



Research Article

# Predictable Features Attract Urban Coyotes to Residential Yards

MAUREEN H. MURRAY,<sup>1,2</sup> *University of Alberta, Department of Biological Sciences, 11455 Saskatchewan Drive, Edmonton, AB T6G 2E9, Canada*

COLLEEN CASSADY ST. CLAIR, *University of Alberta, Department of Biological Sciences, 11455 Saskatchewan Drive, Edmonton, AB T6G 2E9, Canada*

**ABSTRACT** Several species of urban-adapted carnivores, including coyotes (*Canis latrans*), use anthropogenic resources in residential areas, which may increase rates of encounters and conflict with people. These negative interactions might be reduced with more understanding of individual variation in the use of residential areas and if attractants were better predicted by residents and targeted for securement or removal. We fitted 19 urban coyotes with global positioning system (GPS) collars (11 healthy, 8 with sarcoptic mange [*Sarcoptes scabiei*]) and compared their selection for residential areas at different times of day. We also identified 173 clusters of GPS locations (representing foraging and bedding sites) and paired them with available sites to measure selection for anthropogenic food, shelter, and visual cover. Seventeen of 19 coyotes avoided residential areas in general, but lesser avoidance of residential areas occurred in animals that used these areas during the day. Backyards selected by coyotes were 66.7 times less likely to have fences, 22.2 times more likely to contain anthropogenic food, and had 3.3 times as much visual cover than available yards. Diseased coyotes were 9 times more likely than healthy animals to select for yards with anthropogenic food. Our results suggest that coarse measurements of habitat selection via land cover classes may underestimate the attraction to wildlife of particular features in residential areas. Greater management of these features by municipal governments, residents, and communities might reduce animal use, disease transmission, and human-wildlife conflict for diverse species in urban areas. © 2017 The Wildlife Society.

**KEY WORDS** Alberta, *Canis latrans*, habitat selection, human-wildlife conflict, residential areas, resource selection, urban wildlife, wildlife disease.

Wildlife persisting in urban areas often exploit anthropogenic resources for food and shelter. Such resources often occur in residential areas where encounters with people, and thus conflict, are most likely. Carnivores in human-dominated landscapes often adjust their habitat selection in space or time (Boitani 1982, Ciucci et al. 1997) to make use of resources, including human infrastructure or food, while avoiding interactions with people. However, this tendency is highly variable among species (Bateman and Fleming 2012) and individuals (Knopff et al. 2014). Encounters with people and subsequent management action were more likely for brown bears (*Ursus arctos*) that became highly habituated to human infrastructure, such as buildings (Rauer et al. 2003, Elfström et al. 2014), which can also be used as den sites by stone marten (*Martes foina*; Herr et al. 2010) and a variety of urban carnivores (Bateman and Fleming 2012, Lowry et al. 2012). Many carnivore species can also make use of anthropogenic food (Contesse et al.

2004, Newsome et al. 2010), and the development of food-conditioned animals who associate people with food usually results in conflict (Herrero 1985, McCarthy and Seavoy 1994).

These conflicts can lead to lethal removal, especially for carnivores that are capable of threatening the security of people and domestic animals. However, such responses to conflict are time consuming, expensive, and are losing public support (Reiter et al. 1999, Dubois and Harshaw 2013). Therefore, wildlife managers require accurate information to predict resource use by carnivores in urban habitats, specifically residential areas, to reduce human-wildlife conflicts. Although the results of habituation and food-conditioning are well-known, there is less understanding of the causes of variation among individuals in their initial propensity to approach people or their infrastructure. One potential factor is individual health, whereby carnivores might be more willing to tolerate human activity to forage or den near houses if they are in poor physical condition.

There are several cases in the literature of injured (e.g., lions [*Panthera leo*]; Yeakel et al. 2009), nutritionally stressed (e.g., polar bears [*Ursus maritimus*]; Towns et al. 2009) or diseased (e.g., lynx [*Lynx lynx*]; Ryser et al. 2002) carnivores approaching people and their houses for food. This trend has led some authors to suggest that poor physical condition

Received: 20 July 2016; Accepted: 2 December 2016

<sup>1</sup>E-mail: mhmurray@uga.edu

<sup>2</sup>Present Address: University of Georgia, Warnell School of Forestry and Natural Resources, 180 E Green Street, Athens, GA 30601, USA.

promotes human-carnivore conflict (Linnell et al. 1999). Greater acceptance of risk with energetic need is well studied in laboratory (Godin and Sproul 1988, Pettersson and Bronmark 1993) and free-living animals (Beale and Monaghan 2004). This relationship between individual condition and avoidance of risk may in part explain why some carnivores are more likely to encounter people. This hypothesis may also explain why some species exhibit a high degree of individual variation in their use of human resources, including urban chacma baboons (*Papio ursinus*; Beamish and O’Riain 2014) and coyotes (*Canis latrans*; Gehrt et al. 2009, Murray et al. 2015b).

The coyote is an opportunistic canid that is thriving in cities across North America (Gehrt and Riley 2010). Although coyote attacks on people are rare, coyote sightings are increasing in many urban areas (White and Gehrt 2009, Lukasik and Alexander 2011), and often elicit concern from the public, especially when coyotes inhabit residential areas. Coyotes typically avoid human activity by primarily using urban natural areas (Gehrt and Riley 2010, Gese et al. 2012) and shifting to more nocturnal activity cycles relative to rural coyotes (Tigas et al. 2002, Riley et al. 2003). Although coyotes typically avoid developed areas, they consume human food (Fedriani et al. 2001, Morey et al. 2007, Murray et al. 2015a), which can account for up to 30% of their diets in urban environments (Gehrt and Riley 2010). Thus, some coyotes may select for specific residential yards to access anthropogenic food but may preferentially do so at night and in areas with cover to minimize their risk of encountering people. Little is known, however, about coyote selection for residential areas and the fine-scale habitat features that promote coyote use of individual yards.

Despite a general tendency for coyotes to avoid people, substantial variation exists among individuals in diet and habitat use. For example, coyote home ranges can contain almost exclusively natural areas or residential and commercial areas (Gese et al. 2012, Murray et al. 2015b) and coyote consumption of prey can vary significantly across individuals (Murray et al. 2015b). Others have reported that these differences can result from social status or sex; transient coyotes are more likely to use suboptimal habitat (Kamler and Gipson 2000) and males are more likely to depredate sheep (Blejwas et al. 2006). Important behavioral differences may also result from coyote health.

Our previous work suggests that coyotes reported as nuisance animals by the public are more likely to have signs of sarcoptic mange (*Sarcoptes scabiei*; Murray et al. 2015a) and coyotes with mange are more likely to use developed urban areas and consume anthropogenic food (Murray et al. 2015b). These changes could be promoted by the physiological costs of mange infection. In infected animals, *Sarcoptes* mites burrow in the skin and cause hair loss, thereby compromising thermoregulation and increasing energy demands (Cross et al. 2016). Alternatively, these changes in behavior could also increase the likelihood of mange infestation if using developed areas increases coyote exposure to parasites or if consuming anthropogenic food increases host susceptibility, for instance by exposing coyotes

to immunosuppressive contaminants (Murray et al. 2016). Regardless of cause, the increased energy demands of infected coyotes may promote their use of residential areas during the day to access anthropogenic food and shelter during warmer temperatures.

In this study, we tested the hypothesis that coyotes select for habitat within residential areas that provides access to anthropogenic resources while minimizing risk of encountering people, and that this trade-off is mediated by individual condition. Under this overarching hypothesis, we had 3 related goals to better understand selection of residential areas by coyotes to inform conflict mitigation. First, we tested whether coyotes avoid residential areas within their home ranges and if they are more likely to avoid residential areas during the day relative to night. Second, we sought to quantify habitat selection in residential yards and test whether coyotes select yards with greater accessibility, greater visual cover, and anthropogenic resources (e.g., accessible garbage, compost, fruit, bird seed) than other available yards. Last, we tested whether coyotes with mange were less likely than healthy coyotes to avoid residential areas, especially during the day, and more likely to select for foraging or bed sites in yards with anthropogenic food and less cover. We predicted that within their home ranges, coyotes would avoid residential areas, especially during the day, but when using residential areas would select for feeding or resting sites that provided accessible anthropogenic food, shelter, and visual cover. We further predicted that diseased animals would make more use of residential areas, especially during the day, and would target anthropogenic resources more often.

## STUDY AREA

We studied coyote habitat selection in the city of Edmonton, Alberta, Canada (53.5472°N, 113.5006°W, elevation = 645 m). The frequency of reports of coyote sightings in Edmonton has increased in recent decades (R. Cox, City of Edmonton, personal communication) and are now reported multiple times per day throughout the year (M. H. Murray, University of Alberta, unpublished data). As a northern city, Edmonton has warm summers (Jun–Aug;  $\bar{x}$  temperature = 17.5°C) and cold winters (Dec–Mar;  $-11.7^\circ\text{C}$ ) and occurs in a transition zone between the prairie grasslands of southern Alberta and the boreal forest. Although relatively large in both human population ( $N=812,2012$  in 2011 census) and area (684.4 km<sup>2</sup>), Edmonton is bisected by the North Saskatchewan River valley, which is connected to several large ravines, providing the largest area of continuous urban park land in North America (City of Edmonton 2013). These natural areas provide habitat for coyotes and several prey species including showshoe hare (*Lepus americanus*), white-tailed jackrabbits (*Lepus townsendii*), white-tailed deer (*Odocoileus virginianus*), beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), and various small mammals. Natural areas comprise 7% of Edmonton’s total area, with the other 93% comprised of residential (52%), commercial (31%), institutional (e.g., schools and government, 14%), and industrial (3%) land uses.

## METHODS

### Capture and Collaring

We captured coyotes from 2009 to 2012 in areas within city limits on private property where coyote sightings had been reported and dogs were prohibited to prevent bycatch, including university property, golf courses, and forested yards (Murray et al. 2015*b*). We trapped coyotes using 4-coil padded foot-hold traps (No. 3 Victor Soft Catch Coilspring; Animal Trap, Lilitz, PA, USA). We physically restrained captured coyotes using catch poles and did not use chemical immobilization. Restrained coyotes were sexed, aged as either subadults (<1 yr old) or adults ( $\geq 1$  yr old) using degree of tooth wear (Bowen 1982), weighed, and tagged. All animal handling was in accordance with the guidelines of the University of Alberta Animal Care and Use Committee and Canadian Council on Animal Care (Protocol no. 689905). We also noted any signs of sarcoptic mange infestation including visible hair loss, skin thickening, and lesions consistent with sarcoptic mange (Samuel et al. 2001). We considered coyotes presenting signs to be diseased and coyotes with no evidence of sarcoptic mange or any other ailment to be healthy. We did not collar 1 coyote with severe hair loss. A full description of signs and evidence of sarcoptic mange, including confirmation of mange from coyote necropsies, is available from Murray et al. (2015*b*). We programmed the global positioning system (GPS) collars to collect fixes every 3 hours and most coyotes were fitted with collars that transmitted coyote locations to us daily over the cell phone network (Lotek Wildcell SG, 17 coyotes) or could be downloaded remotely (Lotek 4400S, 2 coyotes).

### Habitat Selection Within the Home Range

To test for differences in coyote avoidance of residential areas with time of day and with coyote health, we measured selection for land use types by coyotes using landcover data provided by the City of Edmonton (City of Edmonton 2016; spatial resolution = 10 m). We condensed 7 landcover types defined by the city into 4 land use categories that differed in vegetation, human infrastructure, and likelihood of negative encounters. We grouped parks and natural areas as habitat with little to no human infrastructure and relatively natural vegetation (natural; housing density = 0 units/km<sup>2</sup>, road density range = 0–1.6 km/km<sup>2</sup>; City of Edmonton 2016). We grouped residential areas and schoolyards as areas with high human use and potential for conflict (residential; building density range = 9–67 dwelling units/ha, road density range = 1.4–6.9 km/km<sup>2</sup>). We grouped commercial areas with industrial parks as areas with relatively high densities of human infrastructure and little vegetation (industrial; building density = 0.54–4.41 units/km<sup>2</sup>, road density = 2.6–11.3 km/km<sup>2</sup>). We classified undesignated land that typically was comprised by mowed grass or impervious surfaces as open areas (open; building density = 0, road density = 2.9–5.9 km/km<sup>2</sup>).

We estimated habitat selection by coyotes within their home ranges (third-order habitat selection; Johnson 1980) by comparing the land use categories at coyote GPS locations (i.e., used locations) and at an equal number of randomly

generated locations within individual home ranges, which we considered available to coyotes. We estimated coyote home ranges by generating core area (50%) and home range (95%) kernel density utilization distributions using a plug-in bandwidth estimator in Geospatial Modeling Environment (Beyer 2012). We then calculated selection ratios for land use type (used in category/*available in category*; Manly et al. 2002) for each individual coyote with a value of 1 indicating no selection. Using these selection ratios, we used means tests to determine whether avoidance of residential areas differed for coyotes of different age, sex, or health classes.

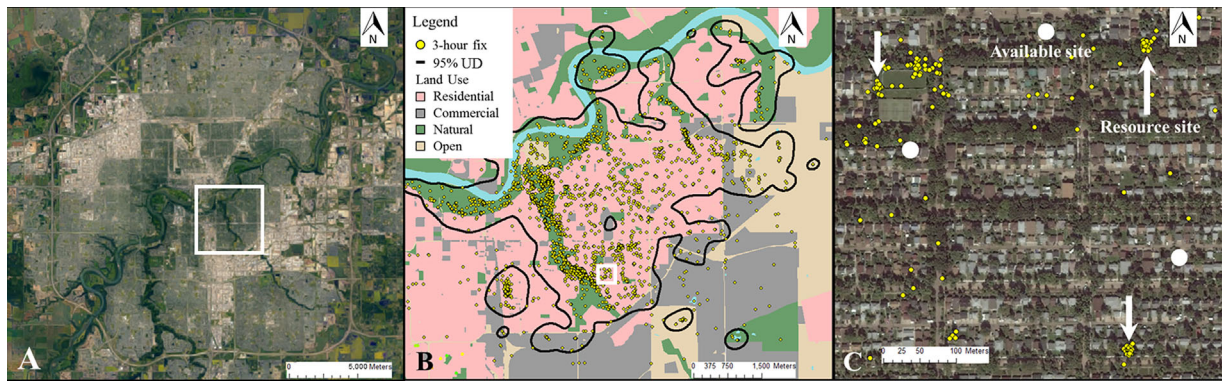
We also tested whether coyotes preferentially avoided residential areas during the day when human activity is often higher. We compared the selection ratios of individual coyotes for residential areas during the day (1 hr after sunrise to 1 hr before sunset) and at night (1 hr after sunset to 1 hr before sunrise) by calculating the ratio of these 2 values (selection ratio for residential areas during the day/selection ratio at night). Using this day/night ratio, we used means tests to determine whether coyotes of different age, sex, and health classes significantly differed in their avoidance of residential areas during the day relative to night ( $\alpha = 0.05$ ). We also tested whether diseased coyotes used residential areas more frequently, and especially during the day, using linear regression.

### Selection for Resources Within the Home Range

Because we were especially interested in the fine-scale selection for anthropogenic resources by coyotes, we identified areas used for prolonged periods or visited multiple times at clusters of GPS locations that were presumably used for feeding or resting (resource sites; comparable to the fourth-order habitat selection for feeding sites; Johnson 1980). We defined a resource site as an area in which a coyote had spent at least 18 hours and delineated a circular area with a diameter of 20 m around the center of the cluster of locations (Fig. 1). We identified these sites by calculating point density in a 20-m moving window in a geographic information system (ArcMap 10.0, ESRI, Redlands, CA, USA) with a threshold of 0.022 locations/m<sup>2</sup>.

To record the presence of resources that we could not measure remotely (e.g., food attractants, use of shelter), we measured habitat variables in the field at a subset of resource sites (i.e., ground-truthing). We identified resource sites to visit by remotely downloading data from all collars each week and selecting sites that were most recently used but where the coyote was not currently active. We confirmed the previous use by a coyote at these sites using tracks in the mud or snow or the presence of scat, hair tufts, or bedding depressions. We measured variables relating to proximity to human activity or infrastructure, presence of natural or anthropogenic food attractants, and availability of cover (Table 1). Because we used GPS collars that transmitted locations remotely, we were able to visit most resource sites (72%) within 1 week of use and we used only these sites when recording the presence of attractants.

To measure selection, we compared each used resource site with a paired available site at a random bearing and a random



**Figure 1.** We measured habitat selection by coyotes in the city of Edmonton, Alberta, Canada (A) within the home range (B) and at resource sites likely used for foraging and bedding by coyotes (C), 2009–2012. The white square in panel A demarcates the boundaries of panel B, which contains a 95% utilization distribution (UD) from an example coyote that used residential, commercial, natural, and open land use types. The white square in panel B demarcates the boundaries of Panel C, which contains a portion of this coyote’s home range to show clusters of coyote locations we defined as sites used for feeding or resting (white arrows, resource sites), which we compared to paired randomly generated available sites (white circles, available sites) to quantify selection for resources and habitat features.

distance between 100–200 m ( $\bar{x}$  distance traveled by collared coyotes in 1 hr = 162 m). We then used conditional logistic regression to model the probability that a resource site was used or available as a function of covariates relating to habitat (Table 1) and individual state (age, sex, and health status; Therneau 2014). Because we were interested in trade-offs related to human resources and encounters, and to make our results more interpretable for management recommendations, we separated resource sites into those in backyards in residential areas (i.e., sites where coyotes would likely come in conflict with people and where residents could reduce the attractiveness of their yard) and those outside of residential areas in natural or grassy undesignated areas (i.e., sites where managers could anticipate coyote presence and use signage, attractant removal, or prohibit off-leash dogs to mitigate coyote encounters with dogs and people; Fig. 1).

We evaluated the influence of these covariates relating to habitat characteristics or individual state using mixed effects

**Table 1.** Habitat variables measured in the field at resource sites (i.e., clusters of locations) visited by coyotes and at paired randomly generated available sites in Edmonton, Alberta, Canada, 2009–2012.

Covariate type	Covariate	Description
Habitat	Dominant vegetation	Vegetation class covering $\geq 50\%$ of 20-m area
	Canopy cover	% of densitometer covered
	Horizontal cover	% of checkerboard covered in each cardinal direction
Attractants	Anthropogenic food	Garbage, compost, bird seed (0/1)
	Fruit	Crabapples or berries on ground (0/1)
	Prey	Prey presence, tracks, or scat (0/1)
Human activity	Land use type	Residential, industrial, natural, open
	Roads	Distance to nearest road (m)
	Buildings	Distance to nearest building (m)
	Trails	Distance to nearest trail (m)
	Under building	Visible bed site under building (0/1)

models in R (Pinheiro et al. 2012). We compared models of all combinations of fixed effects. We used Akaike’s Information Criterion corrected for small sample sizes ( $AIC_c$ ; Bolker et al. 2009) to average the best models (i.e., those within 2  $AIC_c$  points of the model with the highest  $AIC_c$  weight) using the MuMIn package (Bartoń 2013). We accounted for non-independence between resource sites used by the same coyote by including coyote identification code as a random effect. Variables that were highly correlated ( $|r| \geq 0.6$ ) did not appear in the same model.

## RESULTS

From 2009 to 2012, we captured and collared 19 coyotes. These included 11 that appeared to be healthy (5 adult F, 2 subadult F, 2 adult M, and 2 subadult M) and 8 diseased coyotes with signs of sarcoptic mange (4 adult F, 1 subadult F, 2 adult M, and 1 subadult M). We collared most coyotes (15 of 19) during coyote dispersal season (Sep–Dec) and monitored them for an average of 4 months (range = 1–10 months), resulting in on average 618 3-hour GPS locations/coyote (range = 161–1,867 fixes). There was a high degree of variation in home range sizes, which ranged from 1.4–109.0 km<sup>2</sup> but were stable over time, and no coyotes overlapped in both space and time (Table 2; Murray et al. 2015b). We were able to ground-truth 173 used and 173 available resource sites (sites/coyote:  $\bar{x} = 23 \pm 9$  SD, range = 15–49). Of these 173 sites, 106 were in natural areas, 46 were in residential areas, 33 were in open areas, and 2 were in industrial areas. Coyotes revisited the same resource sites up to 5 months later and were slightly more likely to revisit sites in residential than in natural areas (no. days during which a site was used =  $6.2 \pm 3.4$  [residential],  $4.5 \pm 3.8$  [natural]).

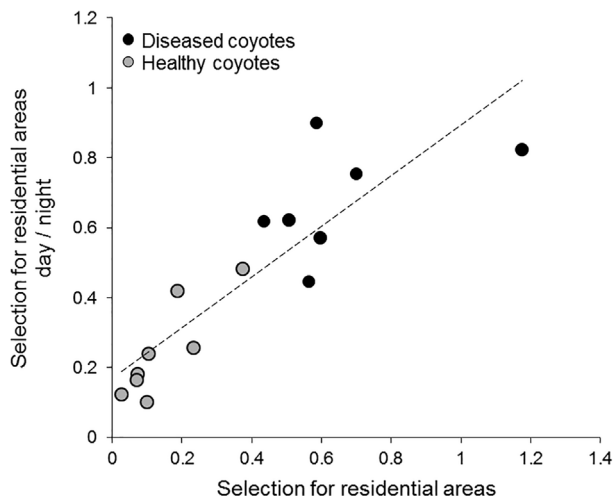
All but 2 coyotes avoided residential areas within their home ranges ( $\bar{x}$  selection ratio =  $0.38 \pm 0.38$ ), but healthy coyotes were  $>4$  times more likely to avoid residential areas ( $0.12 \pm 0.11$ ) than diseased coyotes ( $0.55 \pm 0.21$ ;  $t_2 = 1.91$ ,  $P = 0.031$ ; Fig. 2). There were no significant differences in selection between coyotes of different age or sex classes

**Table 2.** Summary of coyote age, sex, and health status with their accompanying home range areas (95% utilization distribution [UD]) and core areas (50% UD) in km<sup>2</sup> in Edmonton, Alberta, Canada, 2009–2012.

Coyote identification	Age	Sex	Mange status	50% UD	95% UD
2	Adult	F	Yes	3.2	25.6
3	Adult	M	Yes	5.9	34.5
5	Adult	F	Yes	0.6	14.0
9	Subadult	M	Yes	12.6	109.0
11	Adult	F	No	2.8	5.0
12	Subadult	F	No	0.6	3.7
13	Adult	F	Yes	3.3	40.5
15	Adult	F	No	0.4	4.1
16	Adult	F	Yes	2.5	17.2
17	Adult	F	No	0.5	5.5
18	Adult	M	No	0.9	8.0
19	Adult	M	Yes	4.1	36.4
20	Subadult	M	No	0.3	2.1
21	Adult	F	No	0.3	2.2
23	Adult	F	No	0.7	6.1
26	Adult	F	Yes	2.8	18.1
27	Adult	F	Yes	0.4	4.2
28	Subadult	M	No	2.9	5.6
29	Subadult	F	No	0.2	1.4

( $t_2 \leq 0.091$ ,  $P \geq 0.49$ ). Coyotes that exhibited more selection for residential areas within their home ranges were also more likely to select for resource sites in residential areas ( $r^2 = 0.77$ ,  $F_{17,1} = 58.78$ ,  $P < 0.001$ ).

Of the 14 coyotes for which we had adequate GPS data in residential areas, all coyotes avoided residential areas more during the day than at night ( $\bar{x}$  selection ratio during the day/at night =  $0.52 \pm 0.30$ ). However, coyotes that used residential areas more frequently also did so more often during the day ( $r^2 = 0.76$ ,  $F_{1,13} = 41.16$ ,  $P < 0.001$ ; Fig. 2).



**Figure 2.** Individual variation in avoidance of residential areas in time and space across urban coyotes in Edmonton, Alberta, Canada, 2009–2012. We measured the selection for residential areas using selection ratios and regressed these values against the ratio of using residential areas during the day and at night. The dashed line indicates the best-fitting linear regression line ( $r^2 = 0.76$ ). Coyotes that showed less avoidance of residential areas were also more likely to use residential areas during the day and these individuals were more likely to have sarcoptic mange (diseased).

Diseased coyotes exhibited less avoidance of residential areas during the day relative to at night ( $0.72 \pm 0.24$ ) compared to healthy coyotes ( $0.34 \pm 0.25$ ;  $t_{18} = 2.97$ ,  $P < 0.001$ ; Fig. 2). We found no such difference between coyotes of different age and sex classes ( $t_{18} \leq 0.87$ ,  $P \leq 0.42$ ).

Based on odds ratios, backyards selected by coyotes were 66.7 times less likely to have fences, were 22.2 times more likely to contain anthropogenic food, had 3.3 times as much visual cover, and were 1.3 times more likely to have fallen fruit than available yards (Table 3). Diseased coyotes used 73% of the resource sites in residential areas and were 9 times more likely to select for resource sites with accessible anthropogenic food than healthy coyotes (Table 3; Fig. 3a). Of the 46 resource sites revisited by coyotes that contained anthropogenic food, the most common attractants were ripped bags of garbage (25 sites), open compost piles (17 sites), and bird seed (7 sites). Diseased coyotes were also 5 times more likely to occupy resource sites with bed sites under houses or decks than healthy coyotes ( $\beta = 3.14 \pm 1.3$ ,  $Z_{38} = 2.39$ ,  $P = 0.017$ ; Fig. 3b). Of the 38 backyards we ground-truthed that contained bed sites under houses or decks, 82% were used by coyotes with mange in the winter months and 8 (21%) were used by  $>1$  collared coyote. Based on odds ratios, when outside of residential areas, coyotes selected for sites that were 3.3 times more likely to contain anthropogenic food and were 2.5 times more likely to have prey sign than available sites (Table 2).

## DISCUSSION

In this study, we tested whether coyotes select for habitat within residential areas that maximize their access to resources while minimizing risk of encountering people, and if this trade-off is mediated by parasite infection status. We also quantified selection for features of residential yards to support targeted attractant management and habitat modification by managers and the public. We found that the coyotes in our sample generally avoided residential areas within their home ranges, but diseased coyotes used residential areas more frequently, especially during the day, relative to the coyotes that appeared to be healthy at the time of capture. Coyotes selected for feeding and resting sites in backyards without fences, with higher cover, and selected for sites with anthropogenic food inside and outside of residential areas. Diseased coyotes were more likely than healthy coyotes to select for backyards with anthropogenic food and bed sites under houses.

Similarly to carnivores in other human-dominated landscapes (Ciucci et al. 1997, Whittington et al. 2005, Kaczensky et al. 2006), most coyotes in our sample avoided residential areas within their home ranges and especially during the day. Although almost all coyotes avoided residential areas at the home range scale, they still selected for areas within their home ranges that contained accessible anthropogenic food. This difference in selection across spatial scales suggests that coyotes make selective use of particular anthropogenic resources while spending most of their time in natural areas where the probability of encountering people is presumably lower. Anthropogenic

**Table 3.** Model-averaged parameter estimates for coyote habitat selection at the site level in backyards or in natural and undesigned habitat in Edmonton, Alberta, Canada, 2009–2012.

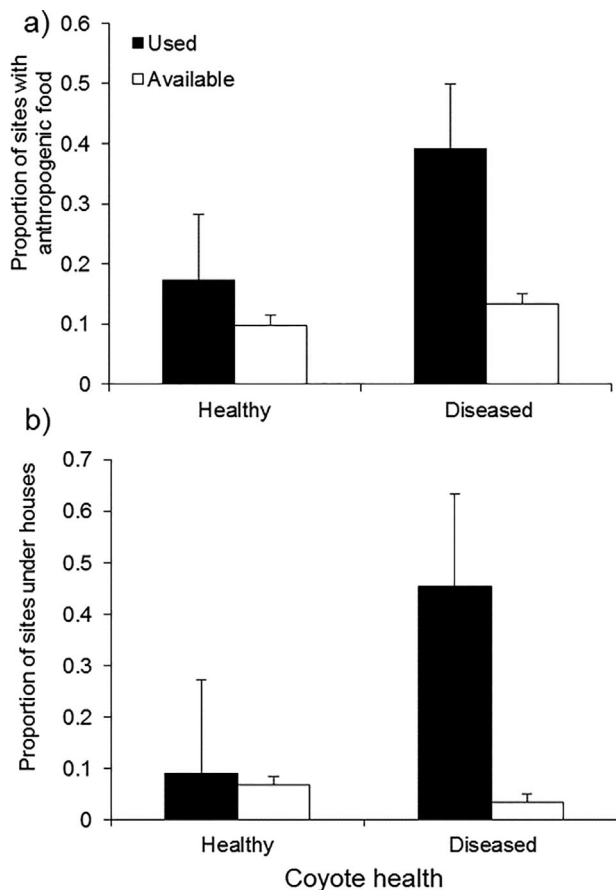
Land use type	Covariate	$\beta$	SE	P	Odds ratio	Odds ratio 95% CI
Residential yard	Intercept	-2.87	0.3	<0.01		
	Fence	-4.20	3.8	0.03	66.7	17.6–132.8
	Anthropogenic food	3.11	1.1	0.02	22.2	16.3–32.1
	Disease	2.18	0.9	<0.01	9.0	4.1–13.9
	Horizontal cover	1.23	0.3	<0.01	3.3	1.6–5.9
	Fruit	0.31	0.5	0.24	1.4	0.6–4.5
	Disease $\times$ anthropogenic food	3.10	1.2	<0.01	22.2	13.7–28.7
Natural or open	Intercept	2.79	0.2	<0.01		
	Anthropogenic food	1.24	0.4	<0.01	3.3	1.4–6.2
	Prey sign	0.92	0.4	0.05	2.5	1.1–5.4
	Slope	-0.61	0.1	0.01	1.8	1.4–2.2
	Distance to trail	0.05	0.06	0.07	1.0	0.3–3.0
	Distance to building	-0.06	0.03	0.05	1.1	1.0–2.99
	Horizontal cover	0.03	0.04	0.46	1.0	0.2–3.1

food tends to be more reliable in space and time than more natural food sources (Oro et al. 2013) and so the locations of accessible anthropogenic food may be easier to learn, either from parents (Mazur and Seher 2008) or from ongoing experience (Nielsen et al. 2013). Five coyotes in our sample

visited the same backyards with anthropogenic food  $\geq 4$  times over several months, suggesting that coyotes may learn to associate specific backyards with food. This association may be particularly problematic for human-wildlife conflict as it changes the neutral perception of people by habituated wildlife to a positive association between humans and food (McCarthy and Seavoy 1994).

Revisiting backyards with anthropogenic food during the day was especially prevalent among coyotes with mange, suggesting that animals in poorer physical condition may be more likely to risk encountering people to access resources. In this way, our results also support the more general hypothesis that human-wildlife conflict may be disproportionately caused by animals in poor condition (Linnell et al. 1999). Diseased coyotes may be more likely to seek out anthropogenic food because it is often reliable in space and time and thus may have lower search and handling costs than hunting prey (Rodewald et al. 2011). Diseased coyotes were also especially likely to select for sites containing compost piles, either in backyards or industrial piles of animal feed. Although we treated mange status as an independent variable in our analysis that may affect habitat and resource selection by coyotes, poor health may be a result of these behaviors. For example, coyotes that use developed areas can be exposed to toxins in the form of rodenticides (Poessel et al. 2015) and in backyard compost contaminated with fungal mycotoxins (Murray et al. 2016). Thus, using residential areas could be in response to, and a promoter of, disease in urban coyotes. This phenomenon, wherein supplemental food sources can increase the likelihood of parasite and pathogen transmission, is applicable to many contexts of wildlife baiting and provisioning (Becker et al. 2015).

Diseased coyotes were also more likely to seek out anthropogenic shelter than healthy coyotes. Although many urban-adapted mammals use houses as bedding and den sites (e.g., raccoons [*Procyon lotor*], Gross et al. 2011; brushtail possums [*Trichosurus vulpecula*], Statham and Statham 1997; and stone martens, Herr et al. 2010), we found that the use of shelter under buildings was dependent on coyote condition. Coyotes with mange were much more likely to bed under houses than healthy coyotes, perhaps to



**Figure 3.** Selection by coyotes for resource sites with accessible anthropogenic food (a) and shelter (b) for diseased and healthy coyotes in Edmonton, Alberta, Canada, 2009–2012. Used resource sites (black;  $n = 173$ ) were more likely to contain accessible anthropogenic food (e.g., garbage cans, compost piles, spilled bird seed) than randomly generated available sites (white;  $n = 173$ ). Coyotes with signs of sarcoptic mange (diseased;  $n = 8$ ) were more likely to select for yards containing accessible anthropogenic food and bed sites under houses than apparently healthy coyotes ( $n = 11$ ). Error bars show standard deviation.

avoid the energetic costs of low temperatures because they suffered from poor coat quality and potentially compromised thermoregulation. Shelter under buildings appeared to be especially important in winter for coyotes in Edmonton, as it is for fox squirrels (*Sciurus niger*; McCleery et al. 2007). For example, 1 coyote in our sample with mange was found dead under a dryer vent in  $-20^{\circ}\text{C}$  temperatures. Coyotes and other wildlife that bed in, under, or around houses may be more likely to have negative encounters with residents. They may also promote the spread of zoonotic disease to humans (e.g., raccoon roundworm [*Baylisascaris procyonis*]; Page et al. 2008) and conspecifics. Several of the bed sites we visited that were under houses were used by  $\geq 2$  different coyotes in the same month, potentially promoting the spread of mange mites between coyotes if fallen mites are still viable (Arlian et al. 1989).

Although the patterns we have observed in coyote habitat selection have interesting implications for ecology and management, several caveats must be taken into consideration when interpreting our results. Our conclusions are drawn from a relatively small pool of animals that was female-biased. We were unable to make seasonal comparisons in habitat selection because of small sample size, the timing of coyote captures in fall (15 of 19 captured in fall), and the short duration of GPS data/coyote ( $< 1$  yr). Several of the variables we measured, such as the prevalence of fruit and the use of shelter under houses, might be strongly influenced by seasonal variation in resource availability and climate and this is an avenue for future research. Despite these issues, we were able to use a novel approach to quantify selection for several variables likely to promote encounters with coyotes that cannot be measured remotely and could be managed through habitat modification and attractant management, an approach likely to be useful in many contexts (Lewis et al. 2015).

## MANAGEMENT IMPLICATIONS

Our results suggest that urban coyotes avoid places and times at which they are likely to encounter humans. Despite this avoidance, many coyotes exhibited fine-scale selection for habitat containing anthropogenic food and shelter, but this tendency was greater for diseased animals when compared to healthy coyotes. To reduce the attraction of coyotes, residents should ensure that garbage is contained in sealed containers, bird feeders are not spilling seed on the ground, compost is kept in a covered container, yards are securely fenced, shrubs are thinned, and decks do not permit access to warm shelters. Although these solutions are already recommended by many cities, our results provide evidence for their importance. Managers should avoid practices that may inadvertently support moribund animals or promote pathogen transmission (e.g., piles of food waste that may promote reliance by animals in poor condition and aggregate foragers; Wright and Gompfer 2005, Murray et al. 2016). Following these simple steps may reduce encounters with people and carnivores in urban areas and other human-dominated landscapes around the world.

## ACKNOWLEDGMENTS

We thank B. Abercrombie, for trapping support. We also thank our field assistants and volunteers for their help with data collection. This work was supported by the Alberta Conservation Association; Alberta Innovates; the Alberta Sport, Recreation, Parks, and Wildlife Foundation; the Canadian Wildlife Foundation; the Natural Sciences and Engineering Research Council of Canada (Discovery Grant to C.C.St.C.); the Royal Alberta Museum; and the Vanier Canada Graduate Scholarships Program (M.M.).

## LITERATURE CITED

- Arlian, L. G., D. L. Vyszenski-Moher, and M. J. Pole. 1989. Survival of adults and development stages of *Sarcoptes scabiei* var. *canis* when off the host. *Experimental & Applied Acarology* 6:181–187.
- Bartoń, K. 2013. MuMIn: multi-model inference. R package version 1.10.0. <http://CRAN.R-project.org/package=MuMIn>. Accessed 21 Oct 2014.
- Bateman, P. W., and P. A. Fleming. 2012. Big city life: carnivores in urban environments. *Journal of Zoology* 287:1–23.
- Beale, C. M., and P. Monaghan. 2004. Behavioural responses to human disturbance: a matter of choice? *Animal Behaviour* 68:1065–1069.
- Beamish E. K., and M. J. O'Riain. 2014. The effects of permanent injury on the behavior and diet of commensal chacma baboons (*Papio ursinus*) in the Cape Peninsula, South Africa. *International Journal of Primatology* 35:1004–1020.
- Becker, D. J., D. G. Streiker, and S. Altizer. 2015. Linking anthropogenic resources to wildlife–pathogen dynamics: a review and meta-analysis. *Ecology Letters* 18:483–495.
- Beyer, H. L. 2012. Geospatial Modelling Environment (Version 0.7.2.0). <http://www.spatialecology.com/gme/>. Accessed 04 Sep 2014.
- Blejwas, K. M., C. L. Williams, G. T. Shin, D. R. McCullough, and M. M. Jaeger. 2006. Salivary DNA evidence convicts breeding male coyotes of killing sheep. *Journal of Wildlife Management* 70:1087–1093.
- Boitani, L. 1982. Wolf management in intensively used areas of Italy. Pages 158–172 in F. H. Harrington and P. C. Paquet, editors. *Wolves of the world*. Noyes Publishing Co., Park Ridge, New Jersey, USA.
- Bolker, B. M., M. E. Brooks, C. J. Clark, S. W. Geange, J. R. Poulsen, M. H. H. Stevens, M. H. H., and J. S. White. 2009. Generalized linear mixed models: a practical guide for ecology and evolution. *Trends in Ecology & Evolution* 24:127–135.
- Bowen, W. D. 1982. Determining age of coyotes, *Canis latrans*, by tooth sections and tooth-wear patterns. *Canadian Field Naturalist* 96:339–341.
- City of Edmonton. 2013. Edmonton, your gateway to scenic settings. Edmonton Economic Development Corporation. <http://edmonton.com/for-visitors/scenic-settings.aspx>. Accessed 25 Oct 2013.
- City of Edmonton. 2016. GeoEdmonton. [https://www.edmonton.ca/city\\_government/initiatives\\_innovation/geoedmonton.aspx](https://www.edmonton.ca/city_government/initiatives_innovation/geoedmonton.aspx). Accessed 15 Sep 2016.
- Ciucci, P., L. Boitani, F. Francisci, and G. Andreoli. 1997. Home range, activity and movements of a wolf pack in central Italy. *Journal of Zoology* 243:803–819.
- Contesse, P., D. Hegglin, S. Gloor, F. Bontadina, and P. Deplazes. 2004. The diet of urban foxes (*Vulpes vulpes*) and the availability of anthropogenic food in the city of Zurich, Switzerland. *Mammalian Biology* 69:81–95.
- Cross, P., E. Almberg, C. Haase, P. Hudson, S. Maloney, M. Metz, A. Munn, P. Nugent, O. Putzeys, D. Stahler, A. Stewart, and D. Smith. 2016. Energetic costs of mange in wolves estimated from infrared thermography. *Ecology* 97:1938–1948.
- Dubois, S., and H. W. Harshaw. 2013. Exploring “humane” dimensions of wildlife. *Human Dimensions of Wildlife* 18:1–19.
- Elfström, M., A. Zedrosser, O.-G. Støen, and J. E. Swenson. 2014. Ultimate and proximate mechanisms underlying the occurrence of bears close to human settlements: review and management implications. *Mammal Review* 44:5–18.
- Fedriani, J. M., T. K. Fuller, and R. M. Sauvajot. 2001. Does availability of anthropogenic food enhance densities of omnivorous mammals? An example with coyotes in southern California. *Ecography* 24:325–331.

- Gehrt, S. D., C. Anchor, and L. A. White. 2009. Home range and landscape use of coyotes in a metropolitan landscape: Conflict or coexistence? *Journal of Mammalogy* 90:1045–1057.
- Gehrt, S. D., and S. P. D. Riley. 2010. Coyotes (*Canis latrans*). Pages 79–95 in S. Gehrt, S. Riley, and B. Cypher, editors. *Urban carnivores: ecology, conflict, and conservation*. Johns Hopkins University Press, Baltimore, Maryland, USA.
- Gese, E. M., P. S. Morey, and S. D. Gehrt. 2012. Influence of the urban matrix on space use of coyotes in the Chicago metropolitan area. *Journal of Ethology* 30:413–425.
- Godin, J. G. J., and C. D. Sproul. 1988. Risk taking in parasitized sticklebacks under threat of predation: effects of energetic need and food availability. *Canadian Journal of Zoology* 66:2360–2367.
- Gross, J., F. Elvinger, L. L. Hungerford, and S. D. Gehrt. 2011. Raccoon use of the urban matrix in the Baltimore Metropolitan Area, Maryland. *Urban Ecosystems* 15:667–682.
- Herr, J., L. Schley, E. Engel, and T. J. Roper. 2010. Den preferences and denning behaviour in urban stone martens (*Martes foina*). *Mammalian Biology* 75:138–145.
- Herrero, S. 1985. *Bear attacks: their causes and avoidance*. Winchester Press, Piscataway, New Jersey, USA.
- Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. *Ecology* 6:65–71.
- Kaczensky, P., D. Huber, F. Knauer, H. Roth, A. Wagner, and J. Kusak. 2006. Activity patterns of brown bears (*Ursus arctos*) in Slovenia and Croatia. *Journal of Zoology* 269:474–485.
- Kamler, J. F., and P. S. Gipson. 2000. Space and habitat use by resident and transient coyotes. *Canadian Journal of Zoology* 78:2106–2111.
- Knopff, A. A., K. H. Knopff, M. S. Boyce, and C. C. St. Clair. 2014. Flexible habitat selection by cougars in response to anthropogenic development. *Biological Conservation* 178:136–145.
- Lewis, D., S. Baruch-Mordo, K. Wilson, S. Breck, J. Mao, and J. Broderick. 2015. Foraging ecology of black bears in urban environments: guidance for human-bear conflict mitigation. *Ecosphere* 6:1–18.
- Linnell, J. D. C., J. Odden, M. Smith, R. Aanes, and J. E. Swenson. 1999. Large carnivores that kill livestock: do “problem individuals” really exist? *Wildlife Society Bulletin* 27:698–705.
- Lowry, H., A. Lill, and B. B. M. Wong. 2012. Behavioural responses of wildlife to urban environments. *Biological reviews of the Cambridge Philosophical Society* 88:537–49.
- Lukasik, V., and S. Alexander. 2011. Human-coyote interactions in Calgary, Alberta. *Human Dimensions of Wildlife* 16:114–127.
- Manly, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. *Resource selection by animals: statistical design and analysis for field studies*. Kluwer Academic, Norwell, Massachusetts, USA.
- Mazur, R., and V. Seher. 2008. Socially learned foraging behaviour in wild black bears, *Ursus americanus*. *Animal Behaviour* 75:1503–1508.
- McCarthy, T. M., and R. J. Seavoy. 1994. Reducing nonspout losses attributable to food conditioning: human and bear behavior. *Bears: Their Biology and Management* 9:75–84.
- McCleery, R. A., R. R. Lopez, N. J. Silvy, and S. N. Kahlick. 2007. Habitat use of fox squirrels in an urban environment. *Journal of Wildlife Management* 71:1149–1157.
- Morey, P. S., E. M. Gese, and S. Gehrt. 2007. Spatial and temporal variation in the diet of coyotes in the Chicago Metropolitan Area. *American Midland Naturalist* 158:147–161.
- Murray, M. H., A. Cembrowski, A. D. M. Latham, V. M. Lukasik, S. Pruss, and C. C. St. Clair. 2015a. Greater consumption of protein-poor anthropogenic food by urban relative to rural coyotes increases diet breadth and potential for human-wildlife conflict. *Ecography* 38:1235–1242.
- Murray, M., M. A. Edwards, B. Abercrombie, and C. C. St. Clair. 2015b. Poor health is associated with use of anthropogenic resources in an urban carnivore. *Proceedings of the Royal Society B* 282:20150009.
- Murray, M. H., J. Hill, P. Whyte, and C. C. St. Clair. 2016. Urban compost attracts coyotes, contains toxins, and may promote disease in urban-adapted wildlife. *EcoHealth* 13:285–292.
- Newsome, S. D., K. Ralls, C. V. H. Job, M. L. Fogel, and B. L. Cypher. 2010. Stable isotopes evaluate exploitation of anthropogenic foods by the endangered San Joaquin kit fox (*Vulpes macrotis mutica*). *Journal of Mammalogy* 91:1313–1321.
- Nielsen, S. E., A. B. A. Shafer, M. S. Boyce, and G. B. Stenhouse. 2013. Does learning or instinct shape habitat selection? *PLoS ONE* 8:1–5.
- Oro, D., M. Genovart, G. Tavecchia, M. S. Fowler, and A. Martínez-Abraín. 2013. Ecological and evolutionary implications of food subsidies from humans. *Ecology Letters* 16:1501–1514.
- Page, L. K., S. D. Gehrt, and N. P. Robinson. 2008. Land-use effects on prevalence of raccoon roundworm (*Baylisascaris procyonis*). *Journal of Wildlife Diseases* 44:594–599.
- Pettersson, L. B., and C. Bronmark. 1993. Trading off safety against food: state dependent habitat choice and foraging in crucian carp. *Oecologia* 95:353–357.
- Pinheiro J., D. Bates, S. DebRoy, D. Sarkar, and R Development Core Team. 2012. nlme: linear and nonlinear mixed effects models. R package version 3.1-120. <http://CRAN.R-project.org/package=nlme>. Accessed 14 Jul 2015.
- Poessel, S. A., S. W. Breck, K. A. Fox, and E. M. Gese. 2015. Anticoagulant rodenticide exposure and toxicosis in coyotes in the Denver Metropolitan Area. *Journal of Wildlife Diseases* 51:265–268.
- Rauer, G., P. Kaczensky, and F. Knauer. 2003. Experiences with aversive conditioning of habituated brown bears in Austria and other European countries. *Ursus* 14:215–224.
- Reiter, D. K., M. W. Brunson, and R. H. Schmidt. 1999. Public attitudes towards wildlife damage management and policy. *Wildlife Society Bulletin* 27:746–758.
- Riley, S. P. D., R. M. Sauvajot, T. K. Fuller, E. C. York, D. A. Kamradt, C. Bromley, and R. K. Wayne. 2003. Effects of urbanization and habitat fragmentation on bobcats and coyotes in Southern California. *Conservation Biology* 17:566–576.
- Rodewald, A. D., L. J. Kearns, and D. P. Shustack. 2011. Anthropogenic resource subsidies decouple predator-prey relationships. *Ecological Applications* 21:936–43.
- Ryser, A., L. N. Bacciarini, C. Angst, B. Gottstein, M. Janovsky, and U. Breitenmoser. 2002. Notoedric and sarcoptic mange in free-ranging lynx from Switzerland. *Journal of Wildlife Diseases* 38:228–232.
- Samuel, W., M. J. Pybus, and A. A. Kocan. 2001. *Parasitic diseases of wild mammals*. Second edition. Iowa State University Press, Ames, USA.
- Statham, M., and H. L. Statham. 1997. Movements and habits of brushtail possums (*Trichosurus vulpecula*) in an urban area. *Wildlife Research* 24:715–726.
- Therneau, T. 2014. A package for survival analysis in R. <http://cran.r-project.org/package=survival>. Accessed 2 Aug 2014.
- Tigas, L. A., D. H. Van Vuren, and R. M. Sauvajot. 2002. Behavioral responses of bobcats and coyotes to habitat fragmentation and corridors in an urban environment. *Biological Conservation* 108:299–306.
- Towns, L., A. E. Derocher, I. Stirling, N. J. Lunn, and D. Hedman. 2009. Spatial and temporal patterns of problem polar bears in Churchill, Manitoba. *Polar Biology* 32:1529–1537.
- White, L. A., and S. D. Gehrt. 2009. Coyote attacks on humans in the United States and Canada. *Human Dimensions of Wildlife* 14:419–432.
- Whittington, J., C. C. St. Clair, and G. Mercer. 2005. Spatial responses of wolves to roads and trails in mountain valleys. *Ecological Applications* 15:543–553.
- Wright, A. N., and M. E. Gompper. 2005. Altered parasite assemblages in raccoons in response to manipulated resource availability. *Oecologia* 144:148–156.
- Yeakel, J. D., B. D. Patterson, K. Fox-Dobbs, M. M. Okumura, T. E. Cerling, J. W. Moore, P. L. Koch, and N. J. Dominy. 2009. Cooperation and individuality among man-eating lions. *Proceedings of the National Academy of Sciences* 106:19040–19043.

Associate Editor: Brent Patterson.