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Research article

Effects of landscape cover and yard features on feral and free-roaming cat (*Felis catus*) distribution, abundance and activity patterns in a suburban area

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Abstract

Feral and free-roaming domestic cats (*Felis catus*) are invasive predators throughout the world. In some areas, cats occur in higher densities than native mammalian predators and can have severe effects upon prey populations. We set 48 wildlife game cameras in residential yards in Arkansas, USA, to evaluate which landscape and yard features influenced cat abundance occurring in yards. In addition, we quantified the daily activity patterns of free-roaming cats and explored how habitat features or predator activity influenced the timing of cat activity. We found that cats were present in 70.8% of yards with an average of three recognizable individuals per yard. Abundance of cats was higher than all native mesopredators except for raccoon (*Procyon lotor*) and Virginia opossum (*Didelphis virginiana*). Cat abundance and minimum population decreased when forest cover was high within 400 m of the camera. Cats were active at all times of the day but tended to be more diurnal in areas closer to city centers or in agricultural settings. Conversely, cats were more nocturnal later in the summer and in areas that had high levels of predator activity. Our results indicate that cats are widespread in this region and their relative abundance is driven more by landscape features than by yard features, possibly due to their large home ranges. Cats may alter their activity to better coexist with predators. Alteration in yard features is unlikely to be an effective deterrent for cats and more direct control measures may be necessary.

Key words: activity patterns, camera trap, relative abundance, residential yards, urbanization, yard features

Introduction

Feral and free-roaming domestic cats (*Felis catus*) are a global conservation problem and have contributed to multiple wildlife extinctions throughout the world (Nogales et al. 2004; Doherty et al. 2016). It has been estimated that there are more than 100 million feral and outdoor cats in the USA alone (Jessup 2004). In some areas of the USA, cats are one of the most frequently seen wildlife species and can occur at higher densities than native co-occurring mesopredators (Odell and Knight 2001; Thomas, Baker, and Fellowes 2014; Carter 2019). Given their density and hunting efficiency, cats are high-impact invasive species and in the USA alone, they are estimated to kill over one billion birds a year (Loss, Will, and Marra 2013) including species of special conservation concern (Lepczyk, Mertig, and Liu 2004). Free-roaming domestic cats have also been found to prey on reptiles, small mammals, invertebrates and to some extent, amphibians (Nogales et al. 2013). Because free-roaming domestic cats are so widespread and can depress prey populations (Cypher et al. 2017), it is important to understand where on the landscape cats occur and when they are most active as they kill prey which can affect native mammalian predators, such as red fox (*Vulpes vulpes*), bobcats (*Lynx rufus*) and coyotes (*Canis latrans*).

Because free-roaming cats can be pets, it is unsurprising that several studies have shown that cat densities are higher when closer to homes (Odell and Knight 2001; Bird 2021). Similarly, cats are encountered less frequently in landscapes with high forest cover (Cove et al. 2018; Bird 2021). However, cats have been shown to use agricultural areas and grasslands, particularly for hunting or traveling between housing areas (Gehring and Swihart 2003; Horn et al. 2011; Thomas, Baker, and Fellowes 2014). In some areas, cats may simply be ubiquitous across the landscape and may use the environment at random, without favoring any particular landcovers (Gehring and Swihart 2003).

In addition to the influence of landscape cover on the distribution of cats, particular yard features can influence where cats occur; however, this has been less studied than landscape level habitat associations. Urban carnivores often exploit residential yards as places of shelter and denning sites, using sheds/outbuildings as well as under porches or housing foundations (Bateman and Fleming 2012; Hansen et al. 2020). These sources of shelter have been found to be a key resource allowing coexistence between predators and prey including dominant and subordinate mesopredators, i.e. coyotes and cats respectively (Moll et al. 2018). Cats are more likely to occur in yards without coyotes, so features that have been found to attract coyotes, such as water sources and compost piles, could be deterrents to free-roaming domestic cats (Kays et al. 2015). However, some features may attract cats because they concentrate prey (Hansen et al. 2020). For instance, features such as bird feeders may be particularly attractive hunting grounds for cats. Yard features can strongly influence the local prey which may attract cats to particular yards (Hansen et al. 2020).

Like many mammalian predators, cats are capable of hunting during the day or night (Andelt 1985; Grinder and Krausman 2001). Furthermore, these daily activity patterns are often influenced by development (Gese, Morey, and Gehrt 2012; Cove et al. 2018) or the activity patterns of their predators or prey (Arias-Del Razo et al. 2011). Understanding what factors influence when cats or other predators are active, as well as describing their activity patterns, provides insights into the potential impacts on their prey. For instance, cats hunting during the day are more likely to prey on songbirds and lizards, while cats hunting at night may have more of an impact on small mammals.

Given the threat that free-roaming domestic cats pose to wildlife conservation worldwide, our objectives were to use motion-triggered wildlife cameras to identify factors that influence free-roaming domestic cat occurrence and activity across a suburban landscape. Specifically, our objectives were to (i) identify landscape cover variables that influence the abundance of cats in yards, (ii) identify yard features that are linked to cat abundance and (iii) describe the activity patterns of cats and to evaluate if landscape and predator variables influenced when during the diel period, they were active.

Methods

Study sites

Our study took place from 4 April to 4 August 2021 in the greater Fayetteville, AR, USA, area. Fayetteville is a rapidly growing city of approximately 349,000 people located in the Ozark Highlands ecoregion. The landscape is primarily forested by mixed hardwood trees with open areas used for cattle pastures and agriculture. Our study took place in residential yards ranging from downtown Fayetteville to more rural households ∼50 km from downtown Fayetteville. We solicited volunteers from the Arkansas Master Naturalist Program and the University of Arkansas Department of Biological Sciences who allowed us to place motion-triggered wildlife cameras in their yards. We attempted to choose yards that represented a continuum of urban to suburban to rural settings.

Camera setup

To document the presence of cats and other wildlife, we simultaneously deployed 48 motion-triggered wildlife cameras (Browning StrikeForce or Spypoint ForceDark). We placed cameras ∼0.95 m above the ground on either a tripod or a tree. We placed cameras within 100 m of houses and the majority of cameras were ∼15 m from houses. When possible, we positioned cameras near features such as compost piles, water sources (natural or man-made) and fence lines to maximize the detection rate of cats and other wildlife. We coordinated with homeowners to choose locations that would not interfere with yard maintenance or compromise homeowner privacy. When necessary, we removed vegetation that obscured the field of view of cameras. We set cameras to trigger with motion and take bursts of three photographs per trigger with a 5-s reset time. We did not use any bait or lures. Every 2–4 weeks cameras were checked for function, batteries were replaced if needed and data were downloaded. All cameras were set and left in place for the entirety of the study and were not moved between locations.

Yard features

In each yard, we recorded seven yard features predicted to influence the presence of free-roaming domestic cats (Table 1). We recorded the (i) number of bird feeders, (ii) area of denning site: defined as the total area available for wildlife under sheds, outbuildings and decking on the ground, (iii) the volume of brush and firewood piles, (iv) total area of gardens (any maintained garden area), (v) the presence or absence of poultry, (vi) the ownership of pet cats and if pet cats were allowed outdoors or not and (vii) if the camera was placed within a fenced area and if so how permeable the fence was to wildlife. We scored fences by how much we thought they would or would not interfere with the passage of wildlife. Fences that were barbed wire or widely spaced wooden beams or slats, anything a mammal could easily pass through were categorized as 1. Category 2 consisted of fences about 1 m in height that had semi spaced wood slats that offered enough room for an animal to squeeze through. Fences that were at least 1 m in height and generally impassable but for climbing animals or small-bodied wildlife were Category 3 (i.e. chain-link fences). Category 4 created the largest obstacle to wildlife, as they were fences at least 2 m tall and made from a solid, impermeable substance. We used bird feeders, brush and firewood piles, area of gardens and the presence/absence of poultry in our analyses because we predicted that these features influenced the prey base for cats to hunt. We predicted that the total area of denning sites and the type of fence around cameras would be important as they provide safety to cats from larger mammalian predators. We included the presence of a pet cat because this could serve as either a deterrent or a lure for free-roaming domestic cats.

Photo processing

We used timelapse 2.0 (Greenberg et al. 2019) to extract metadata (e.g. date, time) from photos and to assign species ID and the number of individuals present in each sequence of

Table 1: Description of all variables used in analyses of relative abundance, minimum population and activity patterns of free-roaming domestic cats (*Felis catus*) in yards in and around Fayetteville, AR, USA, during the summer of 2021

Landscape variables	
Forest cover	Area of forest cover within 400 m buffer
Open land	Area of open land, land used for parks, cemeteries and lawn space, within 400 m buffer
Agricultural land	Area of land used for agricultural purposes within 400 m buffer
Housing unit density (HUD)	Maximum HUD within 400 m buffer of camera (houses/km^2)
Developed land	Area of developed land within 400 m buffer
Distance to downtown	Distance to nearest downtown center (km)
Yard variables	
Area of denning sites	Area under sheds/outbuildings and under decks near the ground where cats can take refuge
Volume of brush/firewood piles	Total volume of denning sites including brush and firewood piles
Presence of pet cats	Did the property owner have a pet cat? If not, cat(s) were assigned a ‘0’
Indoor	Cat(s) kept indoors were assigned a ‘1’
Outdoor	Cat(s) allowed outdoors were assigned a ‘2’
Bird feeder	Number of bird feeders present in yard
Garden	Area of total maintained gardens
Fence	If a camera was within a fence, it was given a score between 1 and 4, 1 being the least restrictive to wildlife passage and 4 being the most
	0: Not in a fence
	1: Barbed wire
	2: Open slat fence
	3: 4-ft chain-link or privacy
	4: 6-ft chain-link or privacy
Poultry	Presence or absence of poultry being kept in yard
Relative abundance (RA) variables	
RA of dogs	Number of domestic dogs detected divided by trap nights
RA of predators	Number of bobcats, coyotes, red and gray foxes detected at a camera site divided by the number of trap nights

photographs. Photos taken within a 5-min period were grouped into one sequence and considered a unique detection.

At each camera, we calculated the relative abundance (or detection rate) of potential predators of cats [coyote, bobcat, gray fox (*Urocyon cinereoargenteus*) and red fox] and domestic dogs (*Canis familiaris*). We defined relative abundance as the total number of sightings of each species or group of species divided by the number of days the camera was active. We calculated these variables because we predicted they would influence the presence of free-roaming domestic cats in a yard. Relative abundance of domestic dogs was used in place of a binary variable for owning a dog, as some yards without a pet dog had frequent visitation by dogs.

We analyzed two metrics of free-roaming cat abundance. The first is cat relative abundance which is synonymous with detection rate (we will refer to it as relative abundance hereafter) and defined as the number of cat detections in a yard divided by the number of trap nights. This index of abundance is commonly used in camera trap studies and is often a reliable index of true abundance (Gerber et al. 2010; O’Brien 2011). However, we also included another metric that took advantage of the unique pelage of most cats. For each yard, we calculated the minimum number of cats detected (referred to hereafter as minimum population of cats). To calculate this, we attempted to identify each individual cat detected at each camera. We identified cats to individual by their coat colors and patterns, the presence of collars, body size, scars or other unique features. This method was effective for many cats but likely underestimated the amount of fully black cats due to a lack of distinguishing characteristics. Thus, our estimate of cat abundance is likely an underestimate of the number of individuals using a yard. Mark-recapture studies of cats have shown that game cameras often document the total number of cats present within an area if left in place for ~2 months (Bird 2021). We did not distinguish between feral cats and pet cats.

Landscape variables

We used GIS (ArcGIS Pro 10.2; ESRI, Inc., Redlands Inc) to plot the location of all cameras and to quantify the land use of the surrounding landscape. We first created 400-m buffers around each camera; this area should encapsulate the average home range of both pet and feral cats (Horn et al. 2011). Within each buffer, we calculated the area of forest cover, the area of open land (e.g. cemeteries, parks and grass lawns), and the area of agriculture using the 2016 National Land Cover Database (Dewitz 2019). We also quantified the maximum housing unit density (HUD) around each camera using the SILVIS Housing Data Layer (Hammer et al. 2004). Finally, we calculated the straight-line distance from each camera to the nearest downtown city center (Fayetteville, Rogers, Bentonville or Eureka Springs). Distance to downtown is an additional index of urbanization and human activity that has been correlated with animal behavior in this area (DeGregorio et al. 2021).

Variable inclusion and model fit

Before we began analyses, we conducted collinearity tests to evaluate relationships between variables. We considered two variables to be collinear if they had correlation coefficients $\geq|0.6|$. From those we would then decide which of the two variables were more meaningful and only include that variable in subsequent analysis. We found that developed land and forest were highly correlated, $r^2 = -0.72$. Since we already included a measure of human impact (HUD) we chose to retain forest cover going forward and to exclude development. We also found a high correlation between the area of gardens and the volume of brush/firewood piles and subsequently removed brush/firewood piles from analyses. All other variables were retained. We scaled and centered all landscape variables by subtracting the mean and dividing by the standard deviation (SD) to allow comparison with variables measured on a different scale.

Statistical analyses: relative abundance and minimum population

To quantify the relationship between abundance and minimum population of cats observed in a yard and landscape, yard and activity variables, we used a generalized linear model in R 4.12 (R Core Team 2021). We used an information theoretic approach [Akaike's information criterion (AIC)] to rank candidate models (Burnham and Anderson 2002). We included a global model (with all variables included) as well as a null model and simple, single-variable models for each of our retained variables (HUD, agricultural land, open land, forest cover, distance to downtown, denning sites, bird feeders, garden area, pet cats, presence of poultry, relative abundance of predators and presence of a fence). We also included models consisting of all additive two-way combinations of the variables (Supplementary Appendix A). We used the same candidate model set for both the relative abundance and minimum population of free-roaming domestic cat data separately (Supplementary Appendix B). Initial exploratory analyses indicated that relationships between most predictor variables and response variables were linear, and thus, models were not altered. We performed all model fitting in R (R Core Team 2022) with the AICcmodavg package (Mazerolle 2020).

To improve clarity in presenting model selection tables, we only display models that were competitive within 2 ΔAIC for relative abundance although full model rankings are shown in Indices A–C. Similarly, when applicable, parameter estimates were derived by averaging all models within 2 ΔAIC (Burnham and Anderson 2002) (Table 2).

Daily activity patterns

To explore the daily activity patterns of free-roaming cats, the timing of each cat detection was determined. We then calculated the time of each sunset for each camera for each day of the study using the R package 'suncalc' (Thieurmel and Elmarhraoui 2022). Detection of timing was then compared to the daily sunrise and sunset time. Detections that occurred within 30 min of sunrise or sunset time were labeled crepuscular. Timings that occurred outside of that period, but between sunrise and sunset were considered diurnal. Any detection outside of the crepuscular criteria, but between sunset and sunrise, was considered nocturnal.

To explore variables that influenced free-roaming cat activity, we used linear mixed models in R with the 'lme4' package (Bates et al. 2015). The yard was used as the random effect, and 'diurnal' was set as our reference category. For free-roaming cat activity (Supplementary Appendix C), we used the same combination of variables used in the relative abundance (Supplementary Appendix A) and minimum population analyses (Supplementary Appendix B) described above. Model goodness-of-fit was similarly assessed in our top models using residual plots.

Results

Cat abundance and minimum population

We deployed cameras in 48 yards for a total of 4107 trap nights. Cats were detected in 34 of the 48 (70.8%) yards. Using visual characteristics, we identified a total of 96 individual cats with an average of 2.97 ± 1.89 (±1 SD) individuals per yard. Yards ranged from having 0 cats ($n = 17$ yards) to a maximum of 8 individuals ($n = 1$ yard). Cats were detected at higher rates than most native mesopredators, apart from raccoons and Virginia opossums (Fig. 1).

Both the relative abundance and minimum population of free-roaming domestic cats were best predicted by area of forest within 400 m of a camera site. For relative abundance, forest appeared in 7 of the 11 top models paired with fence type, open land, garden area, presence of pet cats and HUD (Table 2). Cumulatively, all 11 models accounted for 40.5% of the weight of evidence. Forest was negatively associated with relative abundance of free-roaming domestic cats indicating that cats were more likely to occur in areas with less forested area around the yard (Fig. 2), although this effect was relatively modest [model-averaged $\beta = -0.15$, 95% confidence interval (CI): −0.31 to 0.00]. Area of open space appeared in 4 of the 11 top models and accounted for 13% of the weight. Open space was positively associated with relative abundance of free-roaming cats. However, because the model-averaged parameter estimate

Table 2: Model selection statistics for relative abundance of free-roaming domestic cats (*Felis catus*)

Models	K	AICc	Delta_AICc	ModelLik	AICcWt	LL	Cum.Wt
Fence + forest	4	70.769	0	1	0.063757	−30.908	0.063
Forest	3	70.882	0.113	0.944	0.060	−32.162	0.123
Forest + open	4	71.701	0.931	0.627	0.040	−31.374	0.164
Open	3	71.895	1.126	0.569	0.036	−32.668	0.200
Abundance of domestic dogs + forest	4	71.907	1.1381	0.566	0.036	−31.477	0.236
Garden + forest	4	71.991	1.222	0.542	0.034	−31.519	0.271
Pet Cat + forest	4	72.294	1.525	0.466	0.029	−31.671	0.300
Fence + open	4	72.368	1.599	0.449	0.028	−31.708	0.329
HUD	3	72.588	1.818	0.402	0.025	−33.015	0.355
HUD + forest	4	72.597	1.828	0.400	0.025	−31.822	0.380
HUD + open	4	72.613	1.843	0.397	0.025	−31.830	0.405

Only top candidate models within 2 ΔAICc are presented. Predictor variables of relative abundance included surrounding landscape and yard variables. Models were ranked using Akaike's information criterion for small sample sizes (AICc) and included with each model is the number of parameters (K), AICc difference between model of interest and model with lowest AIC (ΔAICc), model weight (AICwt) and log-likelihood estimate (LL).

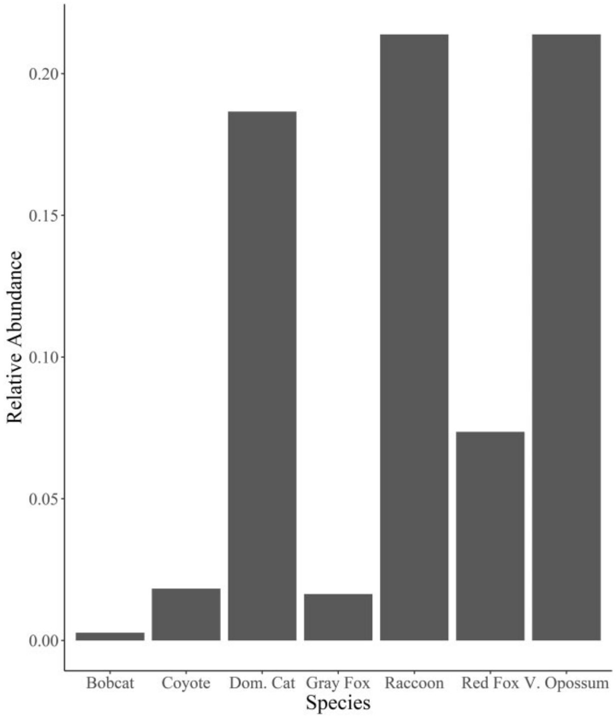

Figure 1: Free-roaming cat (*Felis catus*) relative abundance (±1 standard deviation) in yards in and around Fayetteville, AR, in relation to the detection rate of native mammalian predators encountered at the same sites

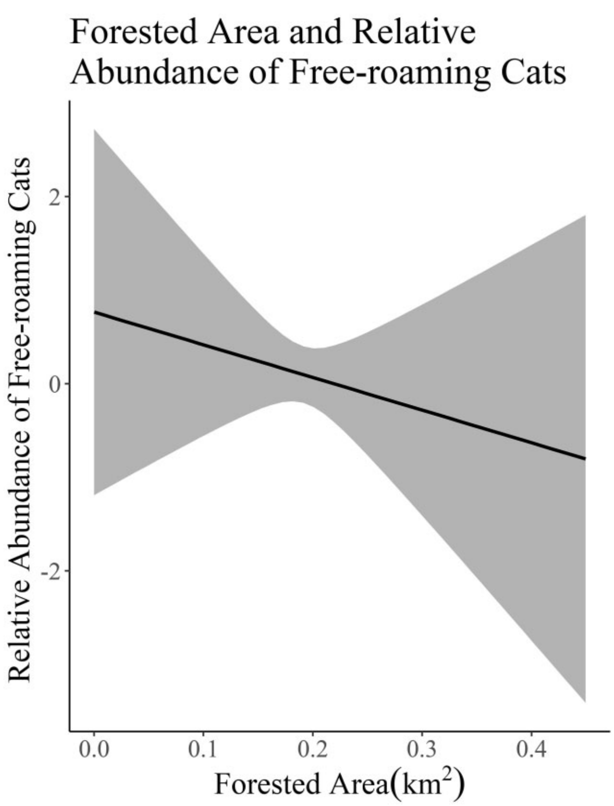

Figure 2: Influence of forest cover (km^2) within a 400-m buffer of a motion-trigger camera in a suburban yard on the relative abundance of free-roaming cats (*Felis catus*). 95% confidence intervals are presented using a gray band

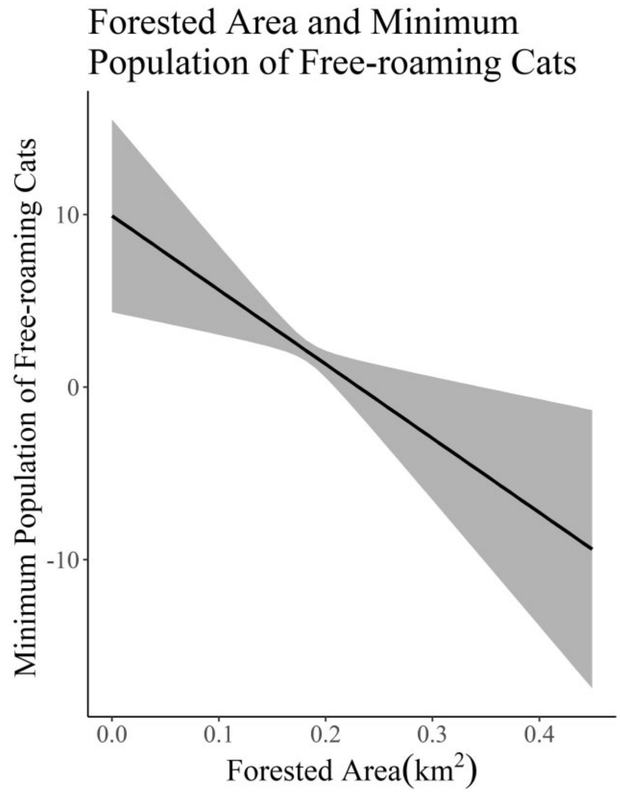

Figure 3: Influence of cover (km^2) of forest within a 400-m buffer of a camera site on the relative abundance of the minimum population of cats (*Felis catus*) in yards of homes in Northwest Arkansas. 95% confidence intervals are presented using a gray band

confidence intervals overlapped zero (model-averaged $\beta = 0.14$, 95% CI: −0.02 to 0.29), there is considerable uncertainty regarding the effect of this model.

Minimum cat population was also most influenced by forest cover. Forest appeared in the top model paired with area of garden. This model accounted for 29.8% of the weight of evidence and no other model was within 2 AIC units (Supplementary Appendix B). Forest cover was negatively associated with minimum population of free-roaming domestic cats ($\beta = -0.79$, 95% CI: −1.35 to −0.24), indicating that more free-roaming cats were in areas with less forested area around the yard (Fig. 3).

Cat activity

We detected cats during the day, night and during crepuscular periods. Of these detections, ∼50.3% were nocturnal, 39.5% were diurnal and 10.2% were crepuscular (data not shown).

The activity patterns of free-roaming domestic cats were best predicted by the relative abundance of domestic dogs at the camera site. The relative abundance of domestic dogs appeared in the top (Supplementary Appendix C). Cumulatively, this model accounted for 37.5% of the weight of evidence. Activity patterns of free-roaming domestic cats were negatively associated with relative abundance of domestic dogs ($\beta = -0.4$, 95% CI: −0.75 to −0.05), indicating that cats are more likely to be diurnal than crepuscular or nocturnal when there is an increase in domestic dog abundance in a yard.

Discussion

Cats have become an ubiquitous component of the human landscape and outnumber native mesopredators in many urban areas (Baker et al. 2010). Our results showed that free-roaming cats are widespread across our study area in Northwest Arkansas with cats documented in 73.2% of the yards studied, and the average residential yard being visited by 3 (+/1) individual cats. Cats in our study were detected at a higher rate than all native predators except raccoons and Virginia opossum (Fig. 1).

We found that cat relative abundance was not significantly linked to any yard features nor HUD. However, we did find that cat relative abundance was negatively affected by area of forest within 400 m of the yard. Though cats are a highly versatile generalist species, which can survive on almost any landscape type (Doherty, Bengsen, and Davis 2014), forested areas may simply be more dangerous to cats due to the presence of more predators such as coyotes. One study found that coyotes show a preference for forested areas especially those that are disturbed and near edges (Kays, Gompper, and Ray 2008), and when cats enter areas that overlap with coyote territories they tend to vanish (Davenport et al. 2022). This can have large implications for prey as studies have found that 80% of hunts performed by cats occurred in a yard or garden (Kays and DeWan 2004).

Although our study did not find housing unity density to be a reliable predictor of cat abundance, we found that forested area was strongly but negatively correlated with developed area, meaning that while cats are avoiding forested areas, they are also choosing areas with high levels of human development consistent with other studies (Cove et al. 2019). Other studies have found that cats tend to be found in areas with higher human subsidies such as food and shelter (Vanek et al. 2020; Bird 2021). Free-roaming domestic cats, regardless of owned status, select areas with higher urbanization than other species, most likely due to the protection from predators afforded by existence in urban landscapes (Gehrt et al. 2013). One reason that cats are often associated with areas of human development is because many of the free-roaming cats documented in this and other studies are likely pets whose home ranges center around their owner's home (Horn et al. 2011).

We found marginal evidence that cat abundance was influenced by open spaces such as cemeteries, yards and parks. Other studies have shown that open spaces have been linked to the persistence of smaller native mesopredators in developed areas (Gallo et al. 2017). Surprisingly, the presence of a pet cat at a home did not influence the abundance of cats detected in a yard. This suggests that the presence of pet cats does not act as either a deterrent or an attractant for other cats and that many of the individual cats documented at a yard do not belong to the homeowner.

We anticipated that the presence of cats at a site would be positively influenced by yard features that attract potential prey, such as bird feeders. Similarly sized native mesopredators, including raccoon and Virginia opossum have been shown to increase relative abundance in yards based on the presence of bird feeders (Hansen et al. 2020). However, we found no relationship between the number of cats in a yard and bird feeders. This may be because most yards included in this study had bird feeders ($n = 34$). However, we found no relationship between any yard features and cat relative abundance or minimum population size of cats. Our results suggest that cats are responding to habitat on a coarser scale and that individual yards are visited regardless of the features present.

We found that cats were active both during the night and during the day, a trait common to many mammalian predators (Andelt 1985). We found that activity patterns of free-roaming domestic cats were only significantly altered by relative abundance of dogs at a camera site. If dogs were detected more frequently at a site, cat detections were more likely to be within the diurnal period. Domestic dogs also tend to be diurnal (Silva-Rodríguez et al. 2021). Since dogs are known to deter predators, this finding suggests that dogs may be providing a shield to cats from native predators (Lenth, Knight, and Brennan 2008). Domestic dogs frequently rely on owners to let them out, namely during the day. However, work schedules can make the diurnal period an advantageous time to be in a yard with increased relative abundance of dogs. The dogs will be inside, and unable to inhibit cat presence, but other studies have found that even the residual scent of domestic dogs will deter other wildlife, which can be advantageous for free-roaming cats (Ugarte, Talbot-Wright, and Simonetti 2021).

Our results suggest that cats are relatively ubiquitous mesopredators within our suburban system and that most yards were visited by multiple individua cats regardless of the presence or absence of particular yard features. We found that landscape cover was more tied to cat abundance with cats negatively associated with forested cover. The ubiquitous presence of cats certainly has consequences for prey species and potentially for co-occurring native predators with which cats are likely competing. Unfortunately, our results indicate that there is relatively little that homeowners can do to manipulate their yards to deter cats. A reduction in free-roaming cats will have to come from homeowners keeping pet cats indoors and managers taking direct action to remove cats.

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Author contributions

Emily Johansson (Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing—original draft, Writing—review & editing [equal]) and Brett DeGregorio (Conceptualization [equal], Data curation [equal], Formal analysis [equal], Funding acquisition [lead], Investigation [equal], Methodology [equal], Project administration [lead], Writing—original draft [equal], Writing—review & editing [equal])

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Data availability

Data have been uploaded and are available via Dryad: https://doi.org/10.5061/dryad.kd51c5bb6.

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