



# The effects of landscape and yard features on mammal diversity in residential yards within Northwest Arkansas, USA

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## Abstract

The human footprint is rapidly expanding, and wildlife habitat is continuously being converted to human residential properties. Surviving wildlife that reside in developing areas are displaced to nearby undeveloped areas. However, some animals can co-exist with humans and acquire the necessary resources (food, water, shelter) within the human environment. This ability to coexist may be particularly true when development is low intensity, as in residential suburban yards. Yards are individually managed “greenspaces” that can provide a range of food (e.g., bird feeders, compost, gardens), water (bird baths and garden ponds), and shelter (e.g., brush-piles, outbuildings) resources and are surrounded by varying landscape cover. To evaluate which residential landscape and yard features influence the richness and diversity of mammalian herbivores and mesopredators; we deployed wildlife game cameras throughout Northwestern Arkansas, USA in 46 residential yards in summer 2021 and 96 yards in summer 2022. We found that mesopredator diversity had a negative relationship with fences and was positively influenced by the number of bird feeders present in a yard. Mesopredator richness increased with the amount of forest within 400 m of the camera. Herbivore diversity and richness were positively correlated to the area of forest within 400 m surrounding yard and by garden area within yards, respectively. Our results suggest that while landscape does play a role in the presence of wildlife in a residential area, homeowners also have agency over the richness and diversity of mammals using their yards based on the features they create or maintain on their properties.

**Keywords** Suburban · Backyard · Mesopredator · Herbivore · Diversity

## Introduction

Human development is converting wildlands to anthropogenic uses at an unprecedented rate and wildlife communities are being displaced and altered as a result (Wilby and Perry 2016). Since 1980, residential area growth in the United States has surpassed population growth by 25% (Theobald 2005). According to the Center for Sustainable Systems at the University of Michigan, residential areas now encompass more than 27.5 million ha in the United States. In these suburban areas, residential lawns account for approximately one third of the space (Mathieu et al. 2007; Giner et al. 2013;

Center for Sustainable Systems, University of Michigan 2021). Given that residential yards are ubiquitous across the suburban landscape, they can provide both habitat and connectivity for wildlife (Bolger et al. 2001). Despite the average size of a residential lawn in the United States being only 0.1 ha, these lawns could be considered independently managed “greenspaces” that can not only potentially offer a variety of resources to wildlife depending on the features present, but also connections to the surrounding landscapes (Daniels and Kirkpatrick 2006; Goddard et al. 2010; Hansen et al. 2020; Fardell et al. 2022; Grade et al. 2022).

Though landscape level variables likely take precedent over where a species can persist and travel to, residential yards often provide a number of human subsidized resources such as food, shelter and water (Goddard et al. 2010; Kays and Parsons 2014; Lepczyk et al. 2004; Lerman and Warren 2011; Murray and St. Clair 2017). Other similar residential yard studies have found that multiple types of wildlife including but not limited to reptiles, birds, and pollinators are all able to exploit human subsidized resources. Snakes

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have been found to utilize yard features that provide sites for basking (i.e. decorative rocks or metal structures), shelter, shedding, or hibernation (Zappalorti and Mitchell 2008). Birds and pollinators have both been found to benefit highly from human subsidized food resources, studies have found that these resources can even attract and sustain rare species in both taxa (Hostetler and McIntyre 2001; Lowenstein et al. 2015; Smallwood and Wood 2023). In fact when people plant native gardens of flowers and grasses, they have the ability to increase both the native bird and bee populations in their yards (Daniels and Kirkpatrick 2006; Pardee and Philpott 2014). The overall richness and diversity of mammals in human-dominated areas can be directly influenced by these yard features (Hansen et al. 2020). Humans supply both intentional and unintentional food sources for wildlife, by providing supplemental food (food left out for wildlife or bird feeders) and by leaving out waste, compost, or pet food (Reed and Bonter 2018). Similar studies have found that compost and gardens can have an enticing influence on mammals using yards (Hansen et al. 2020; Grade et al. 2022). The widespread planting of gardens (both ornamental and vegetable) provides an additional food resource, as well as shelter for many animals (Goddard et al. 2010). Some yards also provide water for wildlife in the form of birdbaths, fountains, or frog ponds. Finally, residential yards may unintentionally provide shelter and denning resources for wildlife that are able to burrow under decking and storage sheds or that seek shelter in stacked firewood and brush piles (Gross et al. 2011).

While some species of wildlife can adapt readily to residential environments, other species are intolerant of human activity and development and may be rare or absent in developed areas, (Ordeñana et al. 2010; Dorresteijn et al. 2015). Although opportunistic wildlife can take advantage of human-subsidized resources there are numerous challenges to wildlife co-existing in the residential environment. Suburban areas are louder, brighter, and have a higher density of roads than natural areas all of which can directly harm wildlife (road mortality) or indirectly stress wildlife (through fear, stress, or disruptions to their activity patterns (Ditchkoff et al. 2006; Bateman and Fleming 2012; Swaddle et al. 2015; Moll et al. 2018). Some species, particularly large-bodied predators (bobcats-black bears; 7.86–62.5 kg), may be perceived as threats to human safety or human property and may be persecuted or removal (Montgomery et al. 2020). Human pets including dogs and free-roaming cats not only kill innumerable wildlife in developed areas but can also increase stress to wildlife and alter critical activities such as foraging (Young et al. 2011; Loss et al. 2013; Mrcuer et al. 2017). Additionally suburban environments may be highly fragmented due to fences (Van Helden et al. 2020). These

fences can disrupt wildlife movement and create fragmentation and prevent access to resources (Jakes et al. 2018).

Despite the aforementioned challenges, some wildlife species can adapt to and sometimes thrive in human environments (McKinney 2006, 2008; Bateman and Fleming 2012). Mammalian species such as raccoons (*Procyon lotor*), Virginia opossums (*Didelphis virginiana*; hereafter opossum), red fox (*Vulpes vulpes*), striped skunk (*Mephitis mephitis*), groundhog (*Marmota monax*), white-tailed deer (*Odocoileus virginianus*), and cottontails (*Sylvilagus floridanus*) have become common throughout North American suburban landscapes. These species use anthropogenic food, water, and shelter available in residential yards. They can sometimes attain population densities higher than those in rural areas (Hadidian 2010). and opossum notoriously use a variety of food sources, from bird feeders to trash (Bozek et al. 2007), while striped skunks and red fox use anthropogenic structures as denning sites (Lesmeister et al. 2015; Moll et al. 2018). Mammalian herbivores are often considered pests in the suburban environment because their browsing and grazing behaviors can cause damage to both crops and residential gardens (Manning 2021). Smaller mammals such as woodchucks and cottontails may also benefit by living in residential yards because the proximity to humans may confer safety from their natural predators that may be wary of being near humans (Berger 2007; Moll et al. 2018; Gallo et al. 2017).

Because some species of mammals can survive and sometimes thrive in suburban areas, the potential for human-wildlife interaction and conflict increases. From an anthropogenic perspective, some of these interactions can be positive such as allowing for time spent viewing wildlife, which studies have shown can be beneficial for the relationship between people and wildlife (Soulsbury and White 2015). While other interactions can be negative such as destruction of resources, pet-wildlife conflict, and transmission of diseases such as distemper and rabies between wildlife and pets (Kapil 2011; Lepczyk et al. 2015; Frank et al. 2019). Understanding how wildlife associate with yard features can provide homeowners agency to increase or reduce interactions with particular wildlife (Hansen et al. 2020).

Northwest Arkansas is one of the fastest growing residential areas in the United States with the population of Fayetteville and surrounding towns expected to double by 2045 (Reynolds et al. 2017). Northwest Arkansas includes four major cities in the state (Fayetteville, Springdale, Rogers, and Bentonville), and all towns within Benton, Washington, and Madison County, Arkansas. As a result, wildlands are being converted to suburban cover and there is increased potential for human-wildlife conflicts in residential areas. Our objectives were to use motion-triggered wildlife

cameras to evaluate the mammalian wildlife associated with residential yards and to identify how surrounding land cover and yard features influence mammalian mesopredator and herbivore diversity and richness.

We focused on the broad guilds of mammalian herbivores and mesopredators based on how we anticipated species in each group would use each yard. Mesopredators in comparison to mammalian herbivores are omnivorous and could use a variety of food resources as well as resources that attract prey, they could also be associated with denning and shelter resources. Herbivores likely used yards primarily for access to gardens and ornamental shrubs to browse and forage on. We also separated these species as we expected them to be perceived differently by homeowners depending on how they were managing their yard resources; i.e. some homeowners may view deer as detrimental to their gardens while others may find raccoons to be threatening or destructive. For our purposes mesopredators include: opossum, raccoon, red and gray foxes, coyotes, bobcats, and black bears; and herbivores include: white-tailed deer, woodchucks, and Eastern cottontails. We predicted that mammalian mesopredator and herbivore diversity and richness would vary with both landscape composition and backyard features. Specifically, we predicted that as housing unity density increased and forested area decreased, fewer mammalian mesopredator and herbivore species would be present in yards. We also predicted that the presence of impermeable fences would reduce the number of herbivores and mesopredators in yards. Furthermore, we predicted that yard features associated with supplemental food (bird feeders, gardens, and compost) would be most associated with high species diversity and richness. These results can improve our understanding of the factors that bring wildlife into residential yards and provide insight into how homeowners can manage the frequency of these interactions.

## Methods

### 2.1 Study sites

Our study took place from 4 April to 4 August 2021 and 2022 within an 80.5 km radius of downtown Fayetteville, Arkansas USA. Northwest Arkansas is a rapidly developing area with a current population of approximately 349,000 people and a yearly growth of 1.86%. Fayetteville is located in the Ozark Highlands ecoregion and the landscape is primarily forested by mixed hardwood trees with open areas used for cattle pastures and some scattered agriculture. Our study took place in residential yards ranging from downtown Fayetteville to yards situated in more rural areas. We solicited volunteers from the Arkansas Master Naturalist Program

and the University of Arkansas Department of Biological Sciences who allowed us to place cameras in their yards. We attempted to choose yards that represented the continuum of urban to rural settings and provided a range of yard features to which wildlife was likely to respond to.

### 2.2 Camera setup

To document the presence of wildlife in residential yards, we deployed motion-triggered wildlife cameras (Browning StrikeForce or Spypoint ForceDark) in numerous residential yards (46 yards in 2021 and 96 yards in 2022). We placed cameras approximately 0.95 m above the ground on either a tripod or a tree and at least 5 m from houses and at most 100 m from houses. When possible, we positioned cameras near features such as compost piles, water sources (natural or human-made), and fence lines to maximize detections of wildlife. We coordinated with homeowners to choose locations that would not interfere with yard maintenance or compromise homeowner privacy. When houses had a clear delineation of front and backyard, only 12 cameras were placed in front yards, this was namely due to homeowner preference on placement. Backyards were also chosen in preference for two reasons; (1) to have fewer false triggers from vehicles, and (2) the “Landscape Mullet Hypothesis” shows that backyards are often of more value to wildlife as people tend to maintain their front yards more stringently and backyards can be more variable and include more resources likely to attract wildlife (Belaire et al. 2015). We set cameras to trigger with motion and take bursts of 3 photographs per trigger with a 5 s reset time. We did not use any bait or lures. We checked and downloaded cameras every 2 weeks to check batteries and download data. We moved cameras around the same yard upwards of 3 times within the season to ensure we captured the full range of wildlife present in each yard.

At each yard, we recorded eight variables associated with food, water, or shelter features in the yard area surrounding the camera, these variables were recorded in both front and backyard (Table 1). First, we recorded the area of maintained gardens occurring in each yard. Next, we recorded the volume of potential den sites available in each yard. Potential denning sites included the total available area under sheds and outbuildings as well as decking that was less than 0.3 m off the ground and provided opportunities for wildlife to burrow beneath and be sheltered. Similarly, we also measured the volume of all brush and firewood piles present in each yard that could be used by smaller wildlife species for shelter or foraging. We counted the number of bird feeders in each yard that were regularly maintained during the study period. We also counted the number of water sources available including bird baths and garden ponds (any human subsidized water source on the ground usually within a lined

**Table 1** Description of all variables predicted to affect diversity and richness of mammalian herbivores and mesopredators in residential yards within 80 km of downtown Fayetteville, Arkansas USA during the April– August of 2021 and 2022

Landscape Variables		Variable Statistics	
		Range	Average ( $\pm 1$ Standard Deviation)
<b>Forest Cover (For.)</b>	Area of forest cover within 400 m buffer	0–0.45	0.18 $\pm$ 0.13
<b>Open Land (Open)</b>	Area of open land, (parks, cemeteries, and lawns) within 400 m buffer	0.003–0.31	0.09 $\pm$ 0.06
<b>Agricultural Land (Ag)</b>	Area of land used for agricultural purposes within 400 m buffer	0–0.43	0.08 $\pm$ 0.11
<b>Developed Land (Dev)</b>	Area of developed land within 400 m buffer	0–0.47	0.13 $\pm$ 0.13
<b>Housing Unit Density (HUD)</b>	Maximum Housing Unit Density within 400 m buffer of camera (houses/km <sup>2</sup> )	1–5095	657 $\pm$ 1026
<b>Yard Variables</b>			
<b>Volume of Denning Sites (Dens)</b>	Volume under sheds/outbuildings and under decks less than 1 m off the ground (m <sup>3</sup> )	0–700	27.3 $\pm$ 82.48
<b>Volume of Brush/Firewood Piles (Pile)</b>	Total volume of denning sites including brush and firewood piles (m <sup>3</sup> )	0–335.94	42.99 $\pm$ 69.16
<b>Water Source</b>	Number of human-maintained water sources	0–7	1 $\pm$ 1
<b>- Bird Bath (B.B.)</b>	Water source that is raised off the ground, so much so that animals that cannot climb or jump cannot access it	0–7	1 $\pm$ 1
<b>- Garden Pond (G.P.)</b>	Water source on or embedded within the ground	0–3	0 $\pm$ 1
<b>Bird Feeder (B.F.)</b>	Number of bird feeders present in yard	0–19	4 $\pm$ 4
<b>Garden (Gar.)</b>	Area of total maintained gardens (m <sup>2</sup> )	0–525	46.13 $\pm$ 85.13
<b>Compost Pile (Com.)</b>	Area of compost pile	0–12	0.64 $\pm$ 1.43
<b>Fence Type (F.T.)</b>	If a camera was within a fence, it was given a score between 1–4, 1 being the most permeable fence and 4 being the most impassable to terrestrial mammals. 0: not in a fence 1: Barbed wire 2: Open slat fence 3: 1.2 m Chain-link or Privacy 4: 1.8 m chain-link or Privacy	Nonapplicable	Nonapplicable
<b>Poultry Presence (P.P.)</b>	Presence or absence of poultry being kept in yard	Nonapplicable	Nonapplicable
<b>Water (Wat.)</b>	Score of presence or absence of natural water source. 0: No natural water source 1: Vernal stream 2: Stream or pond 3: River 4: Lake	Nonapplicable	Nonapplicable
<b>Pets</b>			
<b>- Dogs</b>	Score of presence or absence of dogs: 0: No dogs 1: Indoor or leash walked 2: In fence or free roaming	Nonapplicable	Nonapplicable
<b>- Cats</b>	Score of presence or absence of cats: 0: No cats 1: Indoor only 2: Outdoor; at least partially	Nonapplicable	Nonapplicable

basin or container). We distinguished between these types of water sources in analyses because bird baths were likely not available to all wildlife because of their height. We also categorized the presence and type of natural water source present in each yard including vernal streams, permanent streams or ponds, rivers, or lakes. We also recorded the presence

of agricultural animals (such as domesticated chickens or ducks) and pets (type and indoor/outdoor) present in each yard (although we ultimately excluded the presence of pets from analyses – see below).

We documented whether the part of the yard where each camera was deployed was surrounded by a fence and if so,

we categorized the fence type based upon its permeability to wildlife. We categorized fences into one of four categories ranging from those that posed little barrier to wildlife movement to those that were impassable to most species. For example, fences in our first category presented relatively little resistance to wildlife movement (i.e., barbed wire). A second category of fence consisted of fences made of semi-spaced wood slats or beams that offered enough room for most animals to squeeze through but that may have prevented passage of the largest bodied of the species. Fences that were about at least 1 m in height, but were closed off on the bottom (i.e., privacy or chain-link), meaning that few wildlife would be able to pass through without climbing or jumping over were placed in a third category. Finally, the fourth category of fences were those that were 1.8 m or greater in height and were made from a solid material that would prevent all wildlife except capable climbers from entering.

### 2.3 Landscape variables

We used a GIS (ArcGIS Pro 10.2; Esri, Inc. Redlands Inc) to plot the location of all cameras and to quantify the composition of the surrounding landscape. We first created 400 m buffers around each camera, to encompass the average home range area of most wildlife species likely to occur in suburban yards (e.g., Trent and Rongstad 1974; Hoffman and Gotschang 1977). Within each buffer, we calculated the amount of forest cover, developed open land (e.g., cemeteries, parks, and grass lawns), agriculture, and development using the 2016 National Land Cover Database (Dewitz and U.S. Geological Survey 2021). We also quantified the maximum housing unit density (HUD) around each camera using census data (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 (36.0627° N, 94.1606° W), Rogers (36.3335° N, 94.1257° W), Bentonville (36.3724° N, 94.2102° W), or Eureka Springs (36.4006° N, 93.7393° W). Distance to downtown is an additional index of urbanization and human activity that has been correlated with animal behavior in this Arkansas (DeGregorio et al. 2021).

### Photo Processing

We used phot sorting software (Timelapse 2.0 (Greenberg et al. 2019)) to sort and classify all wildlife photographs. We grouped photographs within 5 min to be counted as one sequence to reduce double counting individuals (Forrester et al. 2016). We extracted metadata (e.g., date, time) from photographs, determined the species present, and the number of individuals present in each sequence of photographs.

For our analyses, we focused on two guilds of mammals that are frequently encountered in yards and are reliably detected by cameras: mesopredators (medium-sized mammalian predators including raccoons, opossums, striped skunks, coyote (*Canis latrans*), bobcat (*Lynx rufus*), gray fox, red fox, and black bears (*Ursus americanus*) and herbivores (white-tailed deer, cottontails, and woodchucks). This approach allowed us to assess how landscape and backyard features affected a group of species that we anticipated used resources in similar ways. At each camera, we calculated the Simpson's diversity (Simpson 1949) and richness of mesopredators and herbivores. Richness was defined as the number of species that were detected in a yard.

### Statistical analyses

Before we began analyses, we conducted a collinearity test to evaluate relationships between variables. We considered two variables that had correlation coefficients  $\geq |0.6|$  collinear. From those, we would then decide which of the two variables were predicted to be more meaningful and only include that variable in subsequent analyses. We found that developed land and forest were highly correlated,  $r^2 = -0.706$ . Because we had a second measure of human development, housing unit density (HUD), already included we chose to keep forest cover going forward, the correlation between forest and HUD was  $r^2 = -0.46$ . We also found a high correlation,  $r^2 = 0.72$  between the area of gardens and the volume of brush/firewood piles and subsequently removed brush/firewood piles from analyses. We subsequently removed the pet variable from analyses because we felt that it did not capture the intended effect of cats and dogs on wildlife because the majority of yards (> 80%) were regularly visited by cats and dogs even if the homeowner did not own cats or dogs. All other variables were retained for analyses. We scaled and centered all landscape variables on their mean to facilitate comparison between variables measured on different scales (Schielzeth 2010).

Because this study spanned two sampling years, we sampled forty-three individual yards in both years. To account for this repeated sampling, we randomly selected one year of monitoring for inclusion in analyses and excluded the other year.

To evaluate which landscape and yard variables most related the Simpson's diversity and richness of mesopredator, and herbivore guilds recorded in yards we used a Generalized Linear Model (GLM) analysis. We used both richness and diversity as response variables because they measure slightly different aspects of the wildlife community. Richness provides a coarse count of all species detected in a yard, while diversity provides a weighted measure of species in a yard accounting for both evenness and richness. We used Simpson's diversity in addition



to richness as it allows us to take into account the rarity of a species and provide an index number that reflects the amount of species based on how frequently they are detected in a yard. We conducted four GLM analyses to explore the effects of landscape and yard features on the response variables of mesopredator diversity, mesopredator richness, herbivore diversity, and herbivore richness. For each analysis we used an iterative approach to assemble ninety-two candidate models (Tables 5, 6, 7 and 8). The candidate model set for each analysis consisted of simple one-way variable models and all additive two-way combinations of the eight yard and four landscape predictor variables as well as a global model (including all additive variables) and a null model (Supplemental appendices 1–4). Using all two-way combinations allowed us to explore the effects of each variable while also assessing

additive effects that could have been important for wildlife but without over parameterizing models with more complex models.

For each analysis we ranked candidate models using an information theoretic approach with Akaike's Information Criterion corrected for small sample sizes (AICc). When appropriate, we derived parameter estimates for candidate models by model averaging all models within 3  $\Delta$ AICc (Burnham and Anderson 2002) (in R (R Core Team 2022) with the AICcmodavg package (Mazerolle 2023)).

To improve clarity in presenting model selection tables, we only display models that were competitive within 3  $\Delta$ AICc for each analysis (Tables 2, 3 and 4). Initial exploratory analyses indicated that relationships between predictor variables and response variables were linear and thus

**Table 2** Model selection statistics for the influence of landscape and yard features on mesopredator richness in yards of homes in North-west Arkansas, USA. Only top candidate models within 3  $\Delta$ AICc (Akaike's Information Criterion corrected), are presented. Predictor variables of relative abundance included surrounding landscape and

Models	K	AICc	Delta_AICc	ModelLik	AICcWt	Log Likelihood	Cum.Wt
Forest + Water	4	328.499	0.000	1.000	0.200	-160.045	0.200
Poultry Presence + Forest	4	329.418	0.919	0.632	0.126	-160.505	0.326
Forest	3	329.543	1.044	0.593	0.119	-161.650	0.445
Hay + Forest	4	330.628	2.129	0.345	0.069	-161.110	0.514
Bird Bath + Forest	4	331.121	2.622	0.270	0.054	-161.356	0.567
Frog Pond + Forest	4	331.151	2.652	0.266	0.053	-161.371	0.621
Garden + Forest	4	331.482	2.983	0.225	0.045	-161.537	0.666

backyard variables. Models were ranked using Akaike's Information Criterion corrected for small samples sizes (AICc) and included with each model is the number of parameters (K), AICc difference between model of interest and model with lowest AIC ( $\Delta$ AICc), model weight (AICwt) and log-likelihood estimate (LL)

**Table 3** Model selection statistics for the influence of landscape and yard features on herbivore diversity in yards of homes in North-west Arkansas, USA. Only top candidate models within 3  $\Delta$ AICc (Akaike's Information Criterion corrected), are presented. Predictor variables of relative abundance included surrounding landscape and

Model	K	AICc	Delta_AICc	ModelLik	AICcWt	Log Likelihood	Cum.Wt
Forest	3	80.393	0.000	1.000	0.103	-37.074	0.103
Frog Pond + Forest	4	81.691	1.297	0.523	0.054	-36.639	0.157
Forest + Dens	4	81.764	1.371	0.504	0.052	-36.676	0.209
Fence Type + Forest	4	81.903	1.509	0.470	0.049	-36.745	0.258
HUD + Forest	4	82.176	1.782	0.410	0.042	-36.882	0.300
Poultry Presence + Forest	4	82.200	1.806	0.405	0.042	-36.894	0.342
Forest + Water	4	82.333	1.939	0.379	0.039	-36.960	0.381
Compost + Forest	4	82.436	2.043	0.360	0.037	-37.012	0.418
Garden + Forest	4	82.499	2.106	0.349	0.036	-37.044	0.454
Bird Bath + Forest	4	82.512	2.118	0.347	0.036	-37.050	0.490
Forest + Open	4	82.543	2.150	0.341	0.035	-37.066	0.525
Forest + Bird Feeder	4	82.549	2.155	0.340	0.035	-37.068	0.560
Hay + Forest	4	82.551	2.158	0.340	0.035	-37.070	0.596
HUD	3	83.169	2.775	0.250	0.026	-38.462	0.621

backyard variables. Models were ranked using Akaike's Information Criterion (AIC) 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 (AICwt) and log-likelihood estimate (LL)

**Table 4** Model selection statistics for the effects of landscape and yard variables on herbivore richness in yards of homes in North-west Arkansas, USA. Only top candidate models within 3  $\Delta$ AICc (Akaike's Information Criterion corrected), are presented. Predictor variables of relative abundance included surrounding landscape and

backyard variables. Models were ranked using Akaike's Information Criterion (AIC) 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 (AICwt) and log-likelihood estimate (LL).

Model	<i>K</i>	<i>AICc</i>	<i>Delta_AICc</i>	<i>ModelLik</i>	<i>AICcWt</i>	Log Likelihood	<i>Cum.Wt</i>
Garden + Forest	4	279.691	0.000	1.000	0.039	-135.640	0.039
Garden	3	279.843	0.152	0.927	0.036	-136.799	0.075
Forest	3	280.315	0.623	0.732	0.029	-137.035	0.104
Forest + Dens	4	280.393	0.702	0.704	0.027	-135.990	0.131
Dens	3	280.434	0.742	0.690	0.027	-137.094	0.158
Garden + Dens	4	280.603	0.912	0.634	0.025	-136.095	0.183
HUD	3	281.040	1.349	0.509	0.020	-137.398	0.203
Compost	3	281.055	1.364	0.506	0.020	-137.405	0.223
HUD + Garden	4	281.141	1.449	0.484	0.019	-136.364	0.241
Garden + Compost	4	281.188	1.496	0.473	0.018	-136.388	0.260
Bird Bath	3	281.231	1.539	0.463	0.018	-137.493	0.278
Garden + Hay	4	281.372	1.680	0.432	0.017	-136.480	0.295
HUD + Dens	4	281.398	1.707	0.426	0.017	-136.493	0.311
Hay	3	281.555	1.863	0.394	0.015	-137.655	0.327
Poultry Presence	3	281.599	1.907	0.385	0.015	-137.677	0.342
Garden + Poultry Presence	4	281.614	1.923	0.382	0.015	-136.601	0.357
Open	3	281.624	1.933	0.381	0.015	-137.690	0.372
Garden + Frog Pond	4	281.635	1.944	0.378	0.015	-136.611	0.386
Bird Bath + Forest	4	281.669	1.977	0.372	0.015	-136.628	0.401
Compost + Dens	4	281.721	2.029	0.363	0.014	-136.654	0.415
Garden + Open	4	281.774	2.083	0.353	0.014	-136.681	0.429
Forest + Open	4	281.838	2.146	0.342	0.013	-136.713	0.442
Fence Type + Garden	4	281.856	2.165	0.339	0.013	-136.722	0.455
Frog Pond	3	281.916	2.225	0.329	0.013	-137.836	0.468
Fence Type	3	281.935	2.243	0.326	0.013	-137.845	0.481
Bird Feeder	3	281.944	2.253	0.324	0.013	-137.850	0.494
Garden + Bird Bath	4	281.950	2.258	0.323	0.013	-136.769	0.506
Compost + Forest	4	281.961	2.269	0.322	0.013	-136.774	0.519
Water	3	281.965	2.273	0.321	0.013	-137.860	0.531
Garden + Water	4	281.987	2.296	0.317	0.012	-136.787	0.544
Garden + Bird Feeder	4	282.004	2.313	0.315	0.012	-136.796	0.556
Poultry Presence + Forest	4	282.022	2.331	0.312	0.012	-136.805	0.568
Bird Bath + Dens	4	282.025	2.334	0.311	0.012	-136.807	0.580
Poultry Presence + Dens	4	282.270	2.579	0.275	0.011	-136.929	0.591
Hay + Dens	4	282.273	2.582	0.275	0.011	-136.930	0.602
HUD + Forest	4	282.312	2.620	0.270	0.011	-136.950	0.612
Hay + Forest	4	282.387	2.696	0.260	0.010	-136.987	0.622
HUD + Hay	4	282.436	2.744	0.254	0.010	-137.012	0.632
Frog Pond + Forest	4	282.445	2.753	0.252	0.010	-137.016	0.642
Open + Dens	4	282.445	2.753	0.252	0.010	-137.016	0.652
HUD + Bird Bath	4	282.457	2.766	0.251	0.010	-137.023	0.662
Fence Type + Forest	4	282.460	2.769	0.250	0.010	-137.024	0.672
Forest + Water	4	282.475	2.784	0.249	0.010	-137.031	0.681
Forest + Bird Feeder	4	282.482	2.791	0.248	0.010	-137.035	0.691
Compost + Hay	4	282.508	2.817	0.245	0.010	-137.048	0.701
Dens + Bird Feeder	4	282.521	2.829	0.243	0.009	-137.054	0.710

**Table 4** (continued)

Model	<i>K</i>	<i>AICc</i>	<i>Delta_AICc</i>	<i>ModelLik</i>	<i>AICcWt</i>	Log Likelihood	<i>Cum.Wt</i>
<b>Frog Pond + Dens</b>	4	282.527	2.835	0.242	0.009	-137.057	0.720
<b>Compost + Open</b>	4	282.528	2.837	0.242	0.009	-137.058	0.729
<b>Fence Type + Dens</b>	4	282.560	2.868	0.238	0.009	-137.074	0.738
<b>HUD + Compost</b>	4	282.582	2.890	0.236	0.009	-137.085	0.747
<b>Dens + Water</b>	4	282.598	2.906	0.234	0.009	-137.093	0.757
<b>Compost + Bird Bath</b>	4	282.636	2.945	0.229	0.009	-137.112	0.766

models were not corrected. Model goodness-of-fit was assessed using residual plots.

## Results

From April 4th to August 4th, 2021, we deployed 46 cameras in yards for a total of 4,107 camera nights. We deployed 96 cameras from April 4th to August 4th in 2022 for a total of 12,688 camera nights. After randomly excluding one year of sampling from yards that were studied in both years, we retained 103 individual residential yards with 10,246 camera nights for analyses. Of the yards retained for analyses, 99% ( $n = 102$ ) had at least one species of wildlife detected.

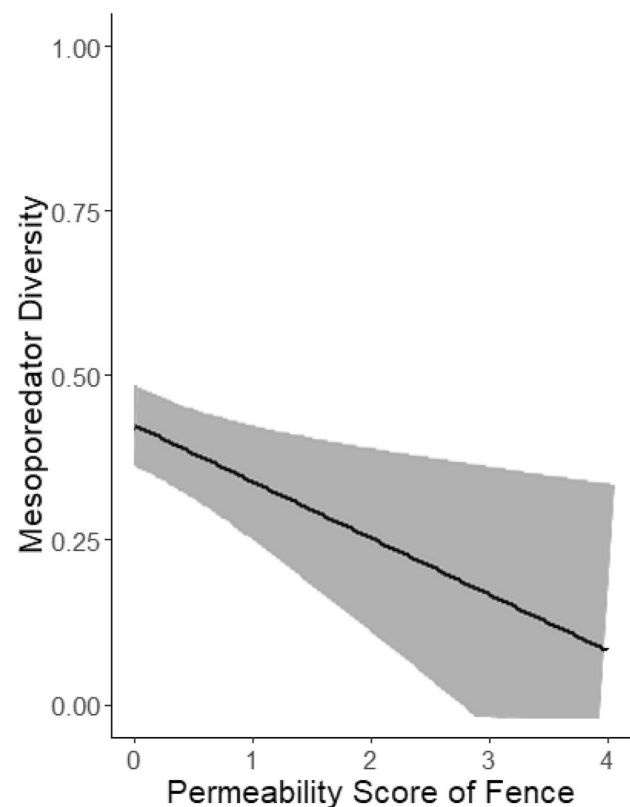
We documented 8 species of mesopredators including raccoons (4,874 observations in 97 yards), Virginia opossum (2,268 observations in 94 yards), red foxes (732 observations in 49 yards), coyotes (417 observations in 61 yards), gray foxes (150 observations in 17 yards), striped skunks (71 observations in 14 yards), bobcats (25 observations in 10 yards), and black bears (2 observations in 2 yards). Mesopredator Simpson's diversity values ranged from 0 to 0.94 with an average of 0.45 ( $\pm 0.25$  SD). Mesopredator richness ranged from 0 to 6 species per yard with an average of 3 ( $\pm 1$  SD).

We detected 3 herbivore species: white-tailed deer (7,372 observations in 90 yards), cottontails (917 observations in 50 yards), and woodchucks (347 observation in 33 yards). Herbivore diversity ranged from 0 to 1 with an average of 0.22 ( $\pm 0.35$  SD). Herbivore richness ranged from 0 to 3 species with an average of 2 ( $\pm 1$  SD).

Mesopredator diversity was most influenced by fence type at a yard. Fence type and number of bird feeders in a yard both appeared in the top model, collectively accounting for 14.8% of the weight of evidence. As fence permeability decreased (i.e., fewer species were able to freely move in and out of yards), the diversity of mesopredators documented in a yard decreased ( $\beta = -0.08$  95% CI = -0.16- -0.01) (Fig. 1). The number of bird feeders in a yard was positively associated with mesopredator diversity ( $\beta = 0.02$  95% CI = 0-0.03) (Fig. 2).

Influence of number of bird feeders present in a yard on mesopredators diversity in yards of homes in Northwest Arkansas, USA from May-August 2021 and 2022. The gray band indicates a 95% confidence interval.

Mesopredators richness was best predicted by area of forested land within 400 m of a yard. Forested area appeared in all 7 of the top models (Table 2). Cumulatively, all models accounted for 66.6% of the weight of evidence. As forested area in the buffer around the yard increased so did



**Fig. 1** Influence of permeability of fences around yards on mesopredators diversity in yards of homes in Northwest Arkansas, USA from May-August 2021 and 2022. Fences were categorized based on their permeability to wildlife with 1 being the most permeable fence offering little resistance to wildlife and 4 representing an impermeable barrier unless wildlife were capable climbers. The gray band indicates a 95% confidence interval



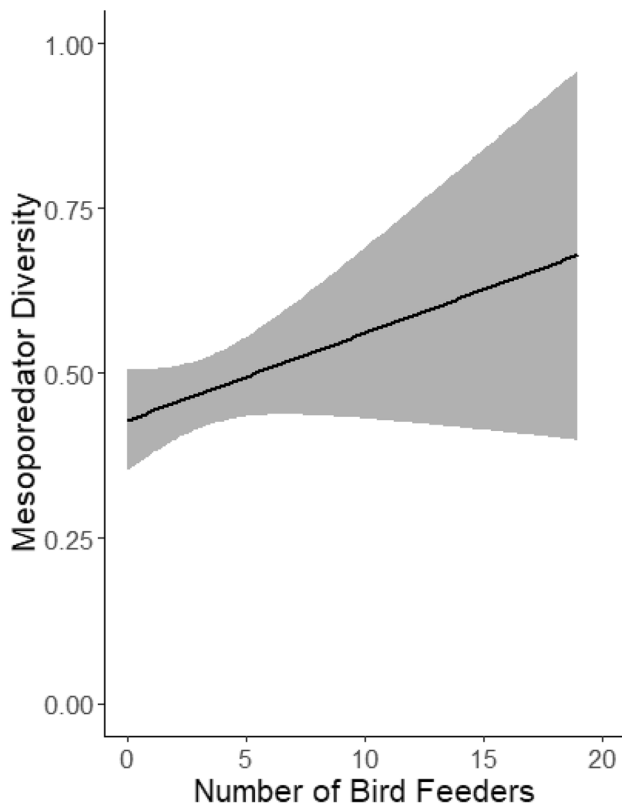


Figure 2

richness of mesopredators (model averaged  $\beta = 2.84$  95% CI = 1.08–4.6) (Fig. 3).

Influence of forested area ( $\text{km}^2$ ) within a 400 m buffer of a yard on mesopredators richness in yards of homes in Northwest Arkansas, USA from May–August 2021 and 2022. The gray band indicates a 95% confidence interval.

Herbivore diversity was best predicted by the amount of forest within 400 m of a yard. Forest appeared in 13 (92.8%) of the 14 top models (Table 3). Cumulatively, these 13 models accounted for 62% of the weight of evidence. Forest was positively related to herbivore diversity, suggesting that more herbivores are present in yards surrounded by higher forest cover (model averaged  $\beta = 0.59$  95% CI = 0.06–1.12) (Fig. 4).

Influence of forest cover within a 400 m buffer of a yard on herbivore diversity in yards of homes in Northwest Arkansas, USA from May–August 2021 and 2022. The gray band indicates a 95% confidence interval.

Herbivore richness was best predicted by the area of gardens in a yard. Garden area appeared in 13 of the 19 top models (Table 4). Cumulatively, all 13 models containing the garden variable accounted for 40.1% of the weight of evidence. Area of gardens was positively related to herbivore richness, suggesting that more garden cover in a yard equates to more herbivore species present in a yard however the effect size was modest, and the 95% confidence

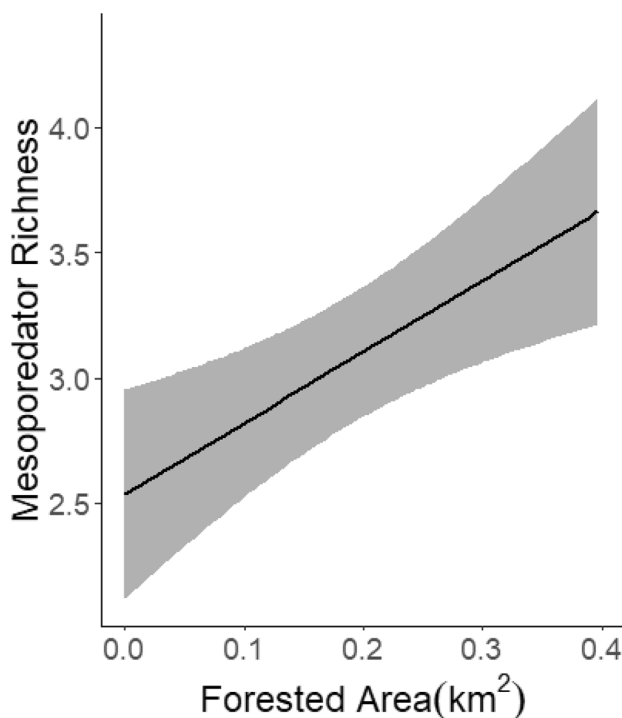


Figure 3

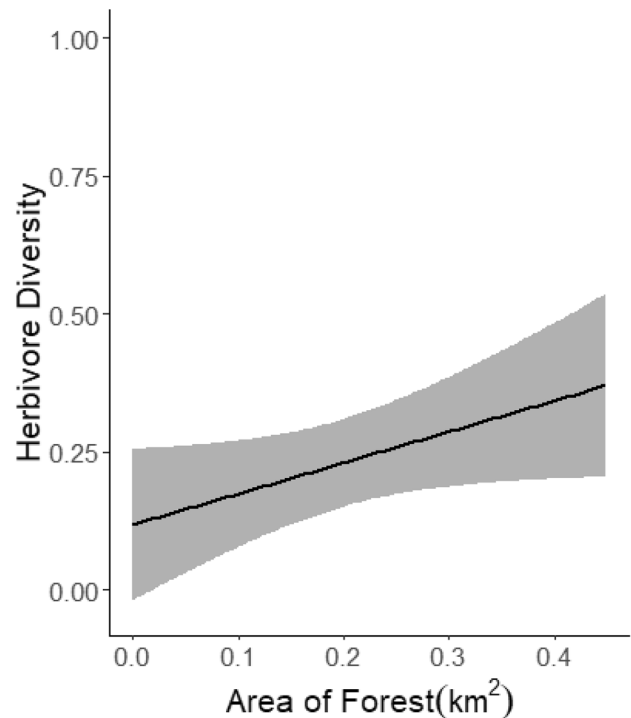


Figure 4

intervals overlapped 0 (model averaged  $\beta = 0.002$  95% CI=-0.001-0.004).

## Discussion

Residential yards account for approximately one third of the landscape in urbanizing areas in the Eastern USA (Mathieu et al. 2007; Giner et al. 2013; Hedblom et al. 2017) and conversion of natural areas to suburban areas causes wildlife communities to be displaced or altered and can change the accessibility of food, water, and shelter resources (Wilby and Perry 2016). Despite these extreme landscape changes some wildlife are able to co-exist with humans in residential habitats (Soulsbury and White 2015). We found that both backyard and landscape features influenced the diversity and richness of mammalian mesopredators and herbivores in residential yards in Northwest Arkansas.

Unsurprisingly, we found that mesopredator diversity was lowest in yards surrounded by solid, impermeable fencing. This result aligns well with results from another study of wildlife diversity in residential yards based in Raleigh, North Carolina, USA (Hansen et al. 2020). We found that larger species such as coyote, bobcats, and black bear were essentially excluded from yards with solid fences. However, via some combination of climbing, burrowing under, or squeezing through, we often documented striped skunks, gray fox, red fox, opossum, and raccoon in yards with either solid or chain link fences. From the perspective of larger-bodied wildlife, fencing creates fragmentation and barriers to movement across the suburban landscape, which can limit access to resources and areas (Jakes et al. 2018). From the homeowner's perspective, certain types of fencing may be effective at preventing larger-bodied mesopredators from entering their yards and reducing interactions with certain species.

We also found that the number of bird feeders in a yard had a positive influence on mesopredator diversity. Studies have shown that raccoons tend to be observed at sites with feeders more often than those without (Reed and Bonter 2018). Although bird feeders may be installed to increase interactions between homeowners and avian wildlife, providing bird feeders also can increase undesired interactions between wildlife and the public (Barden et al. 1995). Other mesopredator species such as coyote and red fox may also be attracted to yards with bird feeders due to an increase in rodents and small mammals that forage on fallen seed (Saad et al. 2020). During our study we photographed raccoons and opossum directly eating seed from or eating seed under bird feeders indicating that some mesopredators are attracted to feeders because they represent a food source. Surprisingly, other food sources that we measured didn't correlate with mesopredator diversity, such as compost piles or poultry presence in a yard. Other studies in Alberta,

Edmonton, Canada, and Raleigh, North Carolina, USA have found that compost piles are an attractant for many species, but of particular interest to coyotes in residential yards (Murray and St. Clair 2017; Hansen et al. 2020). Similar to our findings, another study in the Raleigh-Durham, North Carolina, USA found that poultry presence in a yard did not attract most mesopredators, however other studies have found that raccoons were positively associated with yards containing chicken coops (Kays and Parsons 2014).

As we predicted, mesopredator richness and herbivore diversity both increased with the amount of forested area around yards. Although many species can use and even thrive in residential areas, forested areas are important to create spill-over into suburban areas for mesopredators that require forest cover (Villaseñor et al. 2014). Species such as raccoons likely den in forested areas and move into residential yards to forage at night (Bozek et al. 2007; Bateman and Fleming 2012). Many of the mesopredators comprising our mesopredators guild have been found to be associated with forest cover (Tucker et al. 2008; Rodriguez et al. 2021). Of the three species included in the calculations of herbivore diversity, all have been reported to have associations with forest cover. White-tailed deer, the most frequently detected herbivore species in our study, are commonly associated with forest cover and while they forage in residential areas, they are reliant on forested areas for bedding and resting (DeNicola et al. 2000). White-tailed deer in Illinois, USA have been found to be more abundant in residential areas with higher forest cover (Urbanek and Nielsen 2013). Although relatively little is known about woodchuck ecology and their habitat preferences, it has been documented that they preferentially burrow along wooded areas, forest edges, and hedgerows (Grizzell 1955; Armitage 2000; Erb et al. 2012). Eastern cottontails are often associated with open habitats, but in human dominated landscape they can often be pushed to more forested areas (Tash and Litvaitis 2007; Erb et al. 2012; Herrera et al. 2022). This result suggests that while owners have some agency over the yard features and subsequent wildlife they attract, landscape context, such as forested cover, plays a significant role in the wildlife present. Homeowners have little control over landscape context aside from choosing where to purchase homes.

In addition to our finding that herbivore diversity was positively associated with forest cover on a landscape scale, we also found evidence of a relatively modest positive relationship between herbivore richness and garden area, although the relationship was modest. While some homeowners enjoy seeing deer, woodchucks, and cottontails in their yards, they are viewed by others negatively. Specifically all three species included in our herbivore category have been identified as nuisances that can cause damage to gardens (Manning 2021). Thus, while the association between garden area and herbivore richness is not surprising, it can lead to conflicts. Furthermore, not only are gardens used as a food source by these

herbivores, but they can also provide dense cover for cottontail bedding and possibly predator-free areas due to frequent visitation by humans tending the gardens (Baker and Harris 2007; Van Helden et al. 2020). The association of herbivore richness with garden area is likely to lead to negative associations with homeowners due to the damage these animals can inflict upon flower and vegetable gardens (Flyger et al. 1983).

Perhaps the most surprising result, or lack thereof, from this study is that housing unit density did not significantly affect diversity or richness of either mammalian guild. Because our study spanned a large gradient of housing and development density changes in wildlife communities also occurred across low to high density areas. Previous studies have found that wildlife near cities throughout the world often respond to intensity of development with some species showing a preference to higher development (McKinney 2006, 2008, Bateman and Fleming 2012, Hansen et al. 2020) and others avoiding high intensity development (McKinney 2006; Bateman and Fleming 2012; Rodriguez et al. 2021). However, a similar study in Raleigh, North Carolina, USA, found that only one species, coyotes, responded to housing unit density, while diversity and richness of the rest of the mammal community were not affected (Hansen et al. 2020).

Our results suggest that mammalian wildlife is present in most residential yards in Northwest Arkansas, USA and diversity and richness vary based on some homeowner practices. We found that amount of forested land area is an important driver for biodiversity in this area, increasing both herbivore diversity and mesopredators richness. Homeowners do have some control however, as backyard features such as gardens, bird feeders, and fences all influenced the mammal community in yards. Given the vast area covered by residential yards, the resources they supply, and the level of connectivity they provide to greenspaces they can be important for local conservation management of suburban wildlife (Bolger et al. 2001; Hansen et al. 2020). Homeowners should be aware that their practices (providing bird feeders and gardens) create resources that wildlife will respond to. The intentional or unintentional provisioning of food and cover will attract wildlife and the construction of impermeable fences will reduce access by wildlife.

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**Data availability** Data will be uploaded and freely available in the Dryad Data Repository upon acceptance of this article.

## Declarations

**Competing interests** The authors declare no competing interests.

**Ethics approval** Not Applicable.

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