

# Mesocarnivores in residential yards: influence of yard features on the occupancy, relative abundance, and overlap of coyotes, grey fox, and red fox

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## ABSTRACT

**Context.** As conversion of natural areas to human development continues, there is a lack of information about how developed areas can sustainably support wildlife. While large predators are often extirpated from areas of human development, some medium-bodied mammalian predators (hereafter, mesocarnivores) have adapted to co-exist in human-dominated areas. **Aims.** How human-dominated areas such as residential yards are used by mesocarnivores is not well understood. Our study aimed to identify yard and landscape features that influence occupancy, relative abundance and spatial-temporal overlap of three widespread mesocarnivores, namely, coyote (*Canis latrans*), grey fox (*Urocyon cinereoargenteus*) and red fox (*Vulpes vulpes*). **Methods.** Over the summers of 2021 and 2022, we deployed camera-traps in 46 and 96 residential yards, spanning from low-density rural areas (<1 home per km<sup>2</sup>) to more urban areas (589 homes per km<sup>2</sup>) in north-western Arkansas, USA. **Key results.** We found that mesocarnivore occupancy was marginally influenced by yard-level features as opposed to landscape composition. Fences reduced the occupancy probability of coyotes, although they were positively associated with the total area of potential shelter sites in a yard. We found that relative abundance of grey fox was highest in yards with poultry, highlighting a likely source of conflict with homeowners. We found that all three species were primarily nocturnal and activity overlap between the species pairs was high. **Conclusions.** Thus, these species may be using spatio-temporal partitioning to avoid antagonistic encounters and our data supported this, with few examples of species occurring in the same yards during the same 24-h period. **Implications.** As the number of residential yards continues to grow, our results suggested that there are ways in which our yards can provide resources to mesocarnivores and that homeowners also have agency to mitigate overlap with mesocarnivores through management of their yard features.

**Keywords:** carnivores, mesocarnivores, occupancy, overlap, predators, residential yards, temporal activity patterns, yard features.

## Introduction

Large mammalian predators and humans have a long and tumultuous history of struggling to co-exist (Fardell *et al.* 2020; Farr *et al.* 2022). However, as humans have altered the landscape to an unprecedented degree, mammalian mesocarnivores (medium-sized mammalian predators) such as coyote (*Canis latrans*) and foxes (*Vulpes vulpes* and *Urocyon cinereoargenteus*) often proliferate in human-dominated landscapes (Gehrt *et al.* 2011; Lombardi *et al.* 2017; Parsons *et al.* 2019). As human development expands, some bolder species are better able to occupy spaces within human-dominated areas than are others (Lombardi *et al.* 2017; Breck *et al.* 2019; Rodriguez *et al.* 2021). In these human-dominated areas, coyotes and foxes are often at the top of the food web and exert predatory pressure on deer, birds, and smaller mammals (Gompper 2002; Jones *et al.* 2016; Dyck *et al.* 2021). The presence of these species in and around human-dominated areas often draws extreme public interest in both positive and negative ways (Røskft *et al.* 2007; Wilkinson 2023).

and feelings can be the most extreme when these mesocarnivores are seen living in and around where humans reside (Farr *et al.* 2022).

One of the most prevalent human-dominated landcover types in North America is the suburban yard, which accounts for approximately 17.4% of the United States and covers more than 1.74 million km<sup>2</sup> (Mathieu *et al.* 2007; Giner *et al.* 2013; Hedblom *et al.* 2017). Because homeowners use their yards for a variety of purposes, residential yards can be viewed as independently managed greenspaces that can vary widely in the resources that are of potential use to wildlife (Bolger *et al.* 2001; Gallo *et al.* 2017; Johansson and DeGregorio 2023). Although most yards are far smaller than the home range of mesocarnivores, they are frequently used by these species for foraging (Murray and St. Clair 2017), traveling (Noss *et al.* 2021), or denning (Way *et al.* 2001; Hansen *et al.* 2020; Raymond and St. Clair 2022) if the proper resources are present.

Mesocarnivores found in developed areas are often concentrated in green spaces such as parks and cemeteries (Parsons *et al.* 2019), but foray into residential areas to take advantage of subsidised resources (Prevedello *et al.* 2013) and can even shelter or raise young in residential yards (Way *et al.* 2001; Gosselink *et al.* 2003; Vuorisalo *et al.* 2014; Raymond and St. Clair 2022). Yards may be particularly attractive to mesocarnivores if they have dense populations of small mammal prey species owing to the presence of compost or refuse, bird feeders, pet food, or outdoor pets (Contesse *et al.* 2004; Timm *et al.* 2004; Newsome *et al.* 2014; Soulsbury and White 2015; Murray and St. Clair 2017; Hansen *et al.* 2020). Mesocarnivore diet can consist almost entirely of anthropogenic food sources (Contesse *et al.* 2004; Murray *et al.* 2015; Newsome *et al.* 2015; Reshamwala *et al.* 2018), including domestic pets and poultry (Larson *et al.* 2015). However, coyotes in urban environments may rely on natural prey items such as eastern cottontails (*Sylvilagus floridanus*) (Morey *et al.* 2007) and sometimes white-tailed deer (Newsome *et al.* 2015) and these prey species may preferentially reside in yards that contain features such as gardens. Additionally, infrastructure can provide safe and attractive denning or shelter opportunities under garages, decks, or outbuildings for both mesocarnivores and their prey species (Gosselink *et al.* 2003; Duduś *et al.* 2014). However, the suburban environment can also be heavily fragmented by fences separating yards, which can restrict access to yards. Coyotes and both fox species were less likely to be present in fenced yards (Hansen *et al.* 2020).

However, because yards are typically small, the features present in a yard may not be the only factors that influence where mesocarnivores occur. Wildlife often use habitat in a hierarchical fashion (Johnson 1980) and thus the composition of the surrounding landscape is almost certainly an important factor in mesocarnivore occupancy (Gehrt *et al.* 2009; Cooper *et al.* 2012). Residential yards situated in largely forested areas or surrounded by more open greenspace may be more likely to

have mesocarnivores present, whereas they may be absent in yards surrounded by high-density housing or those surrounded primarily by impervious surface (roads, parking lots, buildings), even if the yards provide similar resources (Riley 1999; Riley *et al.* 2003; Kays *et al.* 2008; Morin *et al.* 2022).

Mesocarnivores living around humans often switch to being active primarily at night to avoid contact with humans and our dogs (Cove *et al.* 2012; Gese *et al.* 2012; Lowry *et al.* 2012; Gallo *et al.* 2017). However, if co-occurring mesocarnivore species concentrate their activity at night, they are more likely to have high activity overlap with one another (Moll *et al.* 2018; Gallo *et al.* 2022). This increase in overlap could possibly lead to antagonistic encounters among species (Gallo *et al.* 2022; Green *et al.* 2022). Thus, it is important to understand how these mesocarnivores alter their activity patterns in response to humans and if that increases temporal overlap among mesocarnivore species.

In the altered mammalian communities occurring around human development in the United States, coyotes, red and grey fox are often present and represent the largest carnivores (aside from black bears (*Ursus americanus*) and bobcats (*Lynx rufus*)) that regularly occur near people (Gehrt *et al.* 2009; Bateman and Fleming 2012; Lombardi *et al.* 2017). Red and grey foxes commonly occur in suburban environments and may even prefer these areas as opposed to more rural areas (Parsons *et al.* 2019; Hansen *et al.* 2020). Red foxes benefit by occurring in suburban areas because they can be protected from larger dominant carnivores such as coyotes and bobcats (Moll *et al.* 2018), a phenomenon referred to as the 'human shield' effect (Berger 2007). Even though coyotes are more cautious of residing in human-dominated areas than is red fox, they can also be regularly present throughout suburban and urban areas (Gehrt *et al.* 2011; Gil-Fernández *et al.* 2020). Grey foxes are not as common across developed areas; however, they often select denning sites near suburban development (Farías *et al.* 2012; Shannon *et al.* 2014; Moll *et al.* 2018; Sarkar and Bhadra 2022).

Our objectives were to use camera-traps to identify how yard features and surrounding landscape composition influence mesocarnivore occupancy, relative abundance (i.e. detection rate, which we defined as number of focal species detected per night), and interspecific temporal overlap in residential yards in a rapidly developing area. We predicted that mesocarnivore occupancy and relative abundance would be highest in yards with supplemental food and water such as compost piles, bird feeders, poultry, and garden ponds. Furthermore, we predicted that fences would decrease occupancy and relative abundance of all three species. We also predicted that both fox species would be less likely to occur in yards with coyote presence (Egan *et al.* 2021). We did not expect that the presence of one fox species would influence the occupancy of the other (Morin *et al.* 2022). Finally, we also predicted that as forest cover increases and housing-unit density decreases, coyote occupancy probability and relative abundance would increase (Riley 1999;

Riley *et al.* 2003; Kays *et al.* 2008), whereas the opposite would be true for grey and red fox, which would most likely occur around developed open space (lawns, cemeteries, parks, golf courses etc.) (Moll *et al.* 2018). We also predicted that all mesocarnivore species would be primarily nocturnal and that the overlap of their activity patterns would thus be high.

## Materials and methods

### Study area

Our study was conducted in the north-western region of Arkansas, USA, which is a rapidly developing area with a population of approximately 350,000 people. Fayetteville is located within the Ozark Highlands Ecoregion, which is primarily forest intermixed with open areas and some pasture lands used for cattle and agriculture. Our study sites encompassed residential yards in and near the centres of Fayetteville, Springdale, Rogers, Eureka Springs, and Bella Vista and less developed areas up to 32 km from city centres (Fig. 1). The yards in which we conducted our study were owned by volunteers from the Arkansas Master Naturalist Program and University of Arkansas Department of Biological sciences. We restricted our study sites to yards occurring within an 80.5 km radius of downtown Fayetteville. We intentionally selected yards that represented a continuum of urban to rural setting as determined by surrounding housing-unit density (described below). We also ensured that we selected yards that contained (or did not contain) varying suites of *a priori* selected yard features associated with supplemental food, shelter, or water for wildlife (see below). Because volunteers came from the Master Naturalist Program and a Biology Department, not all yards contained features to attract wildlife and were representative of the yards available to wildlife in this region.

### Camera deployment

We deployed motion-triggered camera-traps (Browning StrikeForce or Spypoint ForceDark) in residential yards during the summers of 2021 and 2022. We deployed one camera per yard approximately 0.95 m above the ground on either a tripod or strapped to a tree. We placed cameras at least 5 m away from one another and no more than 100 m from a house. We positioned cameras to maximise wildlife detections, when possible, near features such as compost piles, water sources (natural or maintained), and fence lines or animal paths. We coordinated with homeowners to choose locations that would allow them to maintain their privacy and that also would not interfere with yard maintenance. If vegetation grew to impede the view of the camera, we would remove the vegetation. We set cameras to take a burst of three photos per trigger, with a 5 s reset time when triggered. We did not use any bait or lures at camera sites. Cameras were checked every 2 weeks to assess battery life and to download data. We moved cameras

within yards up to three times within the season, to ensure that we captured the full range of wildlife present in each yard.

We surveyed each yard for features that we predicted would influence mesocarnivore occupancy (Table 1). We first recorded variables representing possible food sources, including the presence and number of bird feeders (both seed/suet and nectar), the volume of brush and firewood piles, area of compost piles, and the presence or absence of poultry. All area and volume calculations were undertaken by using a measuring tape to measure height, length, and width of the features. We reasoned that bird feeders could provide direct food to some of our focal species and could also serve as an attractant to prey species such as mice, rats, and birds (Saad *et al.* 2020). We considered the volume of firewood and brush piles as a food source because they could similarly be associated with high numbers of prey species (Goguen *et al.* 2015).

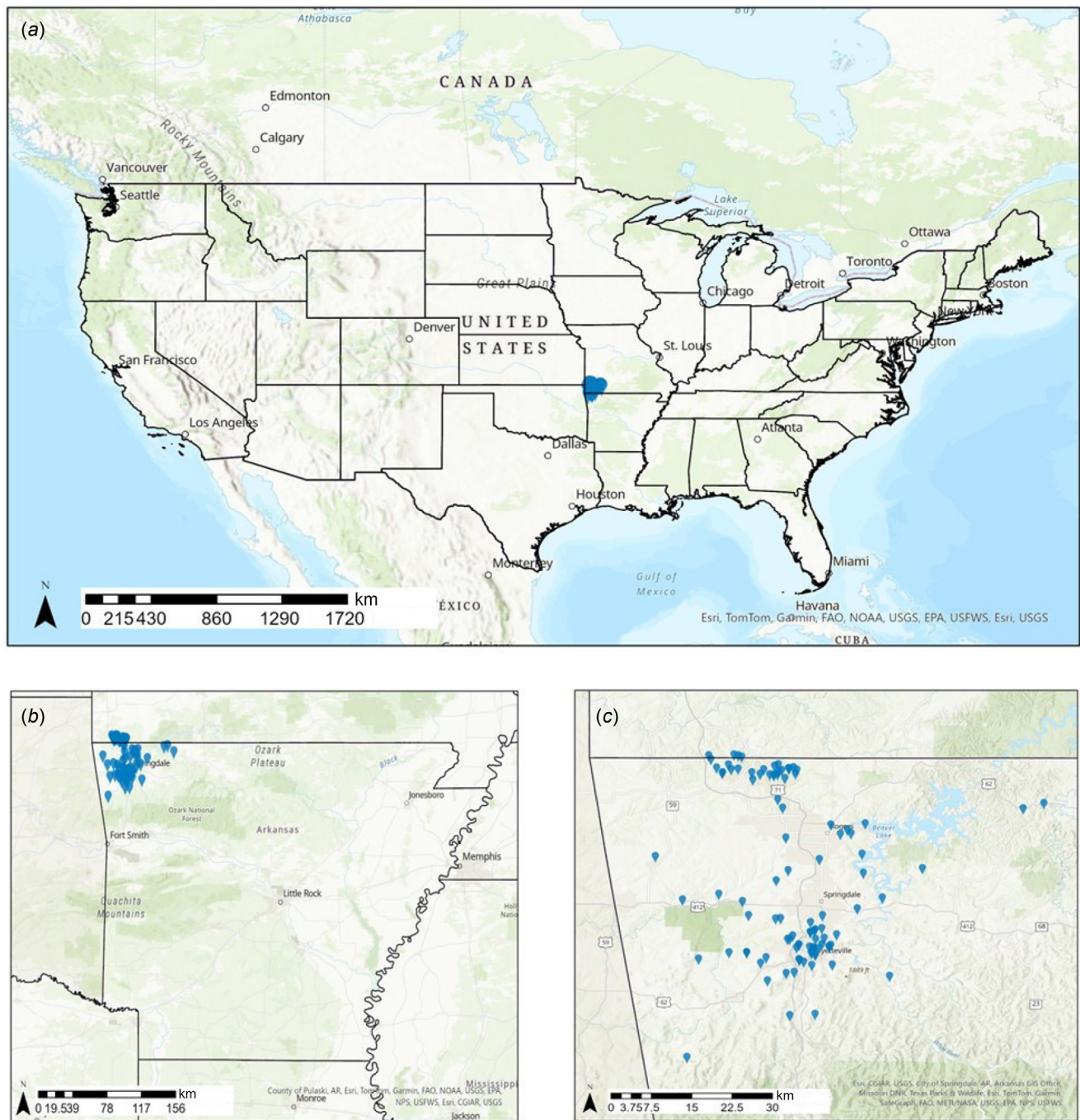
We also recorded the area of potential sheltering sites in a yard. Sheltering sites included the total available area of sheds and outbuildings under which animals could access as well as decking that was less than 0.3 m off the ground (Linduska 1947; Moll *et al.* 2018). We counted the number of supplemental water sources present in a yard, which included bird baths, garden ponds, and fountains that were actively maintained by the homeowner.

If a camera was deployed in an area that was surrounded by a fence, we scored the type of fence based on its ease of access to our focal species. We scored each yard with a binary score of zero or one. Yards without fences or with fences that presented minimal resistance to the movement of our focal species (barbed wire or those made of semi spaced slats 1 m tall that allowed for smaller-bodied species to pass through and most larger species to jump over) were given a zero. If a fence was fallen, had large holes in them, or had a gate that was always left open, the fence also received a score of zero. Privacy and chain-link fences that were 1.8 m or taller and were made of a solid material, that were likely to prevent the passage of focal species, apart from capable climbers, were given a one.

### Landscape and environmental covariates

To acquire landscape-level covariates to explain mesocarnivore occupancy and relative abundance, we calculated the area of several landcover types surrounding each focal yard. First, we imported all camera-location points to GIS (ArcGIS Pro 10.2; ESRI, Inc. Redlands Inc.) and created 1.5 km buffers around each camera on the basis of a reasonable approximation of mesocarnivore home ranges (Šálek *et al.* 2015). Within each buffer, we then calculated the area of forest cover, developed open land (e.g. cemeteries, parks, and grass lawns), and agricultural land (grasslands, cultivated crops, and pastureland) by using the 2019 National Land Cover Database (Dewitz and US Geological Survey 2021). We used two different development categories for analyses because we predicted that our focal species might respond





**Fig. 1.** Map of study sites (residential yards) in north-western Arkansas, USA, during the summers of 2021 and 2022; study sites are indicated with a blue pin. (a) Large-scale view of the USA. (b) Finer-scale view of Arkansas, USA. (c) Finer-scale view of study sites within north-western region of Arkansas, USA.

differently to development of varying intensities. We used low-intensity development, which was represented by areas containing 20–49% of impervious surface. We then grouped the National Land Cover Database (NLCD) categories of medium- and high-intensity development (which we refer to as high intensity development) that contained areas with over 49% impervious surface. We also quantified the

maximum housing-unit density (HUD) around each camera by using the SILVIS Housing Data Layer (Radeloff *et al.* 2018).

### Mesocarnivore occupancy

To explore the effects of covariates on the detection and occupancy of our three focal mesocarnivores (coyotes, red

**Table 1.** Covariates predicted to influence the detection, occupancy, or relative abundance of coyote (*Canis latrans*), grey fox (*Urocyon cinereoargenteus*), and red fox (*Vulpes vulpes*) in residential yards within 80 km of downtown Fayetteville, Arkansas, USA, during the summers of 2021 and 2022. Years are bolded within table, to highlight the difference. NLCD, National Land Cover Database; NOAA, National Oceanic and Atmospheric Administration; NA, not applicable.

Landscape covariate	Description of variable	Minimum	Maximum	Average
Forest cover (NLCD)	Area of forest cover within 1.5 km buffer	0.00	0.45	0.19
Open developed land (NLCD)	Area of open developed land, (parks, cemeteries, and lawns) within 1.5 km buffer	0	0.31	0.09
Agricultural land (NLCD)	Area of land used for agricultural purposes within 1.5 km buffer	0	0.43	0.09
Housing-unit density (HUD) (Radeloff <i>et al.</i> 2018)	Maximum HUD within 1.5 km buffer of camera (houses/km <sup>2</sup> )	0.13	5094.60	589.41
Developed land (high + medium intensity) (NLCD)	Area of land that with greater than 49% impervious surface within 1.5 km buffer	0	0.23	0.04
Developed land (low intensity) (NLCD)	Area of land that contains between 20% and 49% impervious surface within 1.5 km buffer	0	0.30	0.08
Environmental covariates				
Average temperature (NOAA)	Average temperature over a 7-day period (°C)	<b>2021:</b> 14.72 <b>2022:</b> 13.89	<b>2021:</b> 28 <b>2022:</b> 29.67	<b>2021:</b> 26.04 <b>2022:</b> 24.42
Average precipitation (NOAA)	Average precipitation over a 7-day survey period (cm.)	<b>2021:</b> 0 <b>2022:</b> 0	<b>2021:</b> 1.45 <b>2022:</b> 6.25	<b>2021:</b> 0.43 <b>2022:</b> 1.50
Yard-feature covariates				
Volume of denning sites	Volume under sheds/outbuildings and under decks less than 1 m off the ground (m <sup>3</sup> )	0	700	24.35
Volume of brush piles	Volume of brush piles (m <sup>3</sup> )	0	335.94	38.65
Volume of firewood	Volume of firewood piles (m <sup>3</sup> )	0	13	0.72
Supplemental water source	Number of human-maintained water sources	0	7	0.85
Compost pile	Area of compost pile (m <sup>2</sup> )	0	16	0.40
Fence type	If a camera was within a fence, it was given a score of either zero or one, zero being a fence that is permeable to most wildlife and one being the most impassable.	18 yards had fences, 85 did not		
Poultry presence	Presence or absence of poultry being kept in yard	97 yards did not have poultry, 9 did		
Bird feeders	Number of bird feeders at a camera site, including seed feeders, suet, hummingbird feeders, and dried fruit.	0	19	3.15
Year	Year that the yard was surveyed	NA	NA	NA

and grey foxes), we used a single-season multi-species occupancy model (MacKenzie *et al.* 2002). Our occupancy models were used to estimate the probability that a mesocarnivore occurred in a yard and the influence of covariates on occupancy probability while accounting for imperfect detection (MacKenzie *et al.* 2004). We chose multispecies models to account for avoidance or attraction between our focal species. Multispecies occupancy allowed us to simultaneously model environmental covariates, while letting the occupancy of one species vary on the basis of the presence of another. We used individual yards as our survey locations and within each survey location, we used 1-week sampling periods. For each sampling period, we assigned a one or a zero for each species at each survey location. If the focal species was detected during a survey period at a site, a one was assigned, and if none was

detected, a zero was assigned. We used a 1-week sampling period because this represented an appropriate amount of time as to not over- or under-compress statistical power and is consistent with numerous occupancy analyses conducted using camera-traps (Trolle and Kéry 2003; MacDougall and Sander 2022). During the summer of 2022, we resampled 41 of our study yards from 2021. For these sites, we created year-site combinations and treated them as independent sites, as in previous studies (Hines *et al.* 2014; Devenish-Nelson and Nelson 2021; Murray *et al.* 2021). We used year as an occupancy covariate (Linden and Roloff 2013) to explore whether patterns differed between the 2 years of the study. Not all cameras in yards were actively functioning for the duration of the entire season because of camera malfunctions or staggered deployment and pick-up dates. To correct for

this, we censored weeks in which the camera was not operating continuously for all 7 days. We censored these camera weeks by assigning a 'NA' value as opposed to a one or a zero.

We also compiled a number of environmental covariates that we predicted would influence the behaviour or activity of our three focal species. Both rainfall and temperature can influence how active our species were and therefore could affect detection probability (Madsen *et al.* 2020). We defined detection probability as the chance that a species would be detected on a given day. To gather environmental variables, we used publicly available data from a National Oceanic and Atmospheric Association (NOAA) weather station located at the Fayetteville Experimental Station. This weather station was 75 km from the furthest yard studied. We used this data to calculate the average weekly air temperature and average weekly precipitation for each camera site.

Before model fitting, we assessed collinearity of covariates and considered any two covariates to be collinear if they had correlation coefficients  $\geq |0.6|$  (Gilhooly *et al.* 2019). From those, we would then decide which of the two variables were predicted to be more meaningful and only included that variable in subsequent analyses (Gilhooly *et al.* 2019). For detection covariates in occupancy analyses, we found that temperature was correlated with both precipitation ( $r = -0.61$ ) and week of the survey ( $r = 0.72$ ) and was therefore subsequently removed. When assessing occupancy covariates, high-intensity development was correlated with area of low intensity development ( $r = 0.75$ ) as well as forested area ( $r = -0.74$ ). Area of low development was also found to be correlated with forested areas ( $r = 0.73$ ). Both development levels were subsequently removed from analyses. So as to facilitate comparison between variables measured on different scales, we centered all continuous covariates by subtracting the variable mean value and then dividing by one standard deviation (Schielzeth 2010).

To avoid model over-fitting, we used a multi-stage fitting approach (Fuller *et al.* 2016) to select for the best detection covariate. We modelled mean precipitation, week of the year, an additive model of week + precipitation, and a null model as covariates for detection against null occupancy parameters and selected the top covariate model using Akaike's information criterion corrected for small sample size (AICc). The covariate(s) in the top model were then used as the detection covariates in all subsequent analyses of occupancy probability.

For occupancy covariates, we included the area of compost pile, supplemental water sources, poultry presence, number of bird feeders, fence type, as well as the volumes of denning sites, firewood piles, and brush piles (Table 1). We also included four landscape-level occupancy covariates, including the areas of open development, agriculture, forest, and HUD.

Our candidate model set included all possible two-way additive combinations of occupancy covariates with our top identified detection covariate(s) as well as a global and a null model. All model fitting was performed in R (R Core Team 2022, available at <https://www.r-project.org/>) with

the unmarked package (Fiske and Chandler 2011, available at <https://cran.r-project.org/web/packages/unmarked/index.html>). To improve clarity in presenting model selection tables, we display only models that were competitive within two  $\Delta\text{AICc}$ . Because there was model uncertainty, we used full model averaging (Lukacs *et al.* 2009) for all the model estimates to generate an average of unconditional occupancy estimates (Cade 2015).

## Mesocarnivore relative abundance

In addition to mesocarnivore occupancy, we also examined how yard and landcover covariates influenced the relative abundance of each focal species. We defined relative abundance as the number of focal species detections at each site (yard) divided by the total number of trap-nights. Although this metric often correlates with true abundance (Campbell *et al.* 2015), it is more often used as an index of intensity of use within an area and thus could be a good complement to occupancy, which is a coarser metric (Martin *et al.* 2010). Because camera-traps take multiple photographs at once, we combined all photos taken within a 5 min period into one 'detection' to minimise double-counting of individuals. To evaluate which landcover and yard variables most influenced the relative abundance of our mesocarnivore species in each yard, we used a generalised linear model (GLM) analysis. We used separate GLM analyses for each species to explore how landscape and yard features affected how frequently a mesocarnivore was detected in a yard. For each analysis, we evaluated the same candidate models as those used in the occupancy analyses. The candidate model set for each analysis consisted of simple one-way variable models and all additive two-way combinations as well as a global and a null model.

For each analysis, we ranked candidate models by using an information-theoretic approach with AICc. When appropriate, we derived parameter estimates for candidate models by model averaging all models within two  $\Delta\text{AICc}$  (Burnham and Anderson 2002) in R (R Core Team 2022) with the AICcmodavg package (R package version 2.3.2, available at <https://cran.r-project.org/package=AICcmodavg>).

To improve clarity in presenting model selection tables, we display only models that were competitive within two  $\Delta\text{AICc}$  for each analysis. Initial exploratory analyses indicated that relationships between predictor variables and response variables were linear and thus models were not corrected. Full model averaging was used to avoid bias away from zero (Lukacs *et al.* 2009). Model goodness-of-fit was assessed using residual plots and examining the  $R^2$  value ( $R^2 = 0.12$ ).

## Interspecific temporal overlap

To better understand interspecific temporal overlap, we calculated the activity overlap between each species pair by using the R package overlap (Meredith and Ridout 2021; available at <https://cran.r-project.org/web/packages/overlap/index.html>). We created kernels of activity for each species to



quantify when during the diel period they were most active. We first converted the time that each species was detected to radians. We then calculated a species-specific non-parametric kernel around the detection times to quantify when each species was active. For each species pair, we calculated the overlapped area under the kernel curve for the species pair. This number was quantified along a 0–1 index, with zero representing no overlap and one representing complete overlap (Schmid and Schmidt 2006). For our purposes, we used the  $\Delta 4$  value (a vector of densities estimated at the time of observation) because we had over 75 detections of each species (Schmid and Schmidt 2006; Ridout and Linkie 2009). We used detections from across all of our study sites collectively to create activity kernels.

To assess the time between interspecific detections, we calculated the time elapsed between detections of one species in a yard and the next chronological detection of the next focal species in the same yard. We first did this by days between, and then for anything with less than 24 h between detections, we calculated hours between the detections.

## Results

Over the course of two seasons, we surveyed 138 yards across north-western Arkansas. During the 2021 season, we deployed cameras in 46 yards between 1 May and 10 August and surveyed these sites for up to 15 weeks (mean  $\pm$  s.d.,  $14 \pm 1.5$ ). In 2022, we deployed cameras at 92 yards between 1 May and 10 August and surveyed these yards for up to 15 weeks (mean  $\pm$  s.d.,  $14 \pm 2.5$ ).

### Mesocarnivore occupancy

Cumulatively, we conducted 1456 week-long surveys for a total of 10,192 trap-nights and accumulated 1,494 focal mesocarnivore detections (507 coyote, 157 grey fox, and 830 red fox). We detected at least one mesocarnivore (coyote, grey fox, or red fox) in 74% of yards. Two species were present at 25 yards, whereas only six yards had all three species present.

Coyotes were detected at 51% of yards during 191 survey periods, grey fox at 14% of yards in 52 surveys, and red fox at 40% of yards during 160 surveys. The occupancy probability ( $\psi$ ) for at least one mesocarnivore in a yard was 0.74 (95% credibility interval (CI): 0.66–0.80). The  $\psi$  of coyotes was 0.54 (95% CI: 0.43–0.63),  $\psi$  of grey fox 0.14 (95% CI: 0.09–0.26), and  $\psi$  of red fox was 0.41 (95% CI: 0.31–0.53). The detection probability ( $p_i$ ) was similar among the three species, with  $p_i$  of coyotes averaging 0.18 (95% CI: 0.16–0.22),  $p_i$  of grey fox averaging 0.19 (95% CI: 0.14–0.25), and  $p_i$  of red fox averaging 0.20 (95% CI: 0.17–0.24). Preliminary modelling for detection covariates suggested that the best predictors for mesocarnivore detection at a yard were the additive effect of week and average precipitation, and this model accounted for 63% of the weight of evidence (Table 2).

**Table 2.** Model selection statistics for detection covariates of coyote (*Canis latrans*), grey fox (*Urocyon cinereoargenteus*), and red fox (*Vulpes vulpes*) in residential yards, on the basis of a 2-year study conducted in 2021 and 2022 in north-western Arkansas, USA.

Model	K	AICc	$\Delta$ AICc	AICcWt	LL
$\Psi(\cdot), p(\text{week} + \text{rain})$	15	2492.04	0.00	0.63	−1229.07
$\Psi(\cdot), p(\text{week})$	12	2493.30	1.26	0.34	−1233.41

Covariates of detection included week of the survey and average weekly precipitation. Models were ranked using Akaike's information criterion corrected for small sample size (AICc) and included with each model is the number of parameters (K), AICc difference between model of interest and model with lowest AICc ( $\Delta$ AICc), model weight (AICcwt) and log-likelihood estimate (LL).

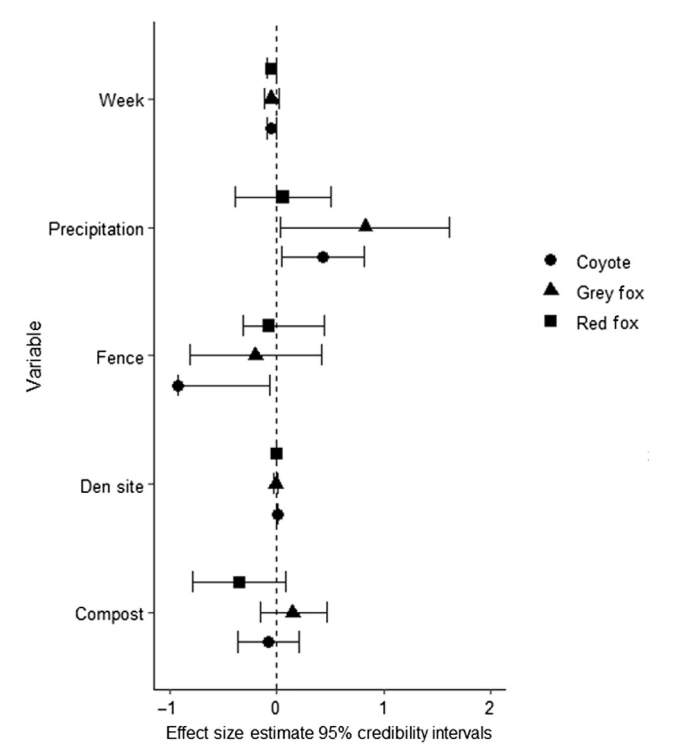
Coyotes and red fox were less likely to be detected later in the summer and coyotes and grey fox were more likely to be detected during rainy weeks. Therefore, we used week and average precipitation as the  $p_i$  covariates for all analyses of  $\psi$ .

The three candidate models predicting mesocarnivore occupancy that were within 2  $\Delta$ AICc units of one another all assumed pairwise dependence between species. These top models accounted for 36% of the weight of evidence (Table 3). Two of the top models included fence type, one of which also included compost piles in the model; however, credibility intervals overlapped for all species for effect of compost pile. The other model that received some weight of evidence was the area of shelter sites (Table 3 and Supplementary material Table S1). Fences reduced coyote  $\psi$  ( $\beta = -0.92$ , 95% CI:  $-0.93, -0.07$ ) but coyote  $\psi$  increased when sheltering area was abundant ( $\beta = 0.01$ , 95% CI: 0.00, 0.01) (Fig. 2). We found no evidence that any of the measured covariates influenced  $\psi$  of red or grey fox (Table 4).

We found that  $\Psi$  of all our study species increased if another species was also present in that yard (Table 5).

**Table 3.** Model selection statistics for detection ( $p_i$ ) and occupancy probability ( $\psi$ ) of coyote (*Canis latrans*), grey fox (*Urocyon cinereoargenteus*), and red fox (*Vulpes vulpes*) in residential yards on the basis of a 2-year study conducted in 2021 and 2022 in north-western Arkansas, USA. Only top candidate models, models within two  $\Delta$ AICc, are presented. Covariates of occupancy included surrounding landscape and yard features and the interaction of average precipitation and week of the survey were set at the covariates of detection. Models were ranked using Akaike's information criterion corrected for small sample size (AICc) and included with each model is the number of parameters (K), AICc difference between model of interest and model with lowest AICc ( $\Delta$ AICc), model weight (AICcwt) and log-likelihood estimate (LL).

Model	K	AICc	$\Delta$ AICc	AICcWt	LL
$\Psi(\text{fence}), p(\text{precipitation} + \text{week})$	18	0.00	0.00	0.17	−1225.85
$\Psi(\text{fence} \times \text{compost}), p(\text{precipitation} + \text{week})$	18	1.12	1.12	0.10	−1226.41
$\Psi(\text{den site}), p(\text{precipitation} + \text{week})$	18	1.35	1.35	0.09	−1226.53



**Fig. 2.** 95% credibility intervals for covariates from our top *a priori* models evaluating detection ( $p$ ) and occupancy probability ( $\psi$ ) of coyote (*Canis latrans*), grey fox (*Urocyon cinereoargenteus*), and red fox (*Vulpes vulpes*) occurring in residential yards during the summers of 2021 and 2022 in north-western Arkansas, USA.

This relationship was strongest for coyote, given that a red fox was present, with grey fox having the weakest influence from coyote presence.

Relative abundance

We found little evidence for the effects of covariates influencing the relative abundance of coyote or red fox in a yard and the null model was the top-ranked model for both species. We found two top models for grey fox relative abundance within two  $\Delta AIC_c$  that accounted for 42% of the weight of evidence (Table 6). Both top models included poultry presence and the top model also included forested area (Table 6). These models suggest that relative abundance of grey fox was highest in yards with a chicken coop (model-averaged  $\beta = 0.06$ , 95% CI: 0.01–0.3) (Fig. 3).

Species temporal overlap

When assessing the activity times of our focal species, we found that they were all predominantly nocturnal. All species had peak activity levels approximately at midnight. Coyotes and grey fox had an 87.8% temporal overlap (95% CI: 79.0–95.3) (Fig. 4) and coyotes and red fox had an 89.6% temporal overlap (95% CI: 84.7–94.4) (Fig. 4). Grey and red fox had a temporal overlap of 78.1% (95% CI: 68.5–87.0) (Fig. 4).

**Table 4.** Top three models with beta values showing influence of different site covariates affecting occupancy ( $\psi$ ) and detectability ( $p$ ) of coyotes (*Canis latrans*), grey fox (*Urocyon cinereoargenteus*), and red fox (*Vulpes vulpes*) in residential yards on the basis of a 2-year study conducted in 2021 and 2022 in north-western Arkansas, USA.

Species	Model	$\psi$ (fence)	$\psi$ (compost)	$\psi$ (shelter site)	$p$ (rain)	$p$ (week)
Coyote	$\Psi$ (fence), $p$ (rain + week)	−0.92 (95% CI = −0.93, −0.07)	−	−	0.43 (95% CI = 0.05, 0.82)	−0.05 (95% CI = −0.09, −0.01)
	$\Psi$ (fence + compost), $p$ (rain + week)	−0.50 (95% CI = −0.93, −0.07)	−0.08 (95% CI = −0.37, 0.21)	−	0.43 (95% CI = 0.05, 0.82)	−0.05 (95% CI = −0.09, −0.01)
	$\Psi$ (shelter site), $p$ (rain + week)	−	−	0.01 (0.00, 0.01)	0.44 (95% CI = 0.05, 0.81)	−0.05 (95% CI = −0.09, −0.01)
Grey fox	$\Psi$ (fence), $p$ (rain + week)	−0.20 (95% CI = −0.82, 0.42)	−	−	0.83 (95% CI = 0.03, 1.61)	−0.05 (95% CI = −0.12, 0.02)
	$\Psi$ (fence + compost), $p$ (rain + week)	−0.18 (95% CI = −0.80, 0.43)	0.15 (95% CI = −0.15, 0.47)	−	0.82 (95% CI = 0.03, 1.61)	−0.05 (95% CI = −0.12, 0.02)
	$\Psi$ (shelter site), $p$ (rain + week)	−	−	−0.01 (−0.03, 0.01)	0.82 (95% CI = 0.03, 1.61)	−0.05 (95% CI = −0.12, 0.02)
Red fox	$\Psi$ (fence), $p$ (rain + week)	−0.07 (95% CI = −0.31, 0.45)	−	−	0.06 (95% CI = −0.39, 0.51)	−0.05 (95% CI = −0.09, −0.01)
	$\Psi$ (fence + compost), $p$ (rain + week)	−0.06 (95% CI = −0.32, 0.45)	−0.35 (95% CI = −0.79, 0.08)	−	0.06 (95% CI = −0.39, 0.50)	−0.05 (95% CI = −0.09, −0.01)
	$\Psi$ (shelter site), $p$ (rain + week)	−	−	0.00 (>0.00, 0.00)	0.06 (95% CI = −0.39, 0.50)	−0.05 (95% CI = −0.09, −0.01)



**Table 5.** Conditional  $\psi$  values showing influence of interspecific interactions of coyote (*Canis latrans*), grey fox (*Urocyon cinereoargenteus*), and red fox (*Vulpes vulpes*) in residential yards on the basis of a 2-year occupancy study conducted in 2021 and 2022 in north-western Arkansas, USA.  $\psi$  of Species A, given that Species B occupies a site ( $A \times B$ ).

Species interaction	Conditional occupancy
Coyote $\times$ grey fox	0.55
Coyote $\times$ red fox	0.58
Grey fox $\times$ coyote	0.15
Grey fox $\times$ red fox	0.17
Red fox $\times$ coyote	0.45
Red fox $\times$ grey fox	0.50

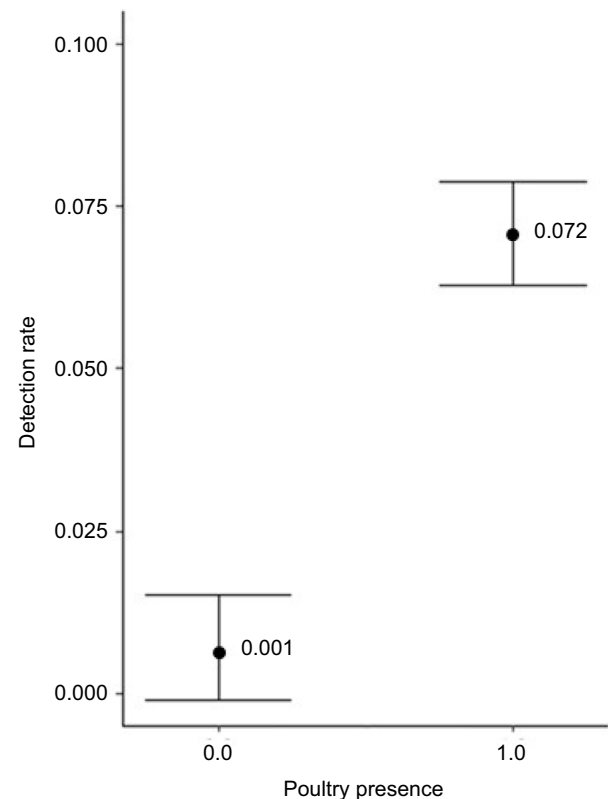
**Table 6.** Model selection statistics for detection of grey fox (*Urocyon cinereoargenteus*) in residential yards on the basis of a 2-year study conducted in 2021 and 2022 in north-western Arkansas, USA. Only top candidate models, models within two  $\Delta\text{AICc}$ , are presented. Covariates of occupancy included surrounding landscape and yard features, and the interaction of average precipitation and week of survey were set at the covariates of detection. Models were ranked using Akaike's information criterion corrected for small sample size ( $\text{AICc}$ ) and included with each model is the number of parameters ( $K$ ),  $\text{AICc}$  difference between model of interest and model with lowest  $\text{AICc}$  ( $\Delta\text{AICc}$ ), model weight ( $\text{AICcwt}$ ) and log-likelihood estimate (LL).

Model	$K$	$\text{AICc}$	$\Delta\text{AICc}$	$\text{AICcwt}$	LL
Poultry presence + forest	4.00	-445.66	0.00	0.27	226.98
Poultry presence	3.00	-444.44	1.22	0.15	225.31

Most of our focal mesocarnivores were not detected during the same night in the same yards. For example, grey fox and coyote detections were, on average, 4 ( $\pm 5.5$  s.d.) days apart (min: 0; max: 22). Coyote and red fox had the longest separation between detections, with an average of 12 ( $\pm 19$ ) days (min: 0; max: 88). Grey fox and red fox were separated by an average of 7 days ( $\pm 4.4$ ) days (min: 0; max: 33). If the species were detected within the same 24-h period, we calculated the average time between detections and found that coyote and grey fox had an average of 11 ( $\pm 9.7$ ) h between detections (min: 0.4; max: 23.5) at nine sites where they were both detected within the same 24-h period. Coyotes and red fox had an average of 7.6 ( $\pm 7.6$ ) h between detections at 15 sites (min: 0.96; max: 22). Red and grey fox were detected within the same 24-h period at only two sites and were detected an average of 14 ( $\pm 5.9$ ) h apart (min: 10.14; max: 18.5).

## Discussion

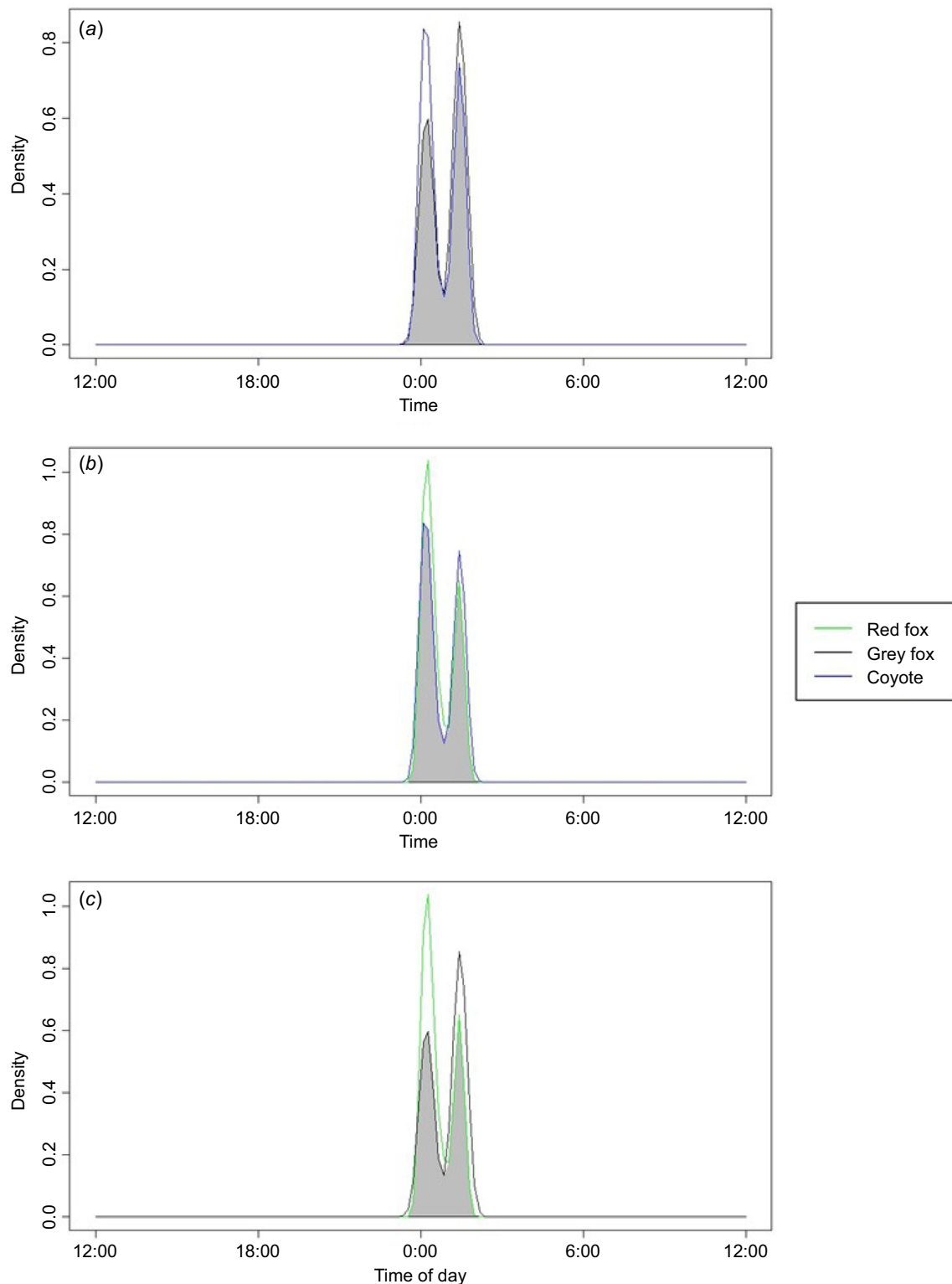
Contrary to our predictions, food resources provided by homeowners in residential yards were not the top factors explaining patterns in occupancy for coyote, red fox, or



**Fig. 3.** Influence of poultry presence on relative abundance of grey fox (*Urocyon cinereoargenteus*) in residential yards on the basis of a 2-year occupancy study conducted in 2021 and 2022 in north-western Arkansas, USA. Values are means with 95% credibility intervals.

grey fox. However, we did find evidence that the relative abundance of grey fox was highest in yards with chickens, although our top model also included forested area. Curiously, Kays and Parsons (2014) and Hansen *et al.* (2020) did not find an association between grey fox and chicken coops. Previous studies have shown that these and other mesocarnivores are attracted to yards on the basis of food resources such as compost piles and bird feeders (Murray *et al.* 2015; Hansen *et al.* 2020; Saad *et al.* 2020). We had expected to find a stronger effect because many mesocarnivores found in suburban areas have been shown to have diets consisting of human-subsidised food items (Bateman and Fleming 2012; Murray *et al.* 2015; Hansen *et al.* 2020).

We also predicted that shelter availability would influence occupancy and relative abundance of our focal species. Red foxes have frequently been documented denning and sheltering in suburban habitats (Gosselink *et al.* 2003; Vuorisalo *et al.* 2014). There is also evidence that coyotes can shelter in residential yards (Way *et al.* 2001; Grubbs and Krausman 2009; Raymond and St Clair 2022). However, we found only modest evidence that coyote occupancy increased in yards with abundant shelter opportunities and no evidence that red fox or grey fox occupancy or relative abundance was



**Fig. 4.** Kernel temporal overlap between species across all sites within a 2-year study conducted in 2021 and 2022 in residential yards in north-western Arkansas, USA. (a) Grey fox (*Urocyon cinereoargenteus*) and coyote (*Canis latrans*). (b) Red fox (*Vulpes vulpes*) and coyote (*Canis latrans*). (c) Grey fox (*Urocyon cinereoargenteus*) and red fox (*Vulpes vulpes*).

influenced by shelter availability in yards. This finding is surprising, given the well-documented history of red fox

denning in yards as well as observations during this study of red fox denning in some of the study yards. Not only do

red foxes frequently shelter in residential yards, but they prey on smaller species that are likely to be attracted to sheltering sites, such as groundhog (*Marmota monax*), eastern cottontails (*Sylvilagus floridanus*) etc. (Linduska 1947; Goguen *et al.* 2015; Moll *et al.* 2018).

Our study found compelling evidence that fences can be used to keep coyotes out of yards. Although coyotes have some ability to climb fences (Thompson 1979), it is unlikely that they can or are willing to climb all fence types. It appears that they spend less time in fenced yards than in unfenced yards. Hansen *et al.* (2020) also found that fences were a deterrent to larger mammalian species in yards (Hansen *et al.* 2020). This is a positive outcome for homeowners unwilling to share their space with coyotes (Baker and Timm 1998). However, in some areas of the United States, 86% of suburban lawns are fenced (Ossola *et al.* 2019; Van Helden *et al.* 2020), which is likely to create fragmentation and barriers to wildlife species such as the coyote.

Our study had several shortcomings that may have contributed to the lack of support for our predictions. We found no support for landscape variables influencing patterns of occupancy or relative abundance and believe that this may be due to the fact that our study area was largely forested. Perhaps a study conducted in a more heterogeneous landscape may find different results. It is also possible that evaluating our data on a different scale or multiple spatial scales could lead to different inferences (McGarigal *et al.* 2016). Finally, our selection of yards might not have been truly representative of the spectrum of available wildlife resources. Although we attempted to choose yards representing the full range of available resources, the majority of our volunteers were from the Arkansas Master Naturalists, a demographic that may be more prone to feeding birds, gardening for wildlife, and providing natural resources than is the public at large.

Although our species can be flexible in their activity, we found that they were overwhelmingly nocturnal in residential yards, having peak activity times from 23:00 hours to 3:00 hours (Fig. 4). This condensing of activity time is most likely to be due to an avoidance of human activity (Gaynor *et al.* 2018; Gallo *et al.* 2022; Green *et al.* 2022; Mims *et al.* 2022). Because these species are pushed to all be active at the same time in the suburban environment, and our results suggest that they choose yards for similar reasons (Fig. 4) (Larson *et al.* 2015), they are likely to be using a form of spatio-temporal partitioning to avoid using the same yards during the same days (Gosselink *et al.* 2003; Mueller *et al.* 2018). This is supported as detections of multiple species in the same yard were spread out by numerous days. Our study found it relatively rare to detect multiple mesocarnivores in a yard within less than 24 h, having only 16 yards in which this occurred. We found that our species were detected an average of 11 days apart. Other studies also showed that when these species overlap in territory (i.e. a yard), foxes tend to shift when and where they are active to avoid encountering

coyotes (Moll *et al.* 2018; Mueller *et al.* 2018; Cervantes *et al.* 2023).

Our study is a representation of how three mesocarnivore species use residential yards in north-western Arkansas. We found that at least one of our focal species (coyote) was detected in 74% of our surveyed residential yards. Because the number of suburban residential yards continues to grow across the country, the factors that bring mesocarnivores to yards and how to mitigate the conflicts that will likely arise (Bolger *et al.* 2001; Hansen *et al.* 2020) are areas for future research. Although large mesocarnivores often face public persecution, they continue to persist in suburban areas despite fear of them and widespread negative public perception (Bonnell and Breck 2016). Homeowners do have some agency in how they manage their yards and how these resources either attract or deter mesocarnivores.

## Supplementary material

Supplementary material is available [online](#).

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