



# The relationship between landscape features and domestic species on the occupancy of native mammals in urban forests

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## Abstract

Landscape features such as roads, hiking trails, and forest edge are prevalent features of urban forests. These features can negatively influence biodiversity through fragmentation and facilitate the penetration of invasive species, particularly predators such as domestic dogs and cats. This study examined how these landscape features affect the distribution of native and domestic mammals and how domestic species affect the occupancy and activity patterns of native mammals. To this end, we conducted camera trap surveys in forested urban and suburban parks in Indiana and Kentucky, USA, to record the presence of native species (deer, raccoons, coyote, and opossums) and non-native predators (domesticated cats and dogs) in relation to distance to nearest roads, hiking trails, and forest edge. We found negative correlations between proximity to roads, hiking trails, and forest edge and the occupancy of the native species with this effect extending up to 300 m. We also found evidence that the presence of dog and cat was negatively correlated with the occupancy for all native species. We recommend park management consider the impact of roads, hiking trails, and forest edge when designing parks and the enforcement of dog leash regulations for the conservation of large mammals in urban parks.

**Keywords** Occupancy · Native species · Carnivores · Urban biodiversity · Domestic dogs and cats

## Introduction

Urban forests face many challenges to their ecological integrity because they are usually small, are surrounded by a matrix of urban development, and are isolated from other forests (Collinge 2009). In addition, an intrinsic characteristic of small forests is that their interior is often within the vicinity of forest edges, exposing the interior habitat and wildlife to a variety of threats (Murcia 1995). These threats include pollution of their watersheds, invasive species colonization, and the reduction of native bird and small mammal populations by non-native domestic predators such as cats (*Felis catus* L.) and dogs (*Canis familiaris* L.) (Pickett et al. 2001).

Roads and hiking trails are a prevalent feature of urban forests. Roads can negatively impact the biodiversity in urban forests through fragmentation and increased mortality as a

result of vehicle collisions (Cole et al. 1997; Fahrig 2003; Melbourne et al. 2004; Coffin 2007; Boston 2016). The noise and disturbance associated with the human activities while using roads and hiking trails put pressure on animals by increasing their energy expenditures and reducing their fecundity (Phillips and Alldredge 2000; Westekemper et al. 2018). Roads and hiking trails have also shown to affect the spatio-temporal habitat use of wildlife (Coppes et al. 2017; Scholten et al. 2018). For instance, some species change their behavior spatially (remaining far from roads and hiking trails) and temporally (being less active during the day time and weekend) (Coppes et al. 2017; Westekemper et al. 2018). Moreover, anthropogenic noise from roads and hiking trails can provoke antipredator behavior of species, which, in turn, negatively affect other ecological and physiological processes such as foraging and reproduction (Frid and Dill 2002; Shannon et al. 2014).

Hiking trails provide opportunities for nature appreciation, passive recreation and education (Farias Torbidoni 2011; Ballantyne et al. 2014; Bötsch et al. 2018). However, some trail systems could potentially have negative ecological effects, especially in small forests, because they fragment the forest by creating significant canopy breaks that act as soft edges and allow access to the interior by invasive or domestic

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species (Wimpey and Marion 2010; Ballantyne et al. 2014; Hammitt and Cole 2015).

Domestic species represent a major threat to native, urban wildlife because they can potentially affect native species through direct predation, disease transmission, and both interference and exploitative competition (Churcher and Lawton 1987; Young et al. 2011; Hughes and Macdonald 2013; Zapata-Ríos and Branch 2016, 2018). For example, feral or stray predators that reside in or with the vicinity of urban forests often have negative effects on native bird and small mammal populations (Keyser et al. 1998; Crooks and Soulé 1999; Lacerda et al. 2009). Several studies have suggested that hunting by domesticated cats may decrease bird and small mammal populations, affecting both biodiversity and food supply for native predators (Liberg 1984; Churcher and Lawton 1987; Meek 2003; Baker et al. 2003; Woods et al. 2003). Several factors contribute to the negative impact that non-native predators have on native wildlife in urban forests: the amount of fragmentation (Zipkin et al. 2009), the size of habitat fragments (Crooks 2002; Ewers and Didham 2007), and edge effects (Murcia 1995; Lacerda et al. 2009). In addition, the presence of domestic dogs with human hikers impacts the flight initiation distances of mule deer (*Odocoileus hemionus*) (Miller et al. 2001) and coyote (*Canis latrans*) abundance has been found to be significantly reduced in recreational areas that allow dogs, regardless of the type of restriction on dog activity (Reed and Merenlender 2011).

The purpose of this study was to examine how the landscape features, particularly roads, hiking trails, and forest edge, affect the occupancy of native and non-native mammals in urban forests. Additionally, we examined if there was a correlation between the occurrences of non-native and native species occupancy and activity.

## Method

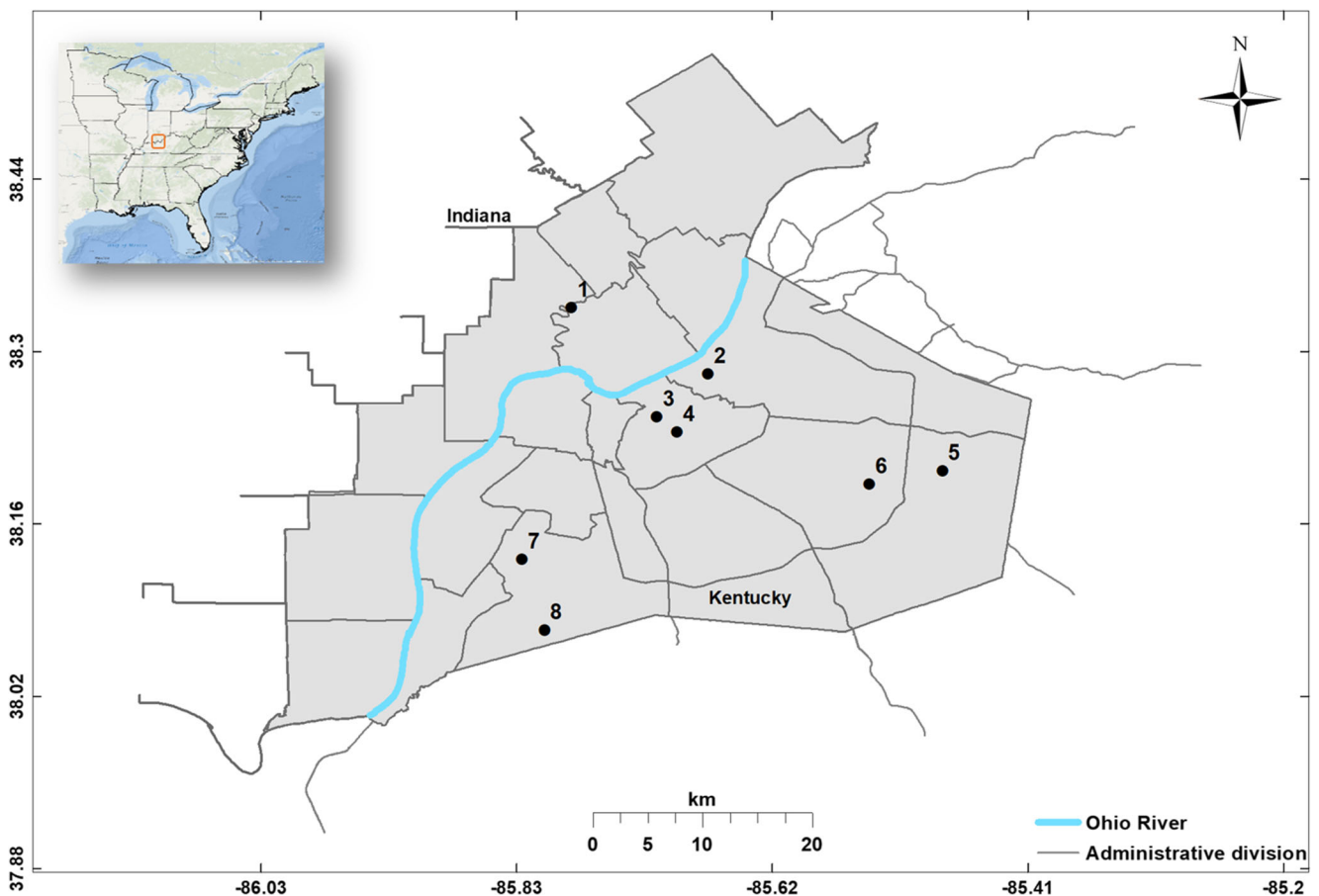
### Data collection

We conducted camera trap surveys from March to April 2018 in eight urban and suburban parks in the states of Indiana and Kentucky, USA. Lapping Park (88.8 ha, 8 sites), Locust Grove (11.2 ha, 8 sites), Cherokee Park (73.94 ha, 7 sites), Beargrass Creek State Nature Preserve (28.6 ha, 10 sites), Parklands (1275.2 ha, 10 sites), Blackacre State Nature Preserve (37.89 ha, 7 sites), Waverly Park (141.1 ha, 8 sites), and Jefferson Memorial Forest (3958 ha, 10 sites) (Fig. 1). All parks are within the boundary of Louisville, Kentucky except Lapping Park, which is located in Clarksville, Indiana. The study areas were mostly old secondary growth, less than 100 years old, dominated by oak species (*Quercus rubra* and *Q. velutina*), maple (*Acer saccharum*), and other species such as hickory (*Carya ovata* and *C. laciniosa*), Kentucky

coffee tree (*Gymnocladus dioica*), pawpaw (*Asimina triloba*), and eastern red cedar (*Juniperus virginiana*). The study sites are surrounded by residential neighborhoods and roads (mean width 3 m/road's lane). All the study sites encourage hiking on the marked trails. The hiking trails, range in width from 0.5 to 2.0 m, consist of loops through the forest interior and along the forest edge. State law prohibits bringing pets onto the two state nature preserves, but are allowed in the other parks if they are leashed.

We mapped the forest area for each park using Google Earth and ArcGIS v.10.4.1 (ESRI, Redlands, CA). Because roads and hiking trails are coincident with forest edge, we considered five variables in our study: 1) forest edge that is coincident with road (hereinafter referred to as “Roads”); 2) forest edge that is coincident with hiking trail (hereinafter referred to as “Hiking trails”); 3) forest edge that is not coincident with hiking trail (hereinafter referred to as “Forest edge”); and 4) forest edge that is not coincident with road (hereinafter referred to as “Forest edge 2”); and size of the forest area (hereinafter referred to as “forest area”). We then measured the distance (in meter) from the sampling sites to the nearest road (mean = 288 m, SD = 232.9), hiking trail (mean = 177 m, SD = 411.53), forest edge (mean = 455 m, SD = 936.73), and forest edge 2 (mean = 198 m, SD = 333.93). Previous studies showed that relatively precise occupancy and detection estimates can be obtained by running camera traps for 3–5 weeks across 40–60 locations (Kowalski et al. 2015; Kays et al. 2020). Accordingly, we randomly selected 68 sampling locations, 7–10 sampling locations/park, to set up the camera traps with an average distance of  $\approx 1$  km between the cameras.

Cameras were installed in locations with natural funnels, which maximize animal detection by forcing the object in front of cameras (Kelly and Holub 2008). Cameras were attached to trees at a height between 1 to 1.5 m, depending on the topographic feature of a given site, with a locking cable and facing the least obscured view from the tree. Using multi-camera traps per camera-site is recommended to improve species detectability, particularly for rare and/or small species (Pease et al. 2016; O'Connor et al. 2017). However, in practice, this approach is not always possible due to topographic features and logistical constraints (Alonso et al. 2015; Peres et al. 2017). Hence, to minimize the bias that could arise from using single cameras and shorter sampling durations, we used attractants (Webster and Beasley 2019). Use of baits and lures increases species detectability without changing the species movement patterns and temporal activities (Barea-Azcón et al. 2007; Gerber et al. 2012; Zapata-Ríos and Branch 2018). Accordingly, we impaled a can of tuna to the ground, approximately 10 m away from the camera to prevent bait removal. We hypothesized that if a species was more likely to use road, hiking trail, or forest edge, then the species would more likely be recorded closer to the roads, hiking trail, or



**Fig. 1** Map of study region and camera trap locations (black dots). Numbers refer to the park sites ordered from north to south (1, Lapping Park; 2, Locust Grove; 3, Beargrass Creek State Nature Preserve; 4, Cherokee Park; 5, Parklands; 6, Blackacre State Nature Preserve; 7, Waverly Park; 8, Jefferson Memorial Forest) Sources: Esri, DeLorme,

HERE, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, and the GIS User Community

forest edge (Wampler et al. 2008). Each camera was programmed to record 30-s videos for each event. The cameras were set to record video with a minimum delay of one minute between events. Mammal records were identified to species level and classified into independent events using a criterion of 30 min or more between consecutive records of the same species (O'Brien et al. 2003). Events were viewed as a random sample taken from an underlying continuous temporal distribution, describing the probability of an event occurring at any particular time (Ridout and Linkie 2009). For each event, we recorded time, date, and location. We also recorded the proportion of individual dogs that were leashed and unleashed.

### Activity overlap

As dogs are mostly a diurnal species, we examined if there was overlap in the activity patterns of domestic dogs and white tailed deer (*Odocoileus virginianus*) (the only diurnal mammal) through a two-step procedure. First, the activity pattern of each species was estimated non-parametrically by

fitting the capture time, obtained from camera traps for a given species, to a kernel density function (Ridout and Linkie 2009; Linkie and Ridout 2011). Second, we measured the degree of overlap between the estimated activities patterns for dogs and deer using the *coefficient of overlap* (Ridout and Linkie 2009; Frey et al. 2017). The value of the *coefficient of overlap* ranges between 0 (*no overlap*) and 1 (*complete overlap*) (Linkie and Ridout 2011; Frey et al. 2017). We performed this activity overlap analysis using “activityOverlap” function implemented in “camtrapR” R package (Niedballa et al. 2016).

### Occupancy model

A detection history for each species was constructed as following, a value of ‘1’ assigned to those occasions in which the species was detected at least once and a ‘0’ in which the species was not occupied. We modeled these data using single season occupancy models (MacKenzie et al. 2002) as part of the “unmarked” R package (Fiske and Chandler 2011). This package uses the likelihood-based approach to estimate

proportion of sites occupied ( $\psi$ ) and detection probabilities ( $p$ ), and allows for incorporating covariates into occupancy models in order to reduce variance in parameter estimates (MacKenzie et al. 2017). We evaluated the correlation among the five variables, distance to road, distance to hiking trail, distance forest edge, distance to forest edge 2, and the forest area, and eliminated one of each pair of covariates with high Spearman's pairwise correlation ( $r_s > 0.7$ ) from the subsequent analysis (Rinehart et al. 2009; Bauder et al. 2017). This resulted in four uncorrelated covariates, distance to road, distance to hiking trail, distance to forest edge, and forest size, to be used in our analysis. To facilitate model convergence, we standardized these correlated covariates using z-score (Bauder et al. 2017).

We did not include covariates such as climate and season because 1) we conducted the survey within one season, 2) the species inhabiting the study area are active year-around and, 3) the bait we used was sufficient enough to attract species occupying the study area regardless of the climatic conditions.

Initially, we created a null model for each species (i.e. both detection probability ( $p$ ) and occupancy ( $\psi$ ) were held constant). We then extended this model by including covariates (i.e. distance to road, distance to trail, distance to forest edge, and forest area) and their interactions. We considered models with estimated  $\psi$  very close to "1" and broad confidence of interval as not well fitted models and excluded them from the subsequent analysis (MacKenzie et al. 2002). Next, we ranked the remaining candidates models using 1) Akaike's Information Criterion (AIC) adjusted for small sample sizes ( $AIC_c$ ), and 2) weighted  $AIC_c$  ( $AIC_{cw}$ ) (MacKenzie et al. 2002; Rinehart et al. 2009). We used parametric bootstrapping approach proposed by MacKenzie and Bailey (2004) to check for model over-dispersion " $c-hat$ ". If the model was over-dispersed (i.e. " $c-hat$ "  $\gg 1$ ) we used quasi-corrected ( $QAIC_c$ ) to select the best approximating models instead of  $AIC_c$  (Burnham and Anderson 2002; MacKenzie and Bailey 2004; Rinehart et al. 2009). A set of best performed models contained all models located within 0.9  $AIC_{cw}$  ( $AIC$  cumulative weight) and had a  $\Delta AIC_c/QAIC_c$  score less than "4", and from this set we performed model-averaging to obtain overall estimates of occupancy and detection probability (Burnham and Anderson 2002; MacKenzie et al. 2002; Sewell et al. 2012). We assessed the relative importance of each variable by summing the AIC weights of all the models containing a given variable (Burnham and Anderson 2002), and variables with relative importance  $> 0.2$  was considered the most significant variable (Dibner et al. 2017; Oberosler et al. 2017).

### Co-occurrence models

We investigated whether the presence of non-native species (domestic cat *Felis catus* and dog) influences the detection probability and occupancy of the native species by pair-wise

comparisons using two-species single-season occupancy models (MacKenzie et al. 2004). The parameters estimated for occupancy were  $\psi_A$  (occupancy of non-native species),  $\psi_{BA}$  (occupancy of native species when the non-native species is present), and  $\psi_{Ba}$  (occupancy of the native species when the non-native species is absent). We incorporated the best covariates obtained from the single-species models for each species while modeling  $\psi_A$ ,  $\psi_{BA}$ , and  $\psi_{Ba}$ . We assumed native species occupancy is independent of the non-native species if ( $\psi_{BA} = \psi_{Ba}$ ), and influenced by non-native species, otherwise (i.e.  $\psi_{BA} \neq \psi_{Ba}$ ) (Nagy-Reis et al. 2017).

## Results

We recorded 248 trap events with a total of 418 animal photographs including white-tailed deer, raccoon (*Procyon lotor*), opossum (*Didelphis virginiana*), coyote (*Canis latrans*), cat, dog, red fox (*Vulpes vulpes*), and the eastern cottontail rabbit (*Sylvilagus floridanus*). The trap nights varied among sites with overall 413 trap nights. The Parklands, Black Acre State Nature Preserve, and Waverly park had the highest number of trap nights (100, 70, and 56 respectively), followed by Beargrass State Nature Preserve, Jefferson Memorial Forest, and Lapping park (each had 40 trap nights), while Cherokee and Locust Grove had the shortest trap nights (35 and 32 respectively). Both red fox and rabbit were excluded from the analysis because of very low detection rates that would fail model convergence and have misleading inference. Most dogs (74%) were observed without a leash.

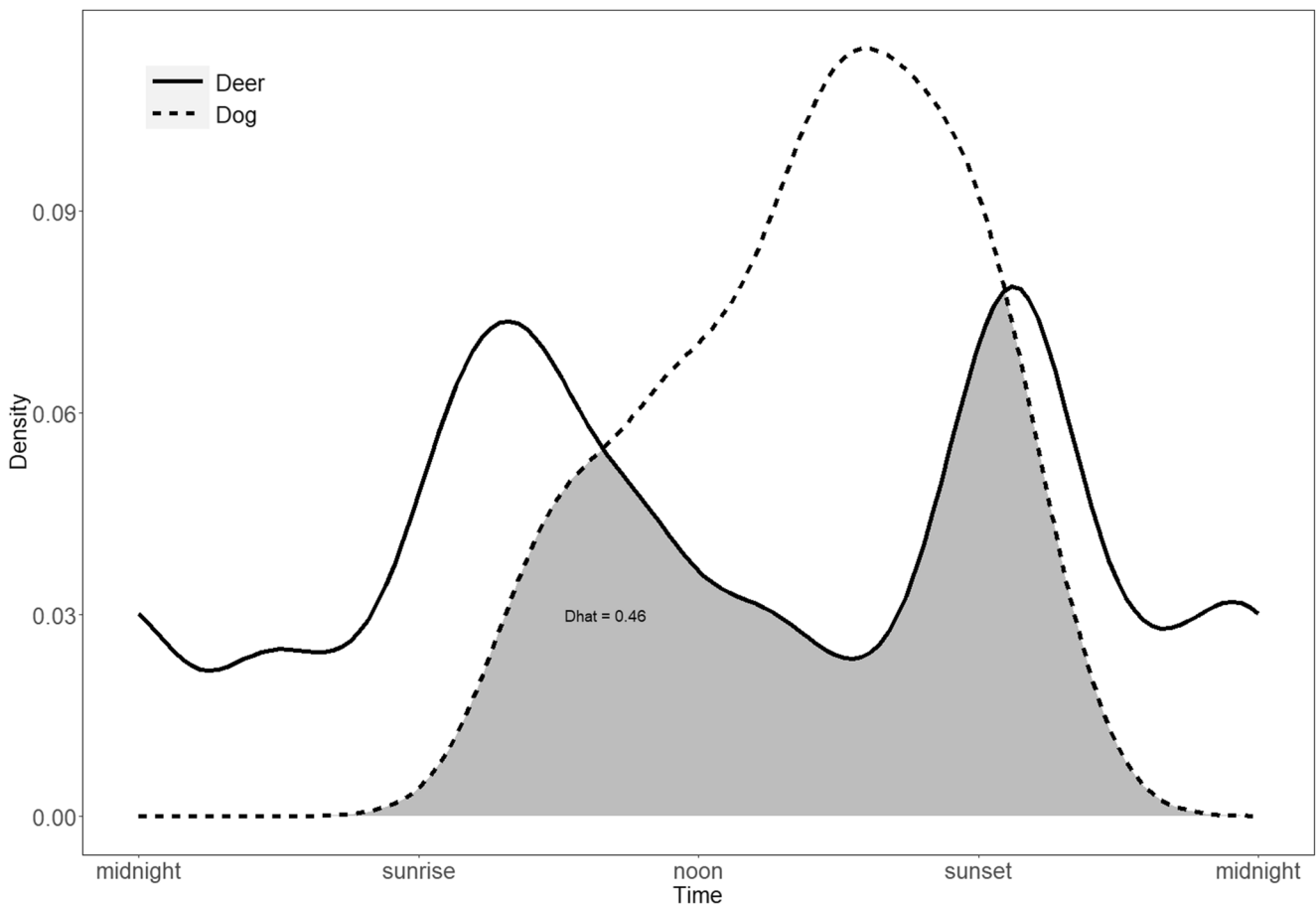
### Activity overlap

Kernel density estimation showed a decrease in deer activity as dogs' activity increased, *coefficient of overlap* = 0.46 (Fig. 2), suggesting that deer could be avoiding dogs.

### Occupancy model

We successfully fitted single-season occupancy models for our focal species. Goodness-of-fit analysis suggested slight to moderate over-dispersion (" $c-hat$ " between 1.16 and 2.3), accordingly model selection was carried out using  $QAIC_c$ . Model selection showed that no single best model could be selected to draw inference from species data (Table 1). For instance, five of 15 coyote's candidate models contained about 95% of the  $QAIC_{cw}$ , while for raccoon and opossum, four models contained about 90% of the  $QAIC_{cw}$  (Table 1).

Therefore, the overall occupancy estimate ( $\psi$ ) and detection probability ( $p$ ) for each species was obtained from the model averaging approach. The results showed that deer and raccoon occupied almost two-thirds of the study area (0.77 and 0.64 respectively) (Table 2). Whereas, cat, and dog were



**Fig. 2** Estimates of the activity patterns of deer and dogs. The dashed lines are kernel-density estimates for dog; the solid lines are kernel density estimates for deer. The coefficient overlap (Dhat) represents the shaded area under the two kernel density curves

estimated to occupy almost one-third of the study area (0.30 and 0.32 respectively). For all species, the estimated occupancy was higher than the naïve one (i.e. the proportion of sites where a species was photographed at least once). Our analysis showed that both deer and raccoon have the highest detection probabilities (0.33 and 0.38 respectively), followed by opossum and dog (0.12 and 0.16 respectively), whereas, coyote and cat have the lowest detection probabilities (0.11 and 0.08 respectively) (Table 2).

Our analysis showed that the occupancy of the native mammals, deer, opossum, coyote, and raccoon, increased the further a site was away from a road, a hiking trail, and a forest edge, while non-native mammal (cats and dogs) occupancy increased the closer a site was to a road, hiking trail, or a forest edge (Fig. 3). For all species, the models containing distance to road, hiking trail, and forest edge had the best support (i.e., contained >80% of the  $QAIC_{cw}$ ). For deer occupancy, a model containing the interaction between the distance to road and the forest edge was among the best. While the interaction between hiking trail and forest edge was among the best fitted occupancy model for raccoon (Table 3). For opossum, one model out of the best four model included the forest area. For coyote, none of the best model included forest edge. For all species,

except coyote, the detection probability was influenced mainly by the size of the forest area, whereas coyote detection probability was influenced by the size of the forest area and the distance to road, hiking trail, and forest edge. The relative importance analysis showed that roads and hiking trails had more importance than forest edge in determining occupancy of most of our focal species, whereas the size of forest area had no significant importance (relative variable importance <0.2) (Table 3).

According to the co-occurrence model, we found evidence that the presence of cat and dog negatively affect the occupancy for all native species (Table 4).

## Discussion

Habitat fragmentation and forest degradation are major causes of the changing biodiversity patterns (Fahrig 2003; Zapata-Ríos and Branch 2018) and we expected these to be the key factors in explaining occupancy patterns of our focal species. The occupancy for most native species was negatively affected by roads, hiking trails and forest edge. Whereas, the domestic species occupancy had a positive association with

**Table 1** Single-season occupancy models and goodness of fit analysis for our focal species. Only the most supported modes ( $\Delta$  QAIC <4) are shown. p(.) and  $\psi$  (.) indicate that species detectability and occupancy were modeled with no predictors. QAICc is the quasi-corrected AIC,  $\Delta$

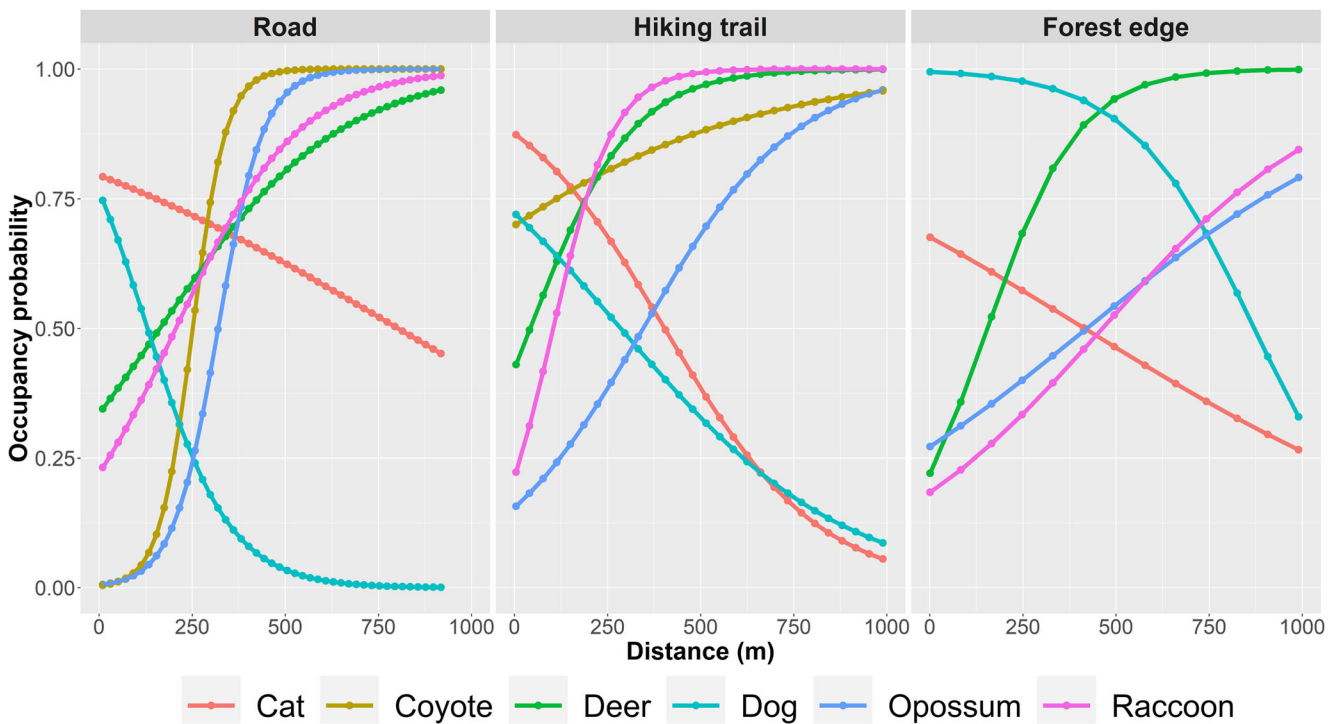
QAIC is the difference between the top-ranked model and a given model, QAICWt is the model weight, and Cum.Wt is the cumulative model weight

Species	model	QAICc	$\Delta$ QAICc	QAICcWt	Cum.Wt	Occupancy ( $\psi$ )	Detectability ( $p$ )
Deer	p(forest area) $\psi$ (distance to road)	292.63	0.00	0.56	0.56	0.77	0.33
	p(distance to road) $\psi$ (distance to trail + forest edge)	295.01	2.38	0.17	0.73	0.77	0.33
	p(distance to road + forest area) $\psi$ (distance to trail + forest edge)	296.15	3.52	0.13	0.86	0.73	0.34
	p(forest area) $\psi$ (distance to road*forest edge)	296.37	3.74	0.05	0.91	0.79	0.33
Raccoon	p(forest area) $\psi$ (distance to road)	279.67	0.00	0.36	0.36	0.64	0.38
	p(.) $\psi$ (forest edge)	280.71	1.04	0.34	0.7	0.63	0.37
	p(.) $\psi$ (distance to road + distance to trail)	280.87	1.2	0.2	0.9	0.64	0.38
	p(.) $\psi$ (distance to trail*forest edge)	282.02	2.35	0.05	0.95	0.65	0.38
Opossum	p(.) $\psi$ (distance to road)	112.02	0.00	0.4	0.4	0.42	0.13
	p(forest area) $\psi$ (distance to road)	112.31	0.29	0.35	0.75	0.58	0.1
	p(forest area) $\psi$ (distance to trail + forest edge)	114.46	2.44	0.15	0.9	0.52	0.1
	p(forest area) $\psi$ (distance to road + distance to trail + forest area)	115.77	3.75	0.04	0.94	0.49	0.1
Coyote	p(forest area+distance to trail + distance to road) $\psi$ (distance to road)	55.96	0.00	0.25	0.25	0.63	0.1
	p(forest area+forest edge) $\psi$ (distance to trail)	56.01	0.05	0.24	0.49	0.43	0.08
	p(forest area+forest edge) $\psi$ (distance to road + distance to trail)	56.1	0.14	0.23	0.72	0.57	0.09
	p(forest area+distance to trail + distance to road) $\psi$ (.)	56.13	0.17	0.23	0.95	0.33	0.1
	p(forest area+distance to trail + distance to road) $\psi$ (distance to trail)	57.77	1.81	0.05	1.00	0.35	0.07
Cat	p(.) $\psi$ (distance to road)	63.03	0.00	0.32	0.32	0.25	0.1
	p(.) $\psi$ (forest edge)	63.52	0.49	0.25	0.57	0.32	0.08
	p(.) $\psi$ (distance to trail)	64.93	1.9	0.12	0.69	0.35	0.07
	p(forest edge) $\psi$ (distance to trail)	65.95	2.92	0.12	0.81	0.31	0.12
	p(forest area) $\psi$ (distance to road + forest edge)	66.54	3.51	0.09	0.9	0.28	0.08
	p(.) $\psi$ (distance to road)	113.92	0.00	0.32	0.32	0.19	0.22
Dog	p(forest area) $\psi$ (distance to road)	114.31	0.39	0.26	0.58	0.25	0.11
	p(forest area) $\psi$ (distance to trail)	115.64	1.72	0.13	0.72	0.37	0.1
	p(forest area) $\psi$ (forest edge)	117.79	3.87	0.05	0.76	0.42	0.1
	p(forest area) $\psi$ (forest edge + forest area)	117.94	4.02	0.05	0.82	0.37	0.1

**Table 2** Naïve and estimated occupancy and detection probability for the focal species. Naïve  $\psi$  is the proportion of sites where a species was photographed at least once,  $\psi$  (s.e.) is the estimated occupancy and its standard error, p (s.e.) is the estimated detection probability and its standard error

Species	Naïve $\psi$	$\psi$ (s.e.)	p (s.e.)	Number of Individual
Deer	0.66	0.77(0.1)	0.33(0.04)	187
Raccoon	0.59	0.64(0.09)	0.38(0.05)	137
Opossum	0.21	0.50(0.24)	0.12(0.05)	18
Coyote	0.09	0.46(0.39)	0.11(0.04)	6
Cat	0.10	0.30(0.29)	0.08(0.06)	9
Dog	0.21	0.32(0.15)	0.16(0.1)	39
Red fox	0.07	–	–	5
Rabbit	0.07	–	–	5

roads, hiking trails, and forest edge. For most species, roads had higher importance in determining occupancy; however, the magnitude of importance of roads, hiking trails, and forest edge differed among species. We believe that roads had more importance in predicting the occupancy of most species because roads exert stronger negative effects than hiking trails and forest edge. Roads have both direct and indirect impacts on wildlife (Boston 2016; Bötsch et al. 2018). Direct impacts include vehicle caused mortality, habitat fragmentations, and limiting species movement (Coffin 2007; Shepard et al. 2008; Boston 2016). Indirect impacts include habitat near roads not being ideal functional sites for wildlife to rest and rear young because of hard edge habitats, noise, and human disturbance (Shepard et al. 2008; Boston 2016). In contrast, hiking trails and forest edge may have lower importance in predicting wildlife occupancy because they are located in suitable habitat, may be used by wildlife to facilitate movement,



**Fig. 3** Relationship between species occupancy and distance to road and hiking trails and forest edge

have lower noise and levels of human disturbance and can be considered a soft edge habitat (Marzano and Dandy 2012; Ballantyne et al. 2014).

White-tailed deer is habitat generalist that avoids dense forest habitats and is most often recorded in fragmented forests (Zeller et al. 2011; Petracca et al. 2014). Deer had a relatively high occupancy near roads and hiking trails (roughly 50%), which was expected as deer are known as fairly adaptable species with high behavioral plasticity and tolerance to human activities (Faas and Weckerly 2010). However, despite their high tolerance of human activities, deer occupancy was still negatively influenced by roads, hiking trails, and forest edge as deer occupancy increased as the distance from roads, hiking trails, and forest edge increased (Fig. 3).

**Table 3** The relative importance of the variables used for estimating our focal species' occupancy

	Relative variable importance			
	Road	Trail	Forest edge	Forest area
Deer	0.61	0.30	0.35	0.00
Raccoon	0.56	0.25	0.39	0.00
Opossum	0.79	0.19	0.15	0.04
Coyote	0.71	0.52	0.00	0.00
Cat	0.41	0.24	0.34	0.00
Dog	0.58	0.13	0.10	0.00

Raccoon and opossum are resource generalist species with high behavioral plasticity who utilize human structures and food sources (Ng et al. 2004; Ordeñana et al. 2010; Fidino et al. 2016), which suggests that forest area, fragmentation, and forest access may not be the only predictors associated with the presence of these two species. Our results together with previous findings imply that raccoon and opossum occupancy may vary according to study sites and could be influenced by other factors such as food availability and intensity of anthropogenic activities (Ordeñana et al. 2010; Reed 2011; Cove et al. 2012; Kowalski et al. 2015).

Coyote were the top predator in our study area and is a known predator of domestic cats and dogs (Grubbs and Krausman 2009; Gehrt et al. 2013; Wang et al. 2015). Coyotes responded negatively to the human activities (i.e. roads and hiking trails), however, the magnitude of the response differed (Fig. 3). For instance, the estimated

**Table 4** Species occupancy ( $\psi$ ) estimated from co-occurrence occupancy model

Species	Cat		Dog	
	Presence	Absent	Presence	Absent
Deer $\psi$	0.3	0.86	0.34	0.80
Raccoon $\psi$	0.06	0.68	0.51	0.60
Opossum $\psi$	0.1	0.65	0.13	0.52
Coyote $\psi$	0.13	0.66	0.23	0.99

occupancy for coyote was almost 75% at the sites close to hiking trails, and gradually increased the further a site was away from hiking trails (Fig. 3). In contrast, coyotes had low occupancy near roads but occupancy probability increased sharply as the distance to roads increased. The relatively high occupancy probability near hiking trails could result from coyote being relatively tolerant of human activities that occur mostly during the day and visiting the periphery of hiking trails to forage for domestic species (Markovchick-Nicholls et al. 2008; Ordeñana et al. 2010; Kowalski et al. 2015).

The detectability and occupancy of domestic species is often higher at the forest edges than forest interiors (Reed and Merenlender 2008; Kowalski et al. 2015; Zapata-Ríos and Branch 2018). As expected, the distribution of cat and dog was positively associated with roads, hiking trails and forest edge. About 86 % of dog and 71 % of cat occurrences were located within a distance of a hundred meters from roads, hiking trails, and forest edges, suggesting that these features provide forest access to domestic species. Our models showed a sharper decline in dog occupancy than the decline in cat occupancy as distance from roads increased implying that free-ranging cats are more likely to occur in forest interiors and therefore could be a greater threat to smaller wildlife compared with dogs. Domesticated species rarely venture more than 100 m into the forest, as they are often fed by their owners and therefore may be indulging in “recreational hunting” and therefore not motivated to expend the effort needed to travel through forest undergrowth (Oehler and Litvaitis 1996; Kays and DeWan 2004; Lenth et al. 2008; Young et al. 2011; Hughes and Macdonald 2013; Morin et al. 2018).

The negative association between cats and dogs with native species is likely to have fitness consequences (Creel and Christianson 2008; Zapata-Ríos and Branch 2016). Domestic species often harass or chase native species, which is an energetically costly behavior and a source of stress (Manor and Saltz 2004; Lenth et al. 2008; Young et al. 2011). Most dogs in our study were unleashed, either walking within the vicinity of their owner or free ranging from their owner’s home, which allowed the dogs to potentially harass or chase native species. Deer are known to alter their activity patterns by becoming more nocturnal to avoid dogs, while deer become more diurnal when dogs are rarer (Hughes and Macdonald 2013; Zapata-Ríos and Branch 2016, 2018). Ungulates can be tolerant of human presence, however, they change their behavior if humans are accompanied by dogs (Miller et al. 2001; Lenth et al. 2008). Although cats cannot prey or do not chase the native species in our study, they may have negative interactions with native species or compete for food (Gehrt et al. 2013; McDonald et al. 2015). Domestic cat is thought to be a major predator of smaller wildlife in urban habitats (Bonnington et al. 2013), and their actual impact depends on many factors such as habitat type, geographic

location and cat classification (i.e. feral or free ranging) (Medina et al. 2011; Loss et al. 2013; Kitts-Morgan 2015).

A possible source of bias in this study is the sampling duration, which likely affect species detectability and introduces bias to the occupancy estimate (Nichols et al. 2019). We acknowledge that longer sampling duration may yield more precise occupancy estimates (Kays et al. 2020), however, our sampling duration was relatively short due to this experimental approach and logistical constraints. We addressed this issue by using bait to maximize species detection and minimize the bias in occupancy estimate. Using bait to lure species has been successfully applied in several studies, especially for rare or species with low detection rate, to maximize detection rate (Kowalski et al. 2015; Pacifici et al. 2016; Ferreira-Rodríguez and Pombal 2019; Kays et al. 2020). Further, our sampling duration, eight weeks, was longer than the sampling duration of other studies. For instance, in our study the shortest trap nights was 32, which is longer than the commonly used sampling duration, 30 trap nights per location, (Ahumada et al. 2011). Another study had successfully fitted a single season occupancy model with data obtained from short sampling duration of 3 weeks (Kowalski et al. 2015). A recent study showed that a precise occupancy estimate could be produced from a sampling duration of four weeks or more (Kays et al. 2020). As such, we believe that the sampling duration in our study was sufficient to obtain a reliable occupancy estimate with minimum bias. Of course, increasing the sampling duration would, indeed, improve the estimate but we believe it would not significantly change the interpretation of our results. Another source of bias is camera trap height. It is recommended to keep the camera’s height at the level of the target species shoulder (Meek et al. 2012). However, a previous study showed that this recommended height is not always the best option as the camera trap height should be adjusted according to the type of camera, species size, and the objective of the study (Apps and McNutt 2018). In our study, following the recommended height was not possible due to the variation in body size of the target species. Therefore, we adjusted the camera trap height according to the habitat features of a given site. Further, the cameras were deployed in locations with natural funnels to ensure better detection through forcing the animal in front of the cameras. Moreover, we made sure that the bait was visible in our videos to avoid false absence due to camera trap height, which allowed us to detect smaller bodied species such as raccoon and opossum with higher frequency than larger bodied species such as coyote and red fox (Table 2). As such, we believe that any meso-sized species walking



near the camera would have been detected (Barea-Azcón et al. 2007; Gerber et al. 2012; Zapata-Ríos and Branch 2018).

## Conclusion

Our study suggests that both fragmentation and domestic species are associated with the distribution and activity patterns of native species in urban forests. From a management perspective, our study suggests that roads have a greater impact on native species occupancy than hiking trails and forest edge and their disturbance effect extends roughly 300 m. We suggest that future hiking trail development in urban or small forests should occur on the periphery of the forest instead of passing through the forest interior. A trail system along the perimeter of small preserves would allow the conservation of an interior forest and the protection of native wildlife while still allowing passive human recreation. Therefore, park management should consider the impact of roads, hiking trails, and forest edge when designing parks and the enforcement of dog leash regulations for the conservation of large mammals in urban parks.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

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