1.2, -0.1	0.02	0.25	0.06	0.97	0.9, 1.0	0.03
Negative perception reports								
Novelty	0.60	0.0, 1.2	0.06	0.17	0.05	1.19	1.0, 1.4	0.09
Intact fence	-0.44	-1.0, 0.1	0.12	0.16	0.04	0.98	1.0, 1.0	0.10
Accessed backyards	0.41	-0.2, 1.0	0.15	0.14	0.04	1.02	1.0, 1.1	0.12
Prey habitat	0.38	-0.2, 0.9	0.16	0.13	0.04	1.01	1.0, 1.0	0.15
Shelter	0.40	-0.2, 1.0	0.21	0.09	0.03	1.16	0.9, 1.5	0.23
Unhealthy animal(s)								
Shelter	0.75	-0.1, 1.6	0.07	0.18	0.05	1.32	1.0, 1.8	0.04



**Fig. 4** Standardized (1 SD) and mean-centered beta coefficient estimates for predictors of five different response variables derived from reports of coyote activity submitted by the public in Edmonton, Alberta, Canada. All results represent univariate negative binomial regression models, offset by the area in which reports occurred. We

report only models within 2  $AIC_c$  of each other (i.e., the top models). Wide inner bars represent 75% confidence intervals, and narrow outer bars represent 95% confidence intervals. Reports were submitted between 2010 and 2020, and predictors were quantified along the ecotone of residential areas and urban natural areas in 2022

## Discussion

The ecotone between residential areas and urban natural areas represents an element of the urban landscape that is often overlooked, but which may have important implications for human-wildlife coexistence. We quantified coyote attractants at this ecotone, and we linked their abundance to coyote access to backyards, scat abundance, and the number and nature of reports of coyote activity submitted by community members. We also explored human demographic predictors of food abundance, coyote access to backyards, and scat abundance. We found abundant evidence of human encroachment into natural areas, including deposition of food resources, which was insignificantly more common in areas with larger houses, and more retired and university-educated individuals. The strongest predictor of coyote access to backyards was the absence of an intact fence, but features that provided coyotes with food or habitat resources also increased access likelihood and did so even among the subset of backyards that lacked fences. Larger houses and higher rates of retired and university-educated individuals were also weakly associated with more backyard access by coyotes. We found some evidence that the presence of deer sign increased local scat abundance, as did larger building footprints and more university-educated residents. Various attractants affected the number and nature of reports of coyote presence. Although our results are based on small sample sizes and moderate effect sizes, we propose that the gradual ecotones we documented between backyards with abundant attractants and natural areas may promote habituation in coyotes and promote human-wildlife conflict in urban areas, particularly in areas adjacent to residential neighbourhoods.

Human residents modified the ecotone between urban natural areas and residential areas most often by establishing bird feeders and dumping yard waste and compost on public lands. This observation is consistent with several other studies (Matlack 1993; Stenhouse 2004; McWilliam et al. 2010, 2014), that document misuse of public land (Fors et al. 2018), and it is consistent with a widespread pattern of ecological degradation where humans live near protected areas (Grant and Samways 2011; Mwampeta et al. 2021). Residents may perceive these practices as innocuous or ecologically beneficial, despite potentially attracting urban carnivores. For example, people often view feeding birds as ecologically beneficial (Cox and Gaston 2016), but birdseed is a common food source for coyotes (Murray et al. 2015; Elliot et al. 2016), and the negative relationship between feeding wildlife and human-wildlife conflict is well understood (McNay 2002; Herrero et al. 2005; Hopkins et al. 2010; Morales-Gonzalez et al. 2020). In this study, one third of coyote scats contained birdseed; by contrast, in a sample of 1173 coyote scats detected throughout natural areas in Edmonton, only 17% of scats contained birdseed (Raymond and St. Clair, unpublished data), suggesting that coyotes are attracted to this ecotone by birdseed. Although many residents consider dumping yard waste in public green spaces unproblematic (McWilliam et al. 2014), our qualitative observations of prey tracks accessing such deposits suggests that these features create habitat for prey species (Hansen et al. 2020), and the positive relationship between prey habitat and backyard access indicates that coyotes are attracted to this resource. In other cases (e.g., dumping garbage on public land, intentionally feeding wildlife other than birds), residents are likely aware they are misusing public land, but

do so regardless. Although not statistically significant, our observation that house footprint, a metric of wealth, and the proportion of retired residents generally increased food abundance were consistent with findings from other studies. Seniors are most likely to feed wildlife, wealthier individuals can more readily afford food for wildlife (Howard and Jones 2004), and bird feeding is more common in neighbourhoods with higher socioeconomic status (van Heezik and Hight 2017). Our insignificant finding that neighbourhoods with more university-educated residents were associated with greater food abundance is inconsistent with other studies, where university-educated individuals were less likely to feed birds (van Heezik and Hight 2017) or where education did not affect food provisioning (Clucas and Marzluff 2012), however wide confidence intervals and small sample sizes limit the interpretation of these results.

The strongest predictor of coyote access to backyards at both the backyard and transect level was the absence of an intact fence. Fences must be tall (> 5.5 feet) and equipped with an apron and overhang to completely exclude coyotes (Thompson 1979), but we found that short or temporary fences dissuaded coyotes from accessing backyards, suggesting that any fence may reduce coyote access to backyards, especially if combined with attractant absence. Shorter fences are less costly and may be more aesthetically attractive to residents. Fencing has been useful in preventing human encroachment into urban natural areas bordering residential areas (McWilliam et al. 2010, 2012). In agricultural lands bordering large protected areas in developing countries, fencing can reduce human-wildlife conflict (Packer et al. 2013; Karanth et al. 2013; Branco et al. 2020), but it can also disrupt animal movements, foster resentment in residents, and culminate in conflict escalation (Soliku and Schraml 2018). Investigation into the effectiveness of fencing to reduce human-wildlife conflict in urban areas is limited, but urban backyards selected by coyotes were 66.7 times less likely to have a fence (Murray and St. Clair 2017), and red fox (*Vulpes vulpes*), grey fox (*Urocyon cinereoargenteus*), and Virginia opossum (*Didelphis virginiana*) abundance were lower in urban residential yards with full fences (Hansen et al. 2020). Electric fences around landfills and other properties in communities in British Columbia, Montana, and Idaho reduced human-bear conflict (Proctor et al. 2018), and electric fencing around farm buildings prevented access by badgers (*Meles meles*, Tolhurst et al. 2008). Although fencing can be cost prohibitive (Packer et al. 2013), cost-share programs can increase community buy-in and compliance, ultimately reducing human-wildlife conflict (Proctor et al. 2018).

At the backyard level, food and novelty items increased coyote access to backyards, even when considering only backyards without fences. The relationship between food presence and access is consistent with the observation that urban coyotes readily access anthropogenic food sources

(Morey et al. 2007; Lukasik and Alexander 2011; Cherry et al. 2016; Murray and St. Clair 2017; Sugden et al. 2020), which promotes human-coyote conflict (Murray et al. 2015). Coyote attraction to novel objects is less frequently described in the literature, although urban coyotes have been documented carrying inedible anthropogenic items (Windell et al. 2020), and chewed anthropogenic items are frequently found at urban coyote dens (Raymond and St Clair 2023). Wildlife often intentionally interact with and chew human-sourced objects (Bacon 1980; McNay 2002; Trapp 2004), but the implications of these interactions for human-wildlife conflict are unclear. Access to these objects could habituate coyotes to human smells and presence, and habituation may increase food conditioning and associated human-wildlife conflict (Hopkins et al. 2010; Morales-Gonzalez et al. 2020). For example, several wolves (*Canis lupus*) that regularly accessed camps and removed inedible items were later involved in attacks on humans (McNay 2002). Because the offspring of habituated coyotes have decreased fear responses to humans (Schell et al. 2018), the perennial presence of habituating stimuli, such as anthropogenic objects, adjacent to natural areas could affect coyote behaviour, with impacts to conflict that persist for generations. At the transect level, backyard access also increased with more shelter. This finding supports previous literature suggesting that urban-adapted coyotes shelter under human buildings and objects (Way 2009; Murray and St. Clair 2017), and underscores the importance of limiting coyote access to structures, especially during the denning period when coyotes may use them for denning (Way 2009). Our finding that house footprint, and the percent of residents that were university-educated may increase rates of coyote access to backyards could be correlated with elevated food abundance. Alternately, it could be an artefact of greater coyote abundance associated with the luxury effect, in which neighbourhoods with higher socioeconomic status have more wildlife habitat (Magle et al. 2021).

Deer presence increased the abundance of coyote scat, especially scats containing anthropogenic material, suggesting both coyotes and deer are attracted to residential yards. This finding could reflect co-occurrence of these species; coyotes may be attracted to areas with abundant deer because deer represent a prey source (Kilgo et al. 2012), or because high-quality habitat is limited for both species (Magle et al. 2014). They may also access common food sources, which was supported by our observations of both coyote and deer tracks accessing birdseed and compost. The limited performance of models predicting scat abundance could mean that coyote scats do not accumulate where coyotes spend the most time, but rather where they deposit them for intraspecific communication (Barja and List 2014). Aggregation near human residences potentially increases the likelihood of disease transmission among individuals for both coyotes (Murray et al. 2016) and deer (Storm et al. 2013). Although



many urban residents enjoy seeing wildlife in and near their residential yards (Soulsbury and White 2015) and even attract them via salt licks and feeding (Howard and Jones 2004), they may be unaware of the zoonotic disease risks this situation presents. In Edmonton, over 50% of coyotes are infected with *Echinococcus multilocularis* (Luong et al. 2020; Sugden et al. 2020), a tapeworm that can cause potentially lethal alveolar echinococcosis in humans who accidentally ingest microscopic eggs deposited in the scat of infected coyotes (Houston et al. 2021). Infection likelihood may increase where attractants encourage aggregation of animals near picnic tables and children's play areas at the edge of fenceless properties as we sometimes observed.

We found several relationships among attractant abundance and the number and nature of reports detailing observations of coyotes from community members. Together, they suggested that various attractants combined with the absence of intact fences increased coyote presence (i.e., total reports) in residential areas and backyards (i.e., reports in backyards), as well as bold or aggressive coyote behaviour (i.e., conflict reports). That shelter abundance predicted the number of conflict reports could reflect coyotes denning under anthropogenic shelters (Way 2009), which would likely increase rates of human-coyote conflict (Farr et al. 2023; Raymond and St Clair 2023). Although reports characterised by negative perceptions of coyotes were increased by several attractants and reduced by intact fences, the models performed poorly, suggesting that predictors of negative sentiments towards coyotes were inconsistent and unpredictable among variables we tested. This observation could reflect that attitudes towards urban coyotes vary widely and may not be related to the rate of incidents with coyotes (Elliot et al. 2016), but rather human mood, media consumption, or past experiences (Hudenko 2012). Lastly, the positive influence of shelter on reports of unhealthy coyotes is consistent with the finding that diseased coyotes were 5 times more likely to use areas with bed sites under buildings or decks (Murray and St. Clair 2017).

This study had several limitations. The metric we used to assess coyote access to backyards (i.e., tracks in snow) represented a single point in time, and may have been affected by temperature, snowfall, and solar insolation. Similarly, scat presence on the landscape can change; scats can be covered by snowfall, revealed by melting snow, and decayed or deteriorated by weather and time. That we conducted research during a short period of time with little snowfall and consistent weather conditions likely reduced the impacts of these effects. Coyote scats, tracks, and especially damage to novel objects can all be confused with sign created by coyote-sized domestic dogs; we limited this source of error by having the surveyor trained and certified in wildlife track and sign identification and by using multiple metrics of coyote presence. We did not enumerate certain attractants that

are relevant to coyotes, including fruit trees (Murray et al. 2015; Murray and St. Clair 2017) and hiding cover in or adjacent to backyards (Murray and St. Clair 2017; Raymond and St Clair 2023). The short time window during which the study was conducted may have affected results due to seasonal changes in coyote and human behaviour and environmental conditions. Coyote diet changes to accommodate seasonally available foods (Morey et al. 2007), reliance on anthropogenic shelters increases in winter months (Murray and St. Clair 2017), and coyotes are more defensive during the pup-rearing period (Raymond and St Clair 2023). In the winter, snow may have obscured attractants, less yard work occurred, and rates of intentional wildlife feeding may have been lower. Also, the use of a voluntary and community-sourced reporting database may be biased to some neighbourhoods or socioeconomic demographics, the objectivity of reports may be diminished by human factors (Hudenko 2012), and there was a large temporal separation between when reports were submitted (2010 to 2020) and when we quantified attractants. We attempted to reduce this bias in the analysis that limited reports to one per individual per year and by testing for consistency in patterns of reporting among years. Several of the patterns we observed exhibited moderate effects sizes with small sample sizes that did not reach statistical significance, but the consistent directionality of these effects suggests biological relevance (Nakagawa and Cuthill 2007).

Despite some limitations, this study revealed that the area between urban natural areas and adjacent residential properties forms an important ecotone with abundant evidence of attraction by coyotes and other wildlife. This attraction may be an important, but under-appreciated source of habituation by wildlife that also increases opportunities for food conditioning, which is widely associated with human-wildlife conflict (Herrero 1985; McNay 2002; Hopkins et al. 2010; Murray et al. 2015; Morales-Gonzalez et al. 2020). Our results suggest a variety of ways that this ecotone could be managed proactively to prevent conflict. These include education about the need to remove attractants, including birdseed on the ground; bylaw enforcement to prevent intentional wildlife feeding and dumping of compost on public land; and policy changes to require fences where residences back on natural areas. Other authors have appreciated the importance of managing similar ecotones adjacent to human development for preventing human-wildlife conflict in Africa (Siljander et al. 2020; Mwampeta et al. 2021) and Asia (Gurung et al. 2008; Karanth et al. 2012, 2013), but this topic appears to have received little attention in the context of human-wildlife conflict in urban areas. Contrasting traditional literature on reserve design that recommends gradual transition zones to buffer the effects of human activity on wildlife (Shafer 1994, 1999; Hawkes et al. 1997; Williams et al. 2005), we suggest that a clear boundary separating

human-dominated areas from urban natural areas could reduce the detrimental effects of human encroachment and prevent conditioning of wildlife to human presence, especially among species that are susceptible to habituation, food conditioning, and human-wildlife conflict.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s11252-023-01402-3>.

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**Author contributions** Both authors contributed to the study conception, design, and data collection. Material preparation, analysis, and development of the first draft were performed by Sage Raymond. Colleen Cassidy St. Clair commented on previous versions of the manuscript, and both authors read and approved the final manuscript.

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**Data availability** Data are available upon request.

**Code availability** The code developed to conduct analyses and create figures can be found at the following repository link: <https://github.com/sageraymond/CoyoteEcotones>

## Declarations

**Ethics approval** N/A.

**Consent to participate** N/A.

**Consent for publication** N/A.

**Conflicts of interest/competing interests** None.

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