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## Density and Occupancy of Mammals Along an Urban to Rural Gradient in Northwest Arkansas

Leah E. McTigue

*University of Arkansas-Fayetteville*

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Density and Occupancy of Mammals Along an Urban to Rural Gradient in Northwest Arkansas

A thesis submitted in partial fulfillment  
of the requirements for the degree of  
Master of Science in Biology

by

Leah McTigue  
Michigan State University  
Bachelor of Science in Animal Science, 2017

August 2023  
University of Arkansas

This thesis is approved for recommendation to the Graduate Council.

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## ABSTRACT

Human development is a rapidly expanding phenomenon impacting wildlife communities globally. As the human footprint expands, natural greenspace and nature reserves become fragmented and isolated. Wildlife species and communities respond to these changes in different ways. Urban exploiters persist in more urban areas and are able to take advantage of anthropogenic subsidies (food, shelter, etc). Urban avoiders, however, are species that may be pushed out of developed areas or occur in lower densities relative to undisturbed areas. Northwest Arkansas is an optimal location to study the impacts of urbanization on wildlife communities, as the current human population is expected to double in the next 20 years and human development is continually encroaching into natural areas.

In Chapter I, I evaluated mammalian mesocarnivore density along an urban to rural gradient in the Ozark Ecoregion, Northwest Arkansas, USA. I deployed 287 trail cameras across 12 natural areas ranging from urban parks within the city of Fayetteville to more rural sites in the Ozarks. To estimate density, I used the Random Encounter Model (REM), developed to estimate density of unmarked individuals via trail camera data. I focused my analyses on the five most commonly detected mesocarnivore species: bobcat, coyote, raccoon, red fox, and Virginia opossum. I found that both raccoons and coyotes densities had a positive correlation with anthropogenic noise, indicating an affinity for areas with human activity. Red fox and opossum densities both had a positive correlation with developed open space, representing novel, human-maintained habitat within urban areas such as golf courses, cemeteries, and city parks. Red fox density also had a negative correlation to distance to water, and opossum density had a positive though insignificant trend with distance to water. Bobcat density was not correlated with any variables selected for analysis and may need to be evaluated on a larger spatial scale.

My results support past research showing coyote, red fox, opossum and raccoon to be urban exploiters. They also add support for the REM as a reliable method to estimate density based on trail camera data. My density estimates for all five species were comparable to density estimates from the literature that used traditional density estimation techniques and allowed us to evaluate trends in density based on environmental and anthropogenic resources.

In Chapter II, I evaluated the density and occupancy probability of the nine-banded armadillo (*Dasypus novemcinctus*) along an urban to rural gradient. I used a total of 352 camera locations from the 2020-2021 winter season and the 2021-2022 winter season. I found that detection probability increased for the armadillo as temperature increased but decreased as precipitation increased. Occupancy probability had a negative correlation with the angle of the slope, and a positive correlation with elevation. Armadillo density was not influenced by any anthropogenic or environmental variables, but anecdotally was higher at sites with higher levels of human development.

Collectively, these results shed insight into how 6 different mammal species respond to human development across an urbanization gradient in a quickly growing part of the country. Understanding impacts of urbanization on wildlife allows managers to predict populations of wildlife and potential conflicts that may arise in response to changes in their natural environments, as well as make well informed management decisions.

## ACKNOWLEDGEMENTS

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## LIST OF PUBLISHED PAPERS

### Chapter 1

McTigue, L. E. & DeGregorio, B. A. (2023). Effects of Landcover on Mesocarnivore Density Along an Urban to Rural Gradient. *Global Ecology and Conservation*. Submitted for review.

### Chapter 2

McTigue, L. E. & DeGregorio, B. A. (2023) Nine-banded Armadillo (*Dasypus novemcinctus*) occupancy across an urban to rural gradient. *Southeastern Naturalist*. Submitted for review.

## INTRODUCTION

Human development has major impacts on wildlife communities. With the expansion of the human footprint, there is increased isolation and fragmentation of natural greenspaces and nature preserves (De Chant et al. 2010; Soifer et al. 2020). Such changes to the natural landscape can impact wildlife in several ways. Some species may be able to exploit urban areas, taking advantage of anthropogenic subsidies such as food, shelter, and water sources, and living in close proximity to humans (Ordeñana et al. 2010). Other species may be driven from urban areas, or only exist in urban greenspace or on the periphery of human development. Human development may facilitate the range expansion of species as well. Translocation and travel corridors such as roads have aided the range expansion of the nine-banded armadillo (*Dasypus novemcinctus*) northward (Humphry 1974; Taulman & Robbins 1994, Taulman & Robbins 2014).

Mesocarnivores, small and medium sized mammalian predators (Roemer et al. 2009), are particularly adaptable and often known for being urban exploiters. Northern raccoons (*Procyon lotor*, hereafter, raccoon), red fox (*Vulpes vulpes*), coyote (*Canis latrans*), and Virginia opossum (*Didelphis virginiana*, hereafter, opossum) are highly adaptable to urban environments and the densities of these species can be higher in human-dominated areas than more natural sites (Greenspan et al. 2018; Tucker et al. 2021). However more sensitive species such as bobcats (*Lynx rufus*) and gray foxes (*Urocyon cinereoargenteus*), are often rare or absent from areas with higher levels of development (Parsons et al. 2018) and are associated with greater forest cover (Rodriguez et al. 2021).

The Ozark Ecoregion of Northwest Arkansas is an excellent example of an area being rapidly overtaken by human development. The area has been experiencing dramatic growth over the last 30 years, and the current population of 546,725 is expected to double by the year 2045 (NWARPC 2021). While Northwest Arkansas rapidly expands, it accommodates an array of sites

along an urban to rural sites ranging from greenspaces within the city of Fayetteville, to more natural sites within the Ozark Mountains.

To understand the impact of anthropogenic and environmental variables on wildlife populations, I placed motion activated trail cameras at 12 sites along an urban to rural gradient in the Ozark ecoregion. I used data collected by these cameras to estimate density of 5 mesocarnivore species through the Random Encounter Model (REM), which was developed to estimate the density of unmarked species through trail camera photos (Rowcliffe et al. 2008). Chapter I was formatted with the intent of publication in the *Global Ecology and Conservation* with Brett A. DeGregorio.

In addition to evaluating the density of mesocarnivores, I assessed anthropogenic and environmental impacts on the density and occupancy patterns of the armadillo. Armadillo have been rapidly expanding their range since the 1950s and are often able to adapt to human development (Fitch et al. 1952; Taulman & Robbins 1996; Feng and Papes 2014, DeGregorio et al. 2021). Chapter II was formatted with the intent of publication in the *Southeastern Naturalist* with Brett A. DeGregorio.

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## CHAPTER I

# EFFECTS OF LANDCOVER ON MESOCARNIVORE DENSITY ALONG AN URBAN TO RURAL GRADIENT

Leah E. McTigue and Brett A. DeGregorio

## ABSTRACT

Human development has major implications for wildlife populations. Urban-exploiter species can benefit from human subsidized resources, whereas urban-avoider species can vanish from wildlife communities in highly developed areas. Therefore, understanding how the density of different species varies in response to landcover changes associated with human development can provide important insight into how wildlife communities are likely to change and provide a starting point for predicting the consequences of those changes. Here, we estimated the population density of five common mesocarnivore species (coyote (*Canis latrans*), bobcat (*Lynx rufus*), red fox (*Vulpes vulpes*), raccoon (*Procyon lotor*), and Virginia opossum (*Didelphis virginiana*)) along an urban to rural gradient in the greater Fayetteville Area, Northwest Arkansas, USA between November 2021, and March 2022. At each study site, we applied the Random Encounter Model (REM) to data from motion-triggered cameras to calculate the density of our five focal species. Coyote density ranged from 0-3.47 with a mean of 0.4 individuals/km<sup>2</sup>. Raccoon density ranged from 0-93.26 with a mean of 4.2 individuals/ km<sup>2</sup>. Bobcat density ranged from 0-8.87 with a mean of 0.33 individuals/km<sup>2</sup>. Opossum density ranged from 0-27.35 with a mean of 0.76 individuals/km<sup>2</sup>. Red fox density ranged from 0-0.73, with a mean of 0.02 individuals/km<sup>2</sup>. We used generalized linear models to evaluate the density of each species against environmental and anthropogenic variables. Coyotes and raccoons occurred in the greatest densities in areas with high anthropogenic noise levels, suggesting that both species are synanthropic and able to co-exist in areas of high human activity. Alternatively, Virginia opossum and red fox densities were greatest in open, developed areas (lawns, golf courses, cemeteries, and parks) and were absent (red fox) or rare (opossum) in natural areas. We found no evidence that bobcat density varied along the urban to rural gradient studied, but this lack of

evidence may have been driven by the small spatial scale of many of our sites in relation to space needs of this wide-ranging species. The density estimates we report based on game camera data of unmarked animals were consistent with reports from the literature for these same species derived from traditional methods, providing additional support to the REM as a viable, non-invasive method to calculate density of unmarked species.

## 1. Introduction

Human development has major impacts on wildlife communities. As the human footprint expands, greenspace and nature reserves become fragmented, isolated, and the amount of forest edge increases (De Chant et al. 2010; Soifer et al. 2020). Wildlife species can respond to this expansion in different ways, with some species capable of exploiting anthropogenic subsidies (e.g., food, shelter, etc.) and living in close proximity to humans (Ordeñana et al. 2010). These species are often referred to as urban adapters and can persist and thrive in urban areas and in urban greenspaces (Greenspan et al. 2018). Other species, referred to as urban avoiders, may be driven out of developed areas due to food specialization, conflict with domestic animals, or lower tolerance to disturbance (Blair 1996; Lowry et al. 2012; Łopucki et al. 2020).

Mesocarnivores, small and medium sized mammalian predators (Roemer et al. 2009), are a group of animals that are particularly adaptable and often reside in urban areas. Northern raccoons (*Procyon lotor*, hereafter, raccoon), red fox (*Vulpes vulpes*), coyote (*Canis latrans*), and Virginia opossum (*Didelphis virginiana*, hereafter, opossum) are highly adaptable to urban environments and the densities of these species can be higher in human-dominated areas than more natural sites (Greenspan et al. 2018; Tucker et al. 2021). These species have been shown to benefit from urban environments by taking advantage of human-subsidized food resources (waste food, compost, bird seed: (Contesse et al. 2004, Bozek et al. 2007, Handler et al. 2020, Larson et al. 2020). These species can also benefit by using refuges associated with human infrastructure that provide either predator-free space, thermal refugia, or safe space to rear young (Shannon et al. 2014; Herr et al. 2008; Sarkar & Bhadra 2022). Some species may simply benefit and occur in higher densities because their primary predators are less likely to persist in these smaller, isolated greenspaces near humans (Atickem et al., 2014; Moll et al. 2018, Gámez &

Harris 2021). Developed open landcover such as residential lawns, cemeteries, golf courses and parks can serve as novel habitat where other mammals (including predators of smaller mammals and mesocarnivores) may have difficulty persisting, therefore serving as spatial refugia for some species (Imhoff et al. 2000; Gallo et al. 2017).

In contrast to urban adapters, urban avoiders are species that may be pushed out of developed areas or occur in lower densities relative to undisturbed areas (Blair 1996). These more sensitive species, such as bobcats (*Lynx rufus*) and gray foxes (*Urocyon cinereoargenteus*), are often rare or absent from areas with higher levels of development (Parsons et al. 2018) and are associated with greater forest cover (Rodriguez et al. 2021). There is also evidence that larger canids such as coyote and domestic dog (*Canis familiaris*) can competitively exclude gray fox in urban areas (Morin et al. 2022). Some species may persist in developed areas but experience lower fitness or a reduced realized niche (Smith et al. 2018).

While numerous studies have evaluated the occurrence and community composition of mesocarnivores in natural and urbanized greenspaces (Prange & Gehrt 2004; Fidino et al. 2016; Greenspan et al. 2018), we often lack information about the density of animals in these locations. Estimates of density are critical for managers seeking to predict and proactively manage mesocarnivore populations (Wright & Hubbell 1983). Currently, several approaches for generating density of unmarked animals through the use of game cameras exist (Loonam et al. 2021, Ausband et al. 2022, Young et al. 2019, Moeller et al. 2018). These approaches have the advantage of being less expensive and less invasive than traditional methods that rely on capture and marking of animals (Thomas et al. 2011; Meek et al. 2018). One such approach is the Random Encounter Model (hereafter, REM) that was first developed by Rowcliffe et al. (2008) and uses the field of view of a motion-triggered camera combined with movement parameters of

focal species to estimate density. This method has been successfully validated in trials with known population sizes (Rowcliffe et al. 2008, Cusack et al. 2015, Kavčič et al., 2021) and applied to other studies successfully (Manzo et al. 2012; Zero et al. 2013, Palencia et al. 2021). Given that many of the common mesocarnivores in the United States have been intensively studied and we often know the space use and movement parameters of these species, the REM is a promising approach for rapidly estimating the density of mesocarnivores across a number of sites.

Here, we aim to explore variation in the density of five common mesocarnivores (red fox, coyote, bobcat, raccoon, and opossum) at 12 study sites an urban to rural gradient in the Ozark Mountains Ecoregion of Arkansas, USA (Fig. 1). Northwest Arkansas is an optimal area for our study as it has been experiencing dramatic growth over the past 30 years, with the current human population of 546,725 expected to nearly double by the year 2045 (NWARPC 2021). We expected that the density of each of our focal species would vary widely between study sites based on the degree of human activity and development. Specifically, we predicted that red fox, raccoon, and opossum would occur at the highest population densities at the most urban sites and the lowest densities at the most natural, undeveloped sites. We predicted that coyotes would have higher densities at sites with intermediate levels of development and that their densities would be more strongly correlated with landscape cover (habitat heterogeneity, proximity to water, etc.) than strict measures of human development (Rodriguez et al. 2021; Poessel et al. 2016). Finally, we predicted that bobcats would occur at their highest population densities at more natural sites and would be absent or occur at very low densities at the most developed sites.

## 2. Methods

### *2.1 Study Sites*

Our study took place within the Ozark Mountain Ecoregion in the greater Fayetteville metropolitan area in Northwest Arkansas, USA. To account for variation in the wildlife community associated with habitat, we chose only study sites that were dominated by mature oak-hickory forests and located between 220-554m in elevation. Study sites ranged in size from 39 – 42169ha. We did not use any study sites smaller than 20ha in size because we wanted to be able to place a minimum of 12 cameras at each site with a minimum spacing of 150m between cameras.

We chose sites to represent the continuum of human development representative of the area ranging from 2.1 to 58.1km from downtown Fayetteville (36.06162, -94.16114). Our study sites consisted of Arkansas Natural Heritage Commission (ANHC) natural areas, National Forests, Arkansas State Parks, City of Fayetteville parks, and both nongovernmental organizations and private reserves (Table 1).

### *2.2 Camera Placement and Settings*

At each study site, we deployed between 12 and 30 Spypoint Force Dark (Spypoint Inc, Victoriaville, Quebec, Canada) and Browning Strikeforce XD cameras (Browning, Morgan, Utah, USA) during the winter/leaf off season in Arkansas (November 2021 and March 2022), allowing us to control for seasonal variation in mammal communities. At each site, we used the recreational trail systems to facilitate efficient semi-random camera deployment. We used ArcGIS Pro (ArcGIS Pro 2.8.3, 2021; Esri Inc, Redlands, CA) and OnX Hunt Map (OnXMaps

2023, Missoula, MT) to manually delineate available trails at each study site and then created a 150m buffer on each side of all trails. Given the high density of trails at most of our study sites, the buffers created for each trail system used for camera deployment encompassed a large area representative of the entire reserve. We generated random points for camera deployment that lay between 20 and 150m away from the trail using the Create Random Point tool in ArcGIS Pro. Each camera location was a minimum of 150m away from the next nearest camera. We deployed cameras within a 50m buffer around the randomly selected point to ensure suitable topography and a clear field of view devoid of dense vegetation that would reduce our ability to detect animals and result in false triggers. However, we specifically did not place cameras in locations that would have maximized animal detections (such as game trails, water sources, etc.) because this can bias density estimates (Rowcliffe et al. 2013, Kavčić et al., 2021). We deployed cameras between study sites at either 5 or 10 week intervals. Sites with more than 25 cameras were surveyed for 5 consecutive weeks while sites with fewer than 25 cameras remained active for 10 weeks (Table 2). Due to camera malfunction and theft the number of trap nights at each site varied but we ensured that sampling effort exceeded 600 trap nights at each site which is above the minimum number of trap nights needed to conclude that undetected species are absent from the area surveyed (Carbone et al. 2001). The difference in deployment lengths across this study allowed trap nights across the study to remain consistent and was necessary due to the number of cameras available to us, effort within the field, size of study areas, and allowed us to sample all sites within the winter/leaf off season.

We placed cameras on trees 50cm above ground. All cameras were set to take bursts of three photos at each motion-trigger. We set the delay between bursts to the minimum possible for each camera - 0 seconds for Spypoint cameras, and 1 second for Browning cameras, allowing a

near continuous capture when the camera was triggered. We sorted all photos using the Timelapse 2.0 software, developed by Greenberg et al. (2019). We grouped all photos of a single species within a span of 5 minutes into a single “episode” to avoid double counting individuals. A 5 minute episode is a conservative delineation to avoid over-counting, as studies have shown that even shorter episode lengths are sufficient to reduce double-counting bias (Meek et al. 2014). We recorded the species and number of individuals present in each episode.

### *2.3 Density Estimation*

We used the REM approach (Rowcliffe et al. 2008) to estimate density of each focal species at each camera location. The REM has three major assumptions: that animals move randomly throughout their environment (cameras are not baited or set on environmental features that would impact detection probability like trails or roads), detection events represent individual animals, and that the population is closed (Rowcliffe et al. 2008). While some of our sites were in close proximity to one another there were often barriers such as freeways or large roads between sites that would limit movement. We kept our survey period to the winter months where no birth was occurring, and chances of death lower, though this cannot be confirmed.

To estimate the density ( $D$ ) of our five focal species from game camera detections, we applied the Random Encounter Model (REM) equation:

$$D = \frac{y}{t} \times \frac{\pi}{Vr(2 + \theta)}$$

Where  $y$  refers to the total detections of each animal per camera and  $t$  is the total trap nights in hours (measure of trapping effort).  $V$  is the day range of each species, referring to how

far an animal travels in a 24-hour period. We used published day range estimates for each species and used the median day range value for each species from all reported estimates to parameterize our models (Table 2). We chose to use the median value of literature-reported day ranges to avoid the influence of extreme values because the REM is more sensitive to day range than other variables, such as detection angle (Cusack et al. 2015). Values for the detection radius ( $r$ ), and detection angle ( $\theta$ ) were collected for each camera in the field through walk tests. A walk test entailed walking directly towards each camera to calculate detection radius and from each side at 5m from the camera to calculate detection angle in degrees. Detection was determined by whether or not the detection light was triggered on the camera during each walk test. The detection angle was later converted to radians for density calculations (Rowcliffe et al. 2008, Caravaggi et al. 2015). We were not able to collect the detection radius and detection angle for 14 cameras due to camera malfunction (no detection light during walk test) so we applied the average detection angle for the given camera model (Schaus et al. 2020). We used the REM equations modeled in Microsoft Excel (Microsoft Corporation) to calculate the density of each focal species at each camera. Density was then averaged to create one mean estimate for each study site comparison.

## *2.4 Statistical Tests*

To assess which landcover variables most influenced the density of each focal species, we used an iterative approach to assemble 31 Generalized Linear Mixed Models (GLMM) with additive effects using *r* programming and the “lme4” and “AICcmodavg” packages for five predictor variables: HUD, noise, distance to water, and developed open, including a global model (all variables with random effect) and a null model (only random effect). We used study site as a random effect in each model. The zero inflation in the data was accounted for by using a gamma

distribution in all models. We then used AICc selection criteria with an a priori cutoff of two for the  $\Delta AIC$  delta value. Top models were considered those within 2  $\Delta AICc$ . When there were multiple competing models within 2  $\Delta AICc$  that included the same term (e.g., forest cover), we derived a parameter estimate of that term using model averaging (Burnham & Anderson 2002).

To evaluate how the density of each species varied based on anthropogenic and environmental landcover, we used ArcGIS Pro (ArcGIS Pro 2.8.3, 2021; Esri Inc, Redlands, CA) to extract seven predictor variables from 500m buffers created around each camera. We used a 500m buffer around each camera, as this spatial scale has been shown to be biologically meaningful for the focal species and minimizes overlap between cameras (Fidino et al. 2016, Magle et al. 2016, Gallo et al. 2017). We extracted maximum housing unit density (HUD) using the SILVIS housing layer (Hammer et al. 2004, Table 3). We extracted anthropogenic noise from the layer created by Mennitt and Fristrup (2016; Buxton et al. 2017, Table 3) and used the “L50” anthropogenic sound level estimate, which was calculated by taking the difference between predicted environmental noise and the calculated noise level. Therefore, we assume that higher levels of L50 sound corresponded to higher human presence and activity, as prominent features projected by the estimated anthropogenic noise value reflect major U.S. cities and their surrounding transportation networks, reflecting human activity with areas having high noise values having high levels of human activity (voices, vehicles, and other sources of anthropogenic noise; Mennitt & Fristrup 2016; Buxton et al. 2017). Metrics for developed open landcover, forest area, and distance to forest edge were all derived from the 2019 National Land Cover Database (NLDC, Dewitz 2021, Table 3). Developed open landcover refers to open spaces with less than 20% impervious surface such as residential lawns, cemeteries, golf courses, and parks and has been shown to be important for mesocarnivores (Poessel et al. 2012, Gallo et al. 2017). Forest

area was calculated by combining all forest types within the NLDC layer (deciduous forest, mixed forest, coniferous forest), and summarizing the total area (m<sup>2</sup>) within the 500m buffer. Distance to forest edge was derived by creating a 30m buffer on each side of all forest boundaries and calculating the distance from each camera to the nearest forest edge. Distance to water was created by combining the waterbody and flowline features in the National Hydrography Dataset (U.S. Geological Survey) for the state of Arkansas to capture both permanent and ephemeral water sources that may be important to wildlife. Distance to water and distance to forest edge were calculated using the geoprocessing tool “near” in ArcGIS Pro which calculates the distance between a point and the nearest feature. We used a search radius of 50 km when using the “near” tool to ensure features were not missed. Average Daily Traffic (ADT) was extracted from the Arkansas Department of Transportation database (Arkansas GIS Office). The maximum value for ADT was calculated using the Summarize Within tool in ArcGIS Pro. We tested for correlation between covariates with a Spearman correlation matrix and removed any variable with correlation greater than 0.6. Pairwise comparisons between ADT and HUD and between distance to forest edge and forest area were both correlated above 0.6; therefore, we dropped ADT and distance to forest edge from analyses as we predicted that HUD and forest area would have larger biological impacts on our focal species. (Kretser et al. 2007).

### **3. Results**

From the 287 cameras we deployed, we accumulated 28,249 total independent wildlife detections over 11,236 trap nights. Raccoons were the most common species detected with 3,392 individual detections, followed by coyotes (533 detections), opossum (506 detections), bobcats (103 detections), and red fox (20 detections). We detected raccoons, coyotes, and opossum at all

12 study sites, bobcats at 92% of sites (11 of 14), and red fox only at 42% of study sites (5 of 12).

We were able to use the REM to estimate densities for all species (Fig. 2). Raccoon density ranged from 0 to 94.26 individuals/km<sup>2</sup>. The density of coyotes ranged from 0 to 3.47 individuals/km<sup>2</sup>. Opossum ranged in density from 0 to 27.36 individuals/km<sup>2</sup>. The density of bobcats ranged from 0 to 8.87 individuals/km<sup>2</sup>. Red fox density ranged from 0 to 0.73 individuals/km<sup>2</sup>. Density of our focal species varied between sites (Fig. 2), though pairwise comparisons for bobcats revealed the only significant difference between sites occurred between Markham Hill, which recorded no bobcats, and sites that did have detections of bobcats.

For coyotes, anthropogenic noise was the best predictor of density and was included in the top three models (Table 4). No models without noise had an  $\Delta AICc$  value less than two. In all models, noise had a positive relationship with coyote density (model averaged  $\beta = 0.36$ , 95% CI = 0.06 to 0.67), indicating coyotes occurred at higher densities in areas with high levels of human activity (Fig. 3).

As with coyotes, density for raccoons was best predicted by anthropogenic noise after model averaging. Noise occurred in all 5 top models (Table 4). In all models, noise was positively related to raccoon density ( $\beta = 0.95$ , 95% CI = 0.41 to 1.48), indicating that raccoons are more likely to occur at higher densities in areas with high levels of human activity (Fig. 4).

Red fox density was best predicted by developed open space ( $\beta = 0.35$ , 95% CI = 0.19 to 0.51, Fig. 5(A)) and distance to water ( $\beta = -0.13$ , 95% CI = -0.26 to -0.01, Fig. 5(B)) after model averaging. These variables were included in each of the top five models (Table 4). In all models, developed open space had a positive relationship with red fox density (Fig 5(A)) indicating red fox may gravitate toward anthropogenic habitat within developed areas. Additionally, all models showed a negative relationship between red fox density and distance to water (Fig. 5(B)).

Opossum density was best predicted by distance to water and developed open space after model averaging. These variables appeared frequently in the top seven models, and all models below a  $\Delta AICc$  of two included one or both of these variables (Table 4). All models showed a positive, yet non-significant, relationship between opossum density and distance to water ( $\beta = 0.24$ , 95% CI = -0.01 to 0.49, Fig. 6A), although caution should be used when interpreting this relationship because the confidence intervals overlapped zero. In all models, developed open space had a positive relationship with opossum density, which similarly to red fox may indicate opossum are able to take advantage of anthropogenic habitat within developed areas (model averaged  $\beta = 0.72$ , 95% CI = 0.38 to 0.1.06, Fig. 6(B)).

For bobcats, the top model was the null model (Table 4). While the single variable models appear to compete with the null for top model, when model averaged, all other models have beta values overlapping zero.

#### 4. Discussion

We found that the densities of raccoon, coyote, red fox, and opossum were consistent with the expectation for urban exploiter species, although the landcover variables that they responded to were not consistent across species. Opossum and red fox density had a positive correlation with a novel habitat feature created and maintained by humans (developed open space) and were absent (fox) or rare (opossum) in more natural, forested areas. Raccoon and coyotes had higher density estimates with higher human activity, indicating an ability to co-occur near people. We suspect this is likely because they take advantage of subsidized food and possibly shelter resources that accompany human activity. We found no evidence that bobcat density corresponded consistently with the definition of an urban-avoider or an urban-exploiter.

Density estimates for both coyotes and raccoons showed strong positive associations with anthropogenic noise. Our results indicate that both of these species are comfortable occurring in close proximity to human activity. Our results are unsurprising, because both raccoons and coyotes have been shown to be highly adaptable to urban settings and are adept at exploiting human-subsidized resources (Prange et al. 2003; Gross et al. 2012; Bateman & Flemming 2012; Breck et al. 2019). Access to subsidized resources has shown to decrease winter weight loss in raccoons (Mech et al. 1968; Hoffmann et al. 1979, Rosatte et al. 1991, Riley et al. 1998) It is therefore unsurprising that they attained higher densities in areas of high human activity, as this is likely reflective of opportunities for resource subsidies. However, higher densities of raccoons can also create a greater risk of ecological and social conflicts, increasing the risk of disease outbreaks (such as canine distemper) within their populations as well as the potential for these diseases to spread to pets (Prange et al. 2004; Schell et al. 2020). High densities of raccoons in areas of high human activity not only increases the risk of conflict associated with zoonotic

disease spread (Schell et al. 2020), but also of conflict between raccoons and pets or between raccoons and humans (raiding trash cans, etc.).

Contrary to our predictions, we found that coyote density increased in areas with high human activity as measured by estimated anthropogenic noise. Similar to raccoons, this likely reflects an ability of coyotes to co-exist with humans (Tigas et al. 2002, Bateman & Flemming 2012) and likely a benefit to coyotes for exploiting human-subsidized resources (Morey et al. 2007, Fedriani et al. 2008). For coyotes, this likely means preying on species associated with humans such as rodents, cottontails (*Sylvilagus floridanus*), and outdoor pets such as cats, dogs, and chickens (Fox 2006). Coyotes are often perceived as a threat to human safety and are frequently blamed for depredating pets (Loven 1995; Alexander & Quinn 2011), and they can carry diseases that are transmittable to domestic dogs (rabies, canine heartworm disease etc.; Pluemer et al. 2019). Thus, high densities of coyotes in areas of high human activity can lead to both real and perceived conflicts. While coyotes are adept at co-existing with humans, there are both social and ecological reasons why a high density of coyotes in urban greenspaces could be problematic, as conflict increases with higher density of coyotes (Poessel et al. 2017). Coyotes, as an extremely adaptable species, are known to take advantage of anthropogenic food sources (Morey et al. 2007). Since our study sites are all within urban greenspace and forested areas, it would make sense that noise be the top predictor explaining coyotes' affinity for urban areas. It was also unsurprising that coyotes and raccoons occur in high densities within the same areas, because there is relatively little evidence that coyotes regularly prey on raccoons; and raccoons do not fear the presence of coyotes (Chitwood et al. 2020).

We found a weak but positive correlation between opossum density and distance to water, which contradicts previous studies. Fidino et al. (2016) and Bernasconi et al. (2022) showed that opossum patch occupancy rates were highest in patches occurring nearest natural water sources. While our results should be interpreted with caution as they suggest a weak effect with confidence intervals overlapping 0, we found them to be interesting and worthy of further exploration. We should also note that density and occupancy may not necessarily be correlated. Additionally, we found an increase in opossum density in areas with high coverage of developed open space. Opossum were positively associated with these novel habitats, while other mammals (including predators of opossum) may have difficulty persisting in city parks and similar habitats (Gallo et al. 2017), offering opossum refugia from predation within urban environments. While all of our cameras were placed within deciduous forest habitat, this supports our finding that developed open space is an important habitat for opossum in urban environments.

Red fox had a positive correlation with developed open space, and a negative correlation with distance to water. While they were only detected in 5 urban study sites, this suggests that developed green spaces, such as city parks, golf courses and cemeteries, can be utilized by foxes as has been shown previously (Gallo et al. 2017). In Melbourne, Australia, a study conducted on urban foxes indicated that 61% of natal dens occurred in residential, public park, or industrial lands (Marks & Bloomfield 2006). This concurs with our finding, showing a strong positive relationship between developed open space and red fox density. Proximity to water may be correlated with prey abundance for foxes, as small mammals, their primary prey, occur in higher diversity and abundance in riparian areas (Hamilton et al. 2015).

While bobcats were widespread (detected at 11 of 12 study sites) we found little support for landscape variables correlating with bobcat density. The only differences between sites

occurred with Markham Hill. Since Markham Hill was the only site where bobcats were not detected, there may not be enough variance in bobcat density across cameras to measure variables influencing density. It is possible that because bobcats in Arkansas have large home ranges ( $64.2\text{km}^2$  for adult males,  $24.5\text{km}^2$  for adult females; Rucker et al. 1989) the density of the species at most sites is fairly uniform with only a small number of resident individuals being able to be supported in these relatively small natural areas. Because bobcat density tends to be low (Wrangham et al. 1993; Morin et al. 2018; Fenton 2019) detecting differences in density between sites likely needs to be evaluated on a larger spatial scale.

By using only motion-triggered game cameras, we successfully calculated the density of five focal species at twelve different study sites using the REM. The density estimates we calculated were comparable to estimates from the literature (Table 5). The REM relies upon knowledge of how far each focal species travels in a 24-hour period and has been shown to be highly influenced by this movement parameter (Cusack et al. 2015). For this study, we used literature values for each species to parameterize our models. This reliance on previously published movement parameters is one of the reasons we chose well-studied and common mesocarnivores as our focal species. Practitioners focusing on rare or understudied species may not be able parameterize their models with published estimates and may have to rely on concurrent radiotelemetry to generate their own movement parameters. Cusack et al. (2021) describe the movement parameter to be the most important when accurately estimating density through the REM. Therefore, if we had chosen incorrect values for our movement parameter we could have seen much different estimates in density. Fortunately, we found a close alignment between our density estimates and estimates from the literature (Table 5) using traditional approaches, which gave us confidence in our choice of parameters. Additionally, because our

comparisons among sites used the same movement parameters, any bias would have been consistent among sites. However, because our research spanned different levels of urbanization, there is a chance that using literature-derived day ranges could be problematic due to differences in behavior across the urban-rural gradient for our focal species. For example, it has been documented that many species have smaller home ranges in urban environments (Prange et al. 2004; Wright et al. 2012; Šálek et al. 2015). Since the overall goal of our study was to use density estimates to evaluate how species density correlates to environmental and anthropogenic variables, and not explicitly state the number of species per km<sup>2</sup> for each site, we believe our approach still has value for exploring changes in density over a large spatial scale. We attempted to control for possible changes in movement behavior by sampling within intact patches of hardwood forests that were larger than 35 ha.

In general, our density estimates for four of our five focal species aligned with reports from the literature (Table 5), which is encouraging and shows the robustness of the REM approach. However, our density estimates for red fox (0.35 individuals/km<sup>2</sup>) were lower than what appeared in reports from the literature (Table 5), though this is likely due to red fox only being detected at 5 of the 12 sites and having a small number of detections (N = 20). Our application of REM may not be as reliable for rarely encountered species as it was for more common species. Density estimates found in the literature were also higher for raccoons than our estimates, though this is due to two very high values from a single study (Bradfoot et al. 2001). When these outlying values are removed, literature-derived estimates much more closely align with our results.

Through the use of widely available trail cameras and an established model for density estimation (Rowcliffe et al. 2008), we were able to calculate reliable density estimates for five

cryptic, primarily nocturnal, mesocarnivore species. Furthermore, we were able to correlate their density to landcover variables. This approach provides valuable insight into how different species respond to landcover change and may be useful in predicting where potential social or ecological conflicts may arise as a result of these changing densities. We were also able to assess the potential impacts of environmental and anthropogenic variables on variation in mesocarnivore density. However, we should acknowledge that our density estimates were made for only a single year and undoubtedly these population levels fluctuate based on diseases, resources, and environmental factors. We believe there is still value in even short duration studies of this nature. Because the continued spread of urbanization is inevitable, understanding how mammal communities and species respond to different anthropogenic influences is crucial. Remotely sensed datasets, such as anthropogenic noise (Buxton et al. 2017), NLDC (Dewitz, 2021), and HUD (Hammer et al., 2004), continue to improve, allowing us to gain better understandings of specific effects of urbanization on wildlife. Lastly, the REM continues to gain support as a reliable, non-invasive, and cost-effective method for density estimations which could aid and improve traditional methods of population monitoring. While the REM is certainly not the only available method of estimating density from unmarked animals using game cameras (such as time to event or space to event models) these types of models rely on timelapse data rather than motion-triggered detections and movement parameters. (Moeller et al. 2019). We found the REM to be an appropriate choice for our study system, as movement parameters of these heavily studied species were available from the literature, and timelapse requires additional batteries, storage, and frequent downloads. We found estimation of density to be relatively straightforward so long as all components of the model are collected properly and assumptions

are met, which could allow it to be adapted by a wide range of stakeholders for species monitoring.

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## TABLES

**Table 1.** Natural areas located in Northwest Arkansas USA where the densities of five mesocarnivores were estimated using motion-triggered game cameras from Nov 2021 – Mar 2022. Sites were chosen to represent a continuum of human development from urban to natural sites as measured by distance from each site to downtown Fayetteville, AR. Number of cameras present at each site was determined by the size of the site. Sites with fewer cameras were active longer to ensure a minimum of 600 trap nights.

| <b>Site</b>                              | <b>No. of<br/>Cameras</b> | <b>Dates Active</b> | <b>Total Trap<br/>Nights</b> | <b>Distance to<br/>Downtown<br/>Fayetteville (km)</b> |
|--|---------------------------|---------------------|------------------------------|---|
| <b>Mt. Sequoyah Woods</b>                | 13                        | Nov 6 – Jan 8       | 806                          | 2.10  |
| <b>Markham Hill</b>                      | 25                        | Nov 1 – Dec 6       | 853                          | 3.00  |
| <b>Centennial Park/Millsaps Mountain</b> | 12                        | Jan 16 – Mar 21     | 747                          | 4.30  |
| <b>Lake Fayetteville Park</b>            | 12                        | Jan 15 – Mar 22     | 682                          | 9.60  |
| <b>Kessler Mountain Park</b>             | 28                        | Feb 16 – Mar 23     | 996                          | 5.70  |
| <b>Lake Sequoyah Park</b>                | 15                        | Nov 3 – Jan 9       | 1005                         | 9.60  |
| <b>Ozark National Forest, Weddington</b> | 30                        | Dec 8 – Jan 12      | 1025                         | 20.00   |
| <b>Hobbs State Park</b>                  | 29                        | Jan 14 – Feb 8      | 1015                         | 34.70   |
| <b>Bear Hollow Natural Area</b>          | 28                        | Dec 9 – Jan 13      | 1131                         | 46.40   |
| <b>Ozark National Forest, White Rock</b> | 29                        | Feb 20 – Mar 24     | 923                          | 49.60   |
| <b>Devils Eyebrow Natural Area</b>       | 30                        | Jan 10 – Feb 14     | 997                          | 50.60   |
| <b>Ninestone Land Trust</b>              | 30                        | Nov 2 – Dec 7       | 1086                         | 58.10   |

**Table 2.** Literature derived values for daily range length of five mesocarnivore species: coyote (*Canis latrans*), bobcat (*Lynx rufus*), raccoon (*Procyon lotor*), Virginia opossum (*Didelphis virginiana*), and red fox (*Vulpes vulpes*). All literature describing speed for these five species was recorded and converted to kilometers traveled in a 24-hour period. Median values calculated from these literature derived values were used for movement parameters of each species in the Random Encounter Model to calculate population densities in Northwest Arkansas, USA.

| <i>Citation</i>                             | <b>Bobcat</b> | <b>Coyote</b> | <b>Opossum</b> | <b>Red Fox</b> | <b>Raccoon</b> |
|---|---------------|---------------|----------------|----------------|----------------|
| <i>Adkins and Stott 1998</i>                | -             | -             | -              | 11.80          | -              |
| <i>Allen, Marchiton and Lentz 1985</i>      | -             | -             | 1.15           | -              | -              |
| <i>Andelt and Gipson 1979</i>               | -             | 10.90         | -              | -              | -              |
| <i>Artois et al. 1990</i>                   | -             | -             | -              | 10.00          | -              |
| <i>Barding and Nelson 2008</i>              | -             | -             | -              | -              | 6.58           |
| <i>Beasly and Rhodes 2010</i>               | -             | -             | -              | -              | 5.21           |
| <i>Blanco 1986</i>                          | -             | -             | -              | 4.90           | -              |
| <i>Carter, Luck and McDonald 2012</i>       | -             | -             | -              | 20.80          | -              |
| <i>Cavallini 1992</i>                       | -             | -             | -              | 6.15           | -              |
| <i>Chamberlain, Leopold and Conner 2003</i> | 8.50          | -             | -              | -              | -              |
| <i>Doncaster and Macdonald 1997</i>         | -             | -             | -              | 4.40           | -              |
| <i>Eguchi and Nakazono 1980</i>             | -             | -             | -              | 5.70           | -              |
| <i>Elfelt 2014</i>                          | -             | 7.08          | -              | -              | -              |
| <i>Fritzell 1978</i>                        | -             | -             | -              | -              | 15.84          |
| <i>Hodges, Chamberlin, Leopold 2000</i>     | -             | -             | -              | -              | 17.20          |
| <i>Holzman, Conroy and Pickering 1992</i>   | -             | 8.94          | -              | -              | -              |
| <i>Kitchen, Gese and Shauster 1999</i>      | -             | 22.56         | -              | -              | -              |
| <i>Litvatis and Shaw 1980</i>               | -             | 40.80         | -              | -              | -              |
| <i>McNitt et al. 2020</i>                   | 4.42          | -             | -              | -              | -              |
| <i>Meia and Weber 1995</i>                  | -             | -             | -              | 6.45           | -              |
| <i>Mulder 1985</i>                          | -             | -             | -              | 8.10           | -              |
| <i>Newbury and Nelson 2007</i>              | -             | -             | -              | -              | 7.80           |
| <i>Puskas et al. 2010</i>                   | -             | -             | -              | -              | 2.63           |
| <i>Reynolds and Laundre 1990</i>            | -             | 13.10         | -              | -              | -              |
| <i>Rockhill, DePerno, Powell 2013</i>       | 3.34          | -             | -              | -              | -              |
| <i>Rowcliffe et al. 2016</i>                | -             | -             | 4.93           | -              | -              |
| <i>Rucker et al. 1989</i>                   | 52.80         | -             | -              | -              | -              |
| <i>Ryser 1995</i>                           | -             | -             | 4.94           | -              | -              |
| <i>Sasmal et al. 2018</i>                   | -             | 8.98          | -              | -              | -              |
| <i>Saunders et al 1993</i>                  | -             | -             | -              | 7.70           | -              |
| <i>Servin et al. 1991</i>                   | -             | -             | -              | 4.97           | -              |
| <i>Servin et al. 1992</i>                   | -             | -             | -              | 2.90           | -              |
| <i>Servin et al. 1993</i>                   | -             | -             | -              | 7.88           | -              |
| <i>Springer 1982</i>                        | -             | 3.43          | -              | -              | -              |
| <i>Storey 1997</i>                          | -             | -             | -              | -              | 3.07           |
| <i>Sunquist, Austad and Sunquist 1987</i>   | -             | -             | 28.81          | -              | -              |
| <i>Takeuchi and Koganezawa 1992</i>         | -             | -             | -              | 8.93           | -              |
| <i>Travaini et al. 1993</i>                 | -             | -             | -              | 6.69           | -              |
| <i>Turner et al. 2011</i>                   | -             | 20.88         | -              | -              | -              |
| <i>Urban 1970</i>                           | -             | -             | -              | -              | 3.88           |

|   |             |              |             |             |             |
|---|-------------|--------------|-------------|-------------|-------------|
| <i>Walker and Sunkuist 1997</i>             | -           | -            | -           | -           | 4.14        |
| <i>Way, Ortega, Strauss 2004</i>            | -           | 23.50        | -           | -           | -           |
| <i>Wilson 1996</i>                          | -           | -            | 7.83        | -           | 10.13       |
| <i>Wrangham, Gittleman and Chapman 1993</i> | 2.41        | 6.90         | -           | 2.50        | -           |
| <b><i>Median Day Range Value</i></b>        | <b>3.70</b> | <b>13.10</b> | <b>6.86</b> | <b>6.69</b> | <b>6.85</b> |

**Table 3.** Summary statistics for landcover variables used for evaluating density of 5 commonly occurring mesocarnivores estimated with the Random Encounter Model on an urban to rural gradient in Northwest Arkansas, USA. Variables listed were used in analyses and were not correlated above a 0.6 in the Spearman correlation matrix. Values are derived from the 287 camera trap locations used in this study.

| <b>Landcover variable</b>                          | <b>Minimum</b> | <b>Maximum</b> | <b>Mean</b> |
|--|----------------|----------------|-------------|
| <b>Developed open space (m<sup>2</sup>)</b>        | 0.0            | 21.4           | 2.2         |
| <b>Anthropogenic noise (dB)</b>                    | 0.0            | 13.2           | 3.9         |
| <b>Distance to water (m)</b>                       | 1.2            | 743.2          | 179.7       |
| <b>Forest area (m<sup>2</sup>)</b>                 | 13.0           | 78.4           | 65.2        |
| <b>Housing Unit Density (units/km<sup>2</sup>)</b> | 0.0            | 5335.9         | 264.2       |

**Table 4.** Model selection statistics for mesocarnivore density estimates and anthropogenic and environmental variables. Density is derived from motion-activated trail camera data and the REM. Models were ranked using Akaike’s Information Criteria (AICc) and includes the number of parameters (K), difference from the top model ( $\Delta$ AICc), model weight (AICcWt), and cumulative weight included for each model. Table displays the top models with  $\Delta$ AICc values within an apriori cut off of two. Complete AICc tables are available in supplementary materials (Supplemental Tables 1-5).

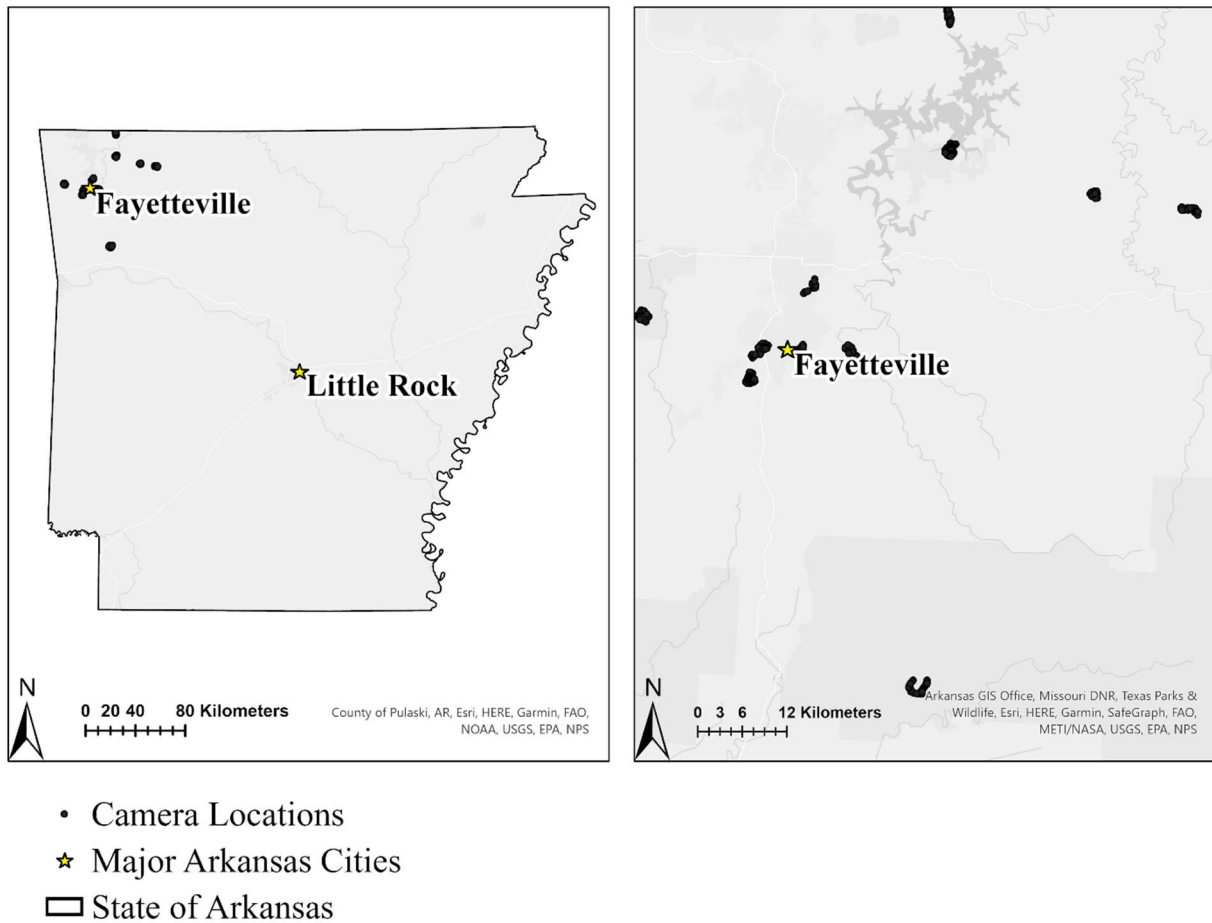
| <b>Model</b>  | <b>K</b> | <b>AICc</b> | <b><math>\Delta</math> AICc</b> | <b>AICcWt</b> | <b>Cum.Wt</b> |
|---|----------|-------------|---------------------------------|---------------|---------------|
| <b>Coyote</b>   |          |             |                                 |               |               |
| <b>noise</b>  | 4        | -103.54     | 0.00                            | 0.17          | 0.17          |
| <b>HUD + noise</b>  | 5        | -102.69     | 0.85                            | 0.11          | 0.29          |
| <b>noise + forest area</b>                                    | 5        | -102.52     | 1.02                            | 0.10          | 0.39          |
| <b>Raccoon</b>  |          |             |                                 |               |               |
| <b>noise</b>  | 4        | 607.80      | 0.00                            | 0.19          | 0.19          |
| <b>noise + forest area</b>                                    | 5        | 608.86      | 1.06                            | 0.11          | 0.30          |
| <b>noise + distance to water</b>                              | 5        | 609.09      | 1.29                            | 0.10          | 0.39          |
| <b>noise + developed open</b>                                 | 5        | 609.18      | 1.37                            | 0.09          | 0.49          |
| <b>HUD + noise</b>  | 5        | 609.68      | 1.88                            | 0.07          | 0.56          |
| <b>Red Fox</b>  |          |             |                                 |               |               |
| <b>distance to water + developed open</b>                     | 5        | -1732.49    | 0.00                            | 0.20          | 0.20          |
| <b>HUD + distance to water + developed open</b>               | 6        | -1732.05    | 0.45                            | 0.16          | 0.35          |
| <b>HUD + noise + distance to water + developed open</b>       | 7        | -1731.16    | 1.33                            | 0.10          | 0.45          |
| <b>noise + distance to water + developed open</b>             | 6        | -1730.93    | 1.56                            | 0.09          | 0.54          |
| <b>distance to water + forest area + developed open</b>       | 6        | -1730.53    | 1.96                            | 0.07          | 0.61          |
| <b>Opossum</b>  |          |             |                                 |               |               |
| <b>HUD + distance to water + forest area + developed open</b> | 7        | -419.06     | 0.00                            | 0.18          | 0.18          |
| <b>HUD + distance to water + developed open</b>               | 6        | -418.20     | 0.85                            | 0.12          | 0.30          |
| <b>distance to water + developed open</b>                     | 5        | -417.94     | 1.11                            | 0.10          | 0.40          |

|   |   |         |      |      |      |
|---|---|---------|------|------|------|
| <b>HUD + developed open</b>                                 | 5 | -417.82 | 1.23 | 0.10 | 0.50 |
| <b>distance to water + forest area +<br/>developed open</b> | 6 | -417.63 | 1.43 | 0.09 | 0.59 |
| <b>Bobcat</b>   |   |         |      |      |      |
| <b>null</b>   | 3 | -678.56 | 0.00 | 0.16 | 0.16 |
| <b>distance to water</b>                                    | 4 | -677.37 | 1.19 | 0.09 | 0.24 |
| <b>HUD</b>  | 4 | -677.14 | 1.42 | 0.08 | 0.32 |
| <b>noise</b>  | 4 | -676.80 | 1.76 | 0.07 | 0.39 |
| <b>developed open</b>                                       | 4 | -676.72 | 1.84 | 0.06 | 0.45 |

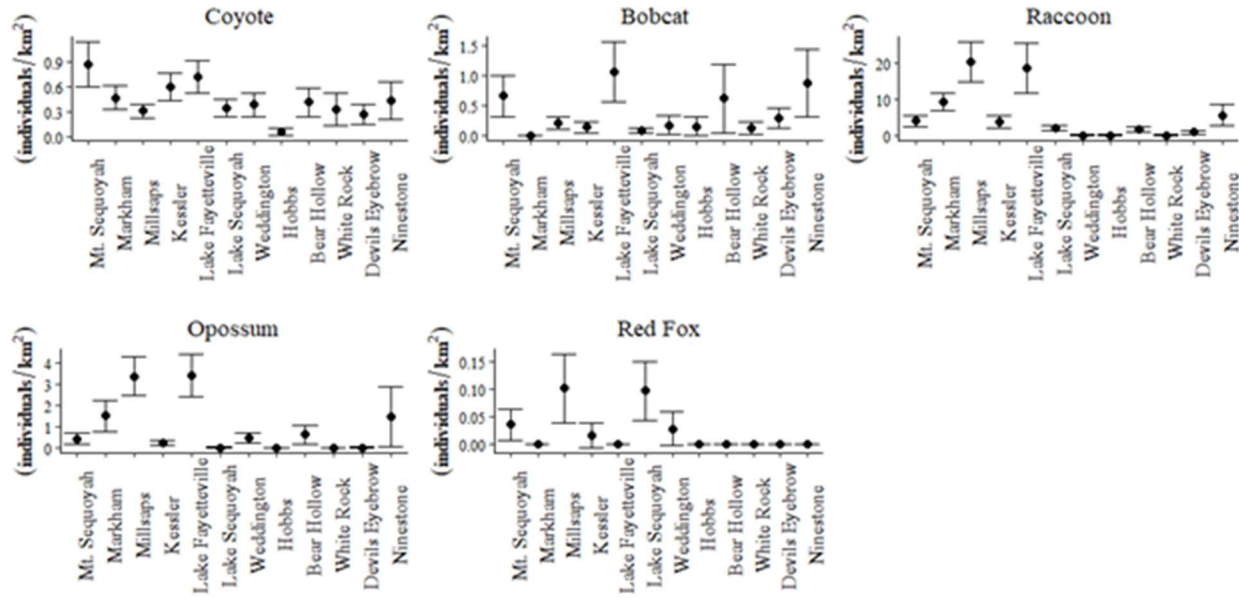
**Table 5.** Literature-derived density estimates for five focal mesocarnivores: raccoon (*Procyon lotor*), red fox (*Vulpes vulpus*), coyote (*Canis latrans*), Virginia opossum (*Didelphis virginiana*), and bobcat (*Lynx rufus*). The study conducted by Bradfoot et al (2001) represents outlying density estimations for raccoons, where the minimum raccoon density was 37 individuals/km<sup>2</sup>, and the maximum raccoon density was 94 individuals/km<sup>2</sup>.

| <b>Citation</b>        | <b>Raccoon<br/>(ind/km<sup>2</sup>)</b> | <b>Red Fox<br/>(ind/km<sup>2</sup>)</b> | <b>Coyote<br/>(ind/km<sup>2</sup>)</b> | <b>Opossum<br/>(ind/km<sup>2</sup>)</b> | <b>Bobcat<br/>(ind/km<sup>2</sup>)</b> |
|------------------------|---|---|--|---|--|
| Kasparian et al. 2004  | -                                       | -                                       | -                                      | 2.35                                    | -                                      |
| Wolcott 2011           | -                                       | -                                       | -                                      | 0.07                                    | -                                      |
| Bernasconi 2020        | -                                       | -                                       | -                                      | 0.26                                    | -                                      |
| Morin et al. 2018      | -                                       | -                                       | -                                      | -                                       | 0.38                                   |
| Stoddard et al. 2001   | -                                       | -                                       | 0.75                                   | -                                       | -                                      |
| Morin et al. 2016      | -                                       | -                                       | 0.067                                  | -                                       | -                                      |
| Bradfoot et al. 2001   | 65.5                                    | -                                       | -                                      | -                                       | -                                      |
| Webbon, et al. 2004    | -                                       | 1.22                                    | -                                      | -                                       | -                                      |
| Sarmiento et al. 2010  | -                                       | 0.83                                    | -                                      | -                                       | -                                      |
| Goszczyński 1989       | -                                       | 0.71                                    | -                                      | -                                       | -                                      |
| Rosatte et al. 2010    | 5.66                                    | -                                       | -                                      | -                                       | -                                      |
| Pandolfi et al. 1997   | -                                       | 5.74                                    | -                                      | -                                       | -                                      |
| Wrangham et al.1993    | -                                       | 2                                       | 0.90                                   | -                                       | 0.30                                   |
| Fenton 2019            | 1.28                                    | -                                       | 0.73                                   | 2.05                                    | 0.21                                   |
| <b>Species Average</b> | <b>18.98</b>                            | <b>2.28</b>                             | <b>0.37</b>                            | <b>0.44</b>                             | <b>0.31</b>                            |

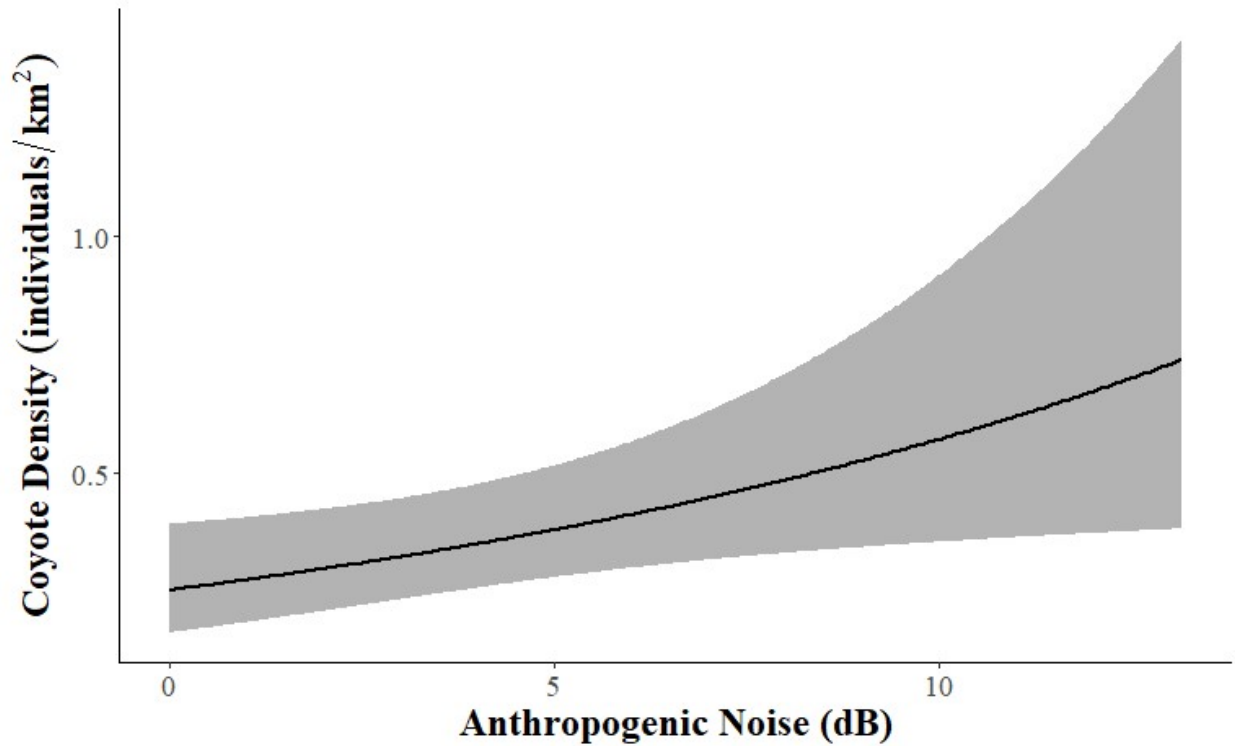
## Figures



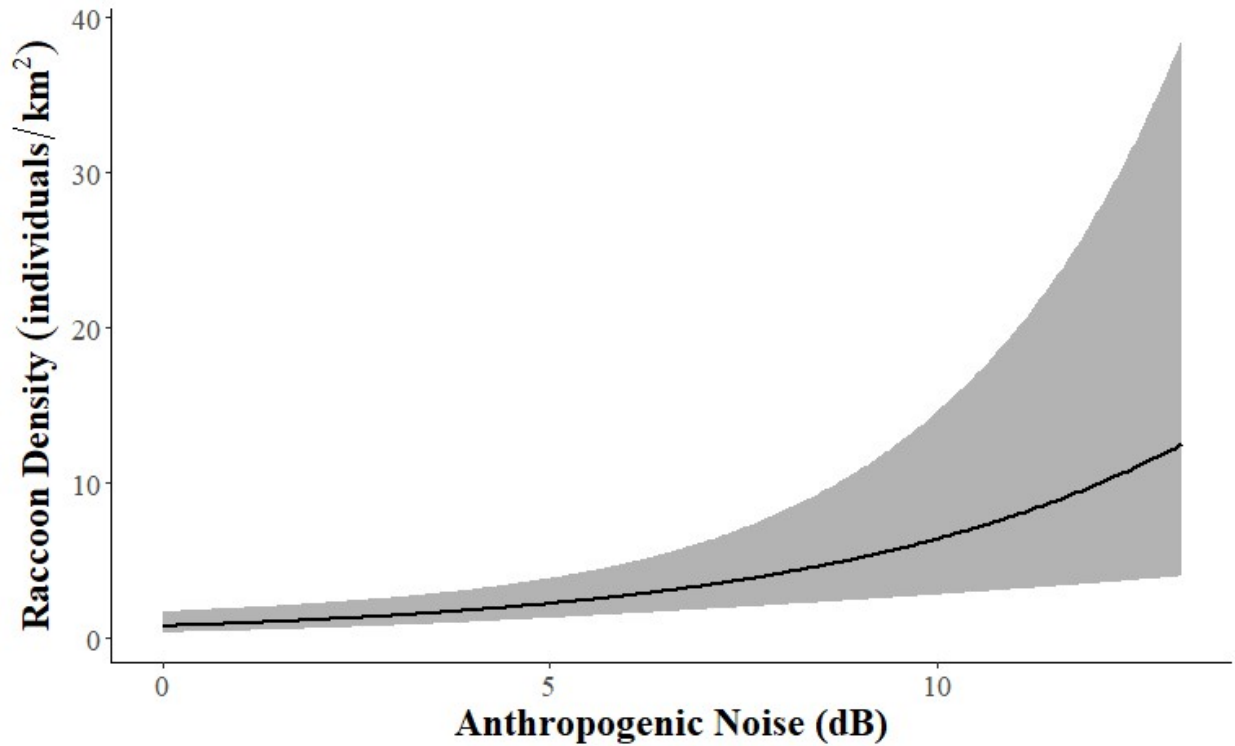
**Fig. 1.** Locations of camera traps in Northwest Arkansas, USA. Sites were chosen to represent a continuum of human activity and development. All sites were of similar habitat and elevation to account for behavioral changes based on habitat. Sites were sampled between November 2021 and March 2022.



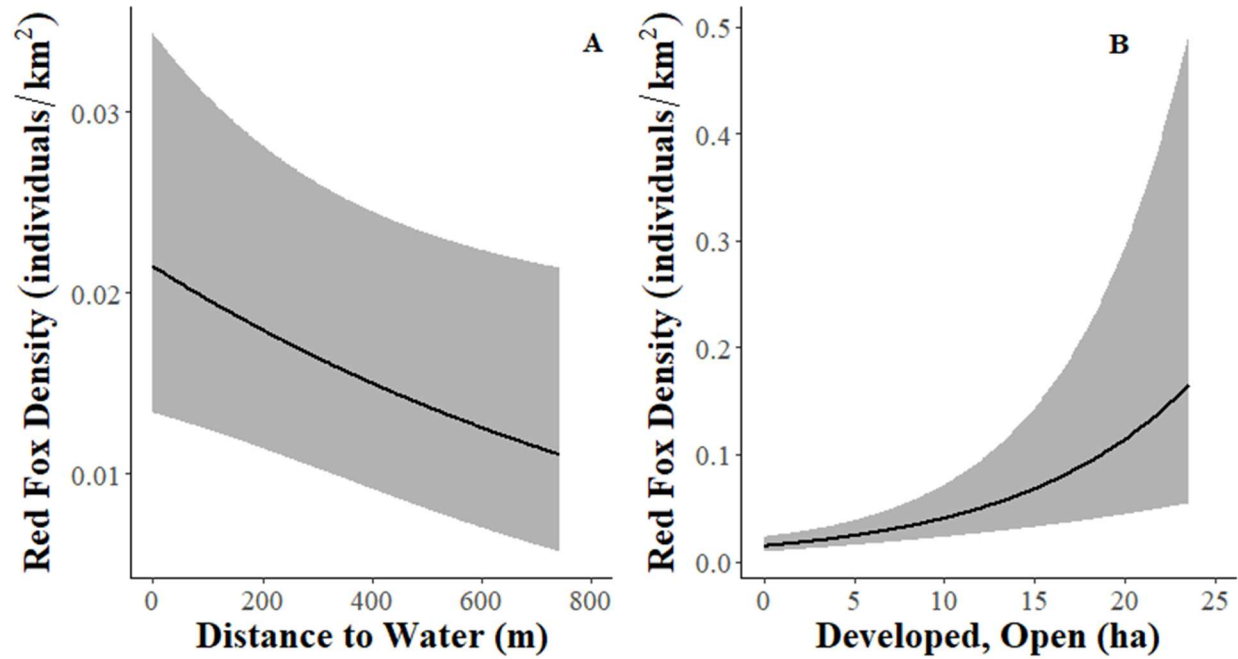
**Fig. 2.** Mean density ( $\pm$  SE) of five mesocarnivores estimated at twelve study sites throughout the Ozark Mountain Ecoregion in Northwest Arkansas, USA. Density estimates were derived from motion triggered game cameras deployed from Nov 2021 – Mar 2022 and estimated using the Random Encounter Model (Rowcliffe et al. 2008). Density estimates were averaged across each site to obtain a single density value. Sites are arranged on x-axis in terms of distance ( $\text{km}^2$ ) to downtown Fayetteville, with Mt. Sequoyah Woods being the closest and Ninestone Land trust the farthest.



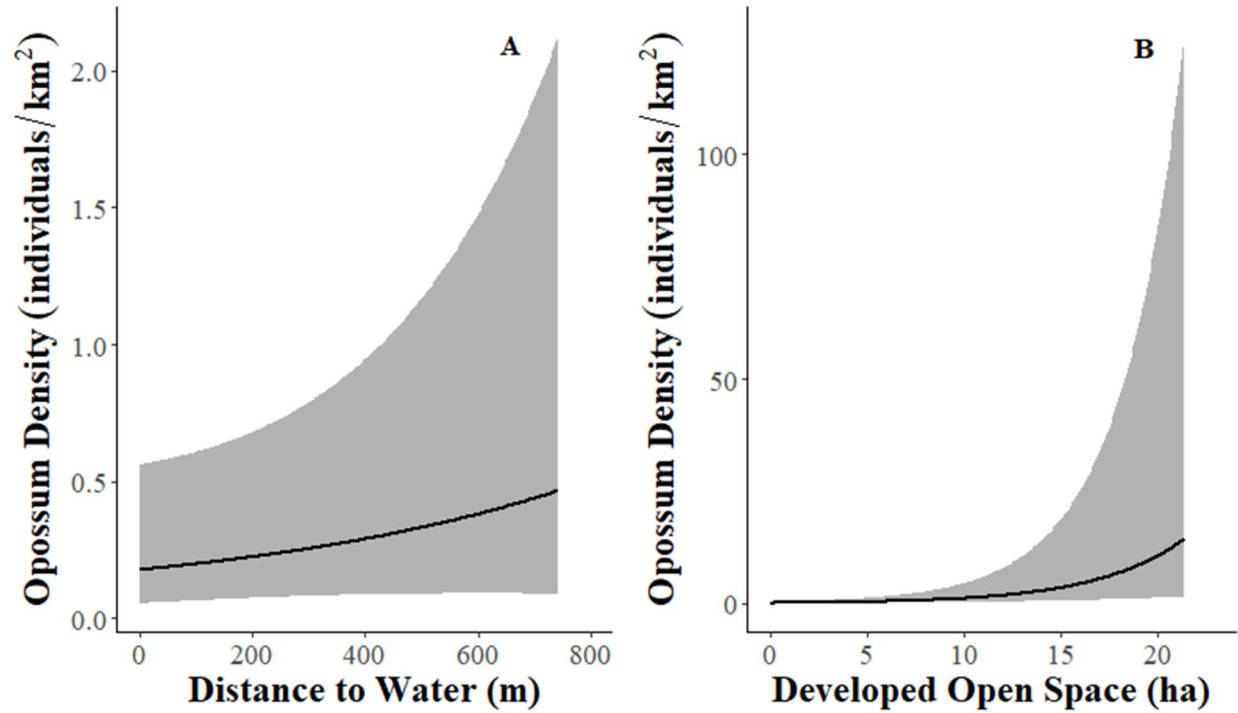
**Fig. 3.** Model averaged relationship between anthropogenic noise and coyote (*Canis latrans*) density estimated through trail cameras and the Random Encounter Model (Rowcliffe et al. 2008) at 12 study sites in northwest Arkansas, USA. The displayed relationship was derived from model averaging the top three models (Table 4) from AICc prediction of the effects of anthropogenic and environmental variables on coyote density.



**Fig. 4.** Model averaged relationship between anthropogenic noise and Northern raccoon (*Procyon lotor*) density estimated through trail cameras and the Random Encounter Model (Rowcliffe et al. 2008) at 12 study sites in northwest Arkansas, USA. The displayed relationship was derived from model averaging the top five models (Table 4) from AICc prediction of the effects of anthropogenic and environmental variables on raccoon density. While other variables appeared in the top models for raccoon, anthropogenic noise was the only significant variables with beta values not overlapping 0.



**Fig. 5.** The model averaged relationship between red fox density and both distance to water (A) and developed open space (B). Density was estimated through trail cameras and the Random Encounter Model (Rowcliffe et al. 2008). Derived from model averaging the top five models (Table 4) from AICc prediction for effects of anthropogenic and environmental variables on red fox density. While other variables appeared in the top models for red fox, developed open space and distance to water were the only significant variables with beta values not overlapping 0.



**Fig. 6.** The model averaged relationship between distance to water (A) and developed open space (B) against opossum density estimates. Density estimates were derived from motion activated trail cameras and the Random Encounter Model (Rowcliffe et al. 2008). Derived from model averaging the top seven models (Table 4) from AICc prediction for effects of anthropogenic and environmental variables on opossum density. While other variables appeared in the top models, developed open space was the only significant variable with beta values not overlapping 0.

## Supplementary Materials

**Supplemental Table 1.** Model selection statistics exploring the effects of landcover on coyote (*Canis latrans*) density. Density was derived from motion-activated trail camera data and the Random Encounter Model. Models were ranked using Akaike's Information Criteria (AICc) and includes the number of parameters (K), difference from the top model ( $\Delta AICc$ ), model weight (AICcWt), and cumulative weight.

| Model  | K | AICc    | $\Delta AICc$ | ModelLik | AICcWt | Cum.Wt |
|--|---|---------|---------------|----------|--------|--------|
| noise  | 4 | -103.54 | 0             | 1        | 0.17   | 0.17   |
| HUD + noise  | 5 | -102.69 | 0.85          | 0.65     | 0.11   | 0.29   |
| noise + forest area                                      | 5 | -102.52 | 1.02          | 0.6      | 0.1    | 0.39   |
| noise + distance to water                                | 5 | -101.52 | 2.01          | 0.37     | 0.06   | 0.46   |
| noise + developed open                                   | 5 | -101.47 | 2.07          | 0.35     | 0.06   | 0.52   |
| HUD + noise + forest area                                | 6 | -101.36 | 2.18          | 0.34     | 0.06   | 0.58   |
| null   | 3 | -101.02 | 2.52          | 0.28     | 0.05   | 0.63   |
| HUD + noise + distance to water                          | 6 | -100.62 | 2.92          | 0.23     | 0.04   | 0.67   |
| HUD + noise + developed open                             | 6 | -100.61 | 2.93          | 0.23     | 0.04   | 0.71   |
| noise + distance to water + forest area                  | 6 | -100.43 | 3.11          | 0.21     | 0.04   | 0.75   |
| Developed open   | 4 | -99.98  | 3.56          | 0.17     | 0.03   | 0.78   |
| noise + distance to water + developed open               | 6 | -99.44  | 4.1           | 0.13     | 0.02   | 0.8    |
| HUD + noise + forest area + developed open               | 7 | -99.27  | 4.27          | 0.12     | 0.02   | 0.82   |
| HUD + noise + distance to water + forest area            | 7 | -99.27  | 4.27          | 0.12     | 0.02   | 0.84   |
| Distance to water  | 4 | -99.23  | 4.31          | 0.12     | 0.02   | 0.86   |
| HUD  | 4 | -98.99  | 4.55          | 0.1      | 0.02   | 0.88   |
| Forest Area  | 4 | -98.96  | 4.58          | 0.1      | 0.02   | 0.89   |
| HUD + noise + distance to water + developed open         | 7 | -98.52  | 5.02          | 0.08     | 0.01   | 0.91   |
| noise + distance to water + forest area + developed open | 7 | -98.36  | 5.17          | 0.08     | 0.01   | 0.92   |
| Distance to water + developed open                       | 5 | -98.06  | 5.47          | 0.06     | 0.01   | 0.93   |
| Forest Area + developed open                             | 5 | -98.04  | 5.5           | 0.06     | 0.01   | 0.94   |
| HUD + developed open                                     | 5 | -98     | 5.54          | 0.06     | 0.01   | 0.96   |
| HUD + distance to water                                  | 5 | -97.17  | 6.37          | 0.04     | 0.01   | 0.96   |
| Global   | 8 | -97.16  | 6.37          | 0.04     | 0.01   | 0.97   |

|   |   |        |      |      |      |      |
|---|---|--------|------|------|------|------|
| <b>Distance to water + forest area</b>                        | 5 | -97.16 | 6.37 | 0.04 | 0.01 | 0.98 |
| <b>HUD + forest area</b>                                      | 5 | -96.92 | 6.62 | 0.04 | 0.01 | 0.98 |
| <b>Distance to water + forest area + developed open</b>       | 6 | -96.06 | 7.48 | 0.02 | 0    | 0.99 |
| <b>HUD + distance to water + developed open</b>               | 6 | -96.05 | 7.49 | 0.02 | 0    | 0.99 |
| <b>HUD + forest area + developed open</b>                     | 6 | -95.99 | 7.55 | 0.02 | 0    | 1    |
| <b>HUD + distance to water + forest area</b>                  | 6 | -95.1  | 8.44 | 0.01 | 0    | 1    |
| <b>HUD + distance to water + forest area + developed open</b> | 7 | -94    | 9.54 | 0.01 | 0    | 1    |

**Supplemental Table 2.** Model selection statistics for raccoon density estimates and anthropogenic and environmental variables. Density is derived from motion-activated trail camera data and the REM. Models were ranked using Akaike's Information Criteria (AICc) and includes the number of parameters (K), difference from the top model ( $\Delta AICc$ ), model weight (AICcWt), and cumulative weight included for each model.

| <b>Model</b>  | <b>K</b> | <b>AICc</b> | <b><math>\Delta AICc</math></b> | <b>ModelLik</b> | <b>AICcWt</b> | <b>Cum.Wt</b> |
|---|----------|-------------|---------------------------------|-----------------|---------------|---------------|
| <b>noise</b>  | 4        | 607.8       | 0                               | 1               | 0.19          | 0.19          |
| <b>noise + forest area</b>                                      | 5        | 608.86      | 1.06                            | 0.59            | 0.11          | 0.3           |
| <b>noise + distance to water</b>                                | 5        | 609.09      | 1.29                            | 0.53            | 0.1           | 0.39          |
| <b>noise + developed open</b>                                   | 5        | 609.18      | 1.37                            | 0.5             | 0.09          | 0.49          |
| <b>HUD + noise</b>  | 5        | 609.68      | 1.88                            | 0.39            | 0.07          | 0.56          |
| <b>noise + distance to water + developed open</b>               | 6        | 610.08      | 2.28                            | 0.32            | 0.06          | 0.62          |
| <b>HUD + noise + forest area</b>                                | 6        | 610.45      | 2.64                            | 0.27            | 0.05          | 0.67          |
| <b>noise + distance to water + forest area</b>                  | 6        | 610.55      | 2.75                            | 0.25            | 0.05          | 0.72          |
| <b>HUD + noise + distance to water</b>                          | 6        | 610.88      | 3.08                            | 0.21            | 0.04          | 0.76          |
| <b>HUD + noise + developed open</b>                             | 6        | 611.05      | 3.25                            | 0.2             | 0.04          | 0.79          |
| <b>HUD + noise + distance to water + developed open</b>         | 7        | 611.83      | 4.03                            | 0.13            | 0.03          | 0.82          |
| <b>noise + distance to water + forest area + developed open</b> | 7        | 611.99      | 4.19                            | 0.12            | 0.02          | 0.84          |

|   |   |        |       |      |      |      |
|---|---|--------|-------|------|------|------|
| <b>HUD + noise + distance to water + forest area</b>          | 7 | 612.1  | 4.3   | 0.12 | 0.02 | 0.86 |
| <b>developed open</b>   | 4 | 612.18 | 4.38  | 0.11 | 0.02 | 0.88 |
| <b>HUD + noise + forest area + developed open</b>             | 7 | 612.26 | 4.46  | 0.11 | 0.02 | 0.9  |
| <b>distance to water + developed open</b>                     | 5 | 612.75 | 4.95  | 0.08 | 0.02 | 0.92 |
| <b>forest Area + developed open</b>                           | 5 | 613.09 | 5.29  | 0.07 | 0.01 | 0.93 |
| <b>global</b>   | 8 | 613.6  | 5.8   | 0.06 | 0.01 | 0.94 |
| <b>Forest Area</b>  | 4 | 613.74 | 5.93  | 0.05 | 0.01 | 0.95 |
| <b>HUD + developed open</b>                                   | 5 | 614.24 | 6.44  | 0.04 | 0.01 | 0.96 |
| <b>distance to water + forest area + developed open</b>       | 6 | 614.34 | 6.54  | 0.04 | 0.01 | 0.97 |
| <b>HUD + distance to water + developed open</b>               | 6 | 614.74 | 6.94  | 0.03 | 0.01 | 0.97 |
| <b>null</b>   | 3 | 614.85 | 7.04  | 0.03 | 0.01 | 0.98 |
| <b>HUD + forest area + developed open</b>                     | 6 | 614.97 | 7.16  | 0.03 | 0.01 | 0.98 |
| <b>HUD + forest area</b>                                      | 5 | 615.54 | 7.74  | 0.02 | 0    | 0.99 |
| <b>distance to water + forest area</b>                        | 5 | 615.72 | 7.91  | 0.02 | 0    | 0.99 |
| <b>HUD + distance to water + forest area + developed open</b> | 7 | 616.18 | 8.38  | 0.02 | 0    | 0.99 |
| <b>distance to water</b>                                      | 4 | 616.48 | 8.68  | 0.01 | 0    | 1    |
| <b>HUD</b>  | 4 | 616.9  | 9.1   | 0.01 | 0    | 1    |
| <b>HUD + distance to water + forest area</b>                  | 6 | 617.51 | 9.71  | 0.01 | 0    | 1    |
| <b>HUD + distance to water</b>                                | 5 | 618.55 | 10.75 | 0.01 | 0    | 1    |

**Supplemental Table 3.** Model selection statistics for red fox density estimates and anthropogenic and environmental variables. Density is derived from motion-activated trail camera data and the Random Encounter Model. Models were ranked using Akaike's Information Criteria (AICc) and includes the number of parameters (K), difference from the top model ( $\Delta AICc$ ), model weight (AICcWt), and cumulative weight included for each model.

| Model   | K | AICc     | $\Delta AICc$ | ModelLik | AICcWt | Cum.Wt |
|---|---|----------|---------------|----------|--------|--------|
| <b>distance to water + developed open</b>                       | 5 | -1732.49 | 0.00          | 1.00     | 0.20   | 0.20   |
| <b>HUD + distance to water + developed open</b>                 | 6 | -1732.05 | 0.45          | 0.80     | 0.16   | 0.35   |
| <b>HUD + noise + distance to water + developed open</b>         | 7 | -1731.16 | 1.33          | 0.51     | 0.10   | 0.45   |
| <b>noise + distance to water + developed open</b>               | 6 | -1730.93 | 1.56          | 0.46     | 0.09   | 0.54   |
| <b>Distance to water + forest area + developed open</b>         | 6 | -1730.53 | 1.96          | 0.38     | 0.07   | 0.61   |
| <b>HUD + developed open</b>                                     | 5 | -1730.28 | 2.21          | 0.33     | 0.06   | 0.68   |
| <b>HUD + distance to water + forest area + developed open</b>   | 7 | -1729.96 | 2.53          | 0.28     | 0.06   | 0.73   |
| <b>developed open</b>   | 4 | -1729.88 | 2.61          | 0.27     | 0.05   | 0.79   |
| <b>HUD + noise + developed open</b>                             | 6 | -1729.54 | 2.95          | 0.23     | 0.05   | 0.83   |
| <b>global</b>   | 8 | -1729.26 | 3.24          | 0.20     | 0.04   | 0.87   |
| <b>noise + distance to water + forest area + developed open</b> | 7 | -1729.22 | 3.28          | 0.19     | 0.04   | 0.91   |
| <b>HUD + forest area + developed open</b>                       | 6 | -1728.31 | 4.18          | 0.12     | 0.02   | 0.93   |
| <b>noise + developed open</b>                                   | 5 | -1728.31 | 4.19          | 0.12     | 0.02   | 0.96   |
| <b>Forest Area + developed open</b>                             | 5 | -1728.25 | 4.24          | 0.12     | 0.02   | 0.98   |
| <b>HUD + noise + forest area + developed open</b>               | 7 | -1727.94 | 4.55          | 0.10     | 0.02   | 1.00   |
| <b>HUD</b>  | 4 | -1718.46 | 14.03         | 0.00     | 0.00   | 1.00   |
| <b>HUD + forest area</b>  | 5 | -1718.41 | 14.08         | 0.00     | 0.00   | 1.00   |
| <b>forest Area</b>  | 4 | -1718.38 | 14.11         | 0.00     | 0.00   | 1.00   |
| <b>null</b>   | 3 | -1717.33 | 15.16         | 0.00     | 0.00   | 1.00   |
| <b>distance to water + forest area</b>                          | 5 | -1717.14 | 15.35         | 0.00     | 0.00   | 1.00   |
| <b>HUD + distance to water</b>                                  | 5 | -1716.91 | 15.58         | 0.00     | 0.00   | 1.00   |

|  |   |          |       |      |      |      |
|--|---|----------|-------|------|------|------|
| <b>HUD + distance to water<br/>+ forest area</b>         | 6 | -1716.85 | 15.64 | 0.00 | 0.00 | 1.00 |
| <b>HUD + noise</b>                                       | 5 | -1716.77 | 15.72 | 0.00 | 0.00 | 1.00 |
| <b>noise + forest area</b>                               | 5 | -1716.44 | 16.05 | 0.00 | 0.00 | 1.00 |
| <b>noise</b>   | 4 | -1716.35 | 16.14 | 0.00 | 0.00 | 1.00 |
| <b>HUD + noise + forest area</b>                         | 6 | -1716.33 | 16.16 | 0.00 | 0.00 | 1.00 |
| <b>distance to water</b>                                 | 4 | -1716.21 | 16.28 | 0.00 | 0.00 | 1.00 |
| <b>noise + distance to water</b>                         | 5 | -1715.49 | 17.00 | 0.00 | 0.00 | 1.00 |
| <b>HUD + noise + distance to<br/>water</b>               | 6 | -1715.39 | 17.10 | 0.00 | 0.00 | 1.00 |
| <b>noise + distance to water<br/>+ forest area</b>       | 6 | -1715.31 | 17.18 | 0.00 | 0.00 | 1.00 |
| <b>HUD + noise + distance to<br/>water + forest area</b> | 7 | -1714.81 | 17.69 | 0.00 | 0.00 | 1.00 |

**Supplemental Table 4.** Model selection statistics for bobcat density estimates and anthropogenic and environmental variables. Density is derived from motion-activated trail camera data and the REM. Models were ranked using Akaike's Information Criteria (AICc) and includes the number of parameters (K), difference from the top model ( $\Delta AICc$ ), model weight (AICcWt), and cumulative weight included for each model.

| <b>Modnames</b>   | <b>K</b> | <b>AICc</b> | <b><math>\Delta AICc</math></b> | <b>ModelLik</b> | <b>AICcWt</b> | <b>Cum.Wt</b> |
|---|----------|-------------|---------------------------------|-----------------|---------------|---------------|
| <b>null</b>   | 3        | -678.56     | 0.00                            | 1.00            | 0.16          | 0.16          |
| <b>distance to water</b>                                | 4        | -677.37     | 1.19                            | 0.55            | 0.09          | 0.24          |
| <b>HUD</b>  | 4        | -677.14     | 1.42                            | 0.49            | 0.08          | 0.32          |
| <b>noise</b>  | 4        | -676.80     | 1.76                            | 0.41            | 0.07          | 0.39          |
| <b>developed open</b>                                   | 4        | -676.72     | 1.84                            | 0.40            | 0.06          | 0.45          |
| <b>Forest Area</b>                                      | 4        | -676.50     | 2.06                            | 0.36            | 0.06          | 0.50          |
| <b>HUD + distance to water</b>                          | 5        | -676.13     | 2.42                            | 0.30            | 0.05          | 0.55          |
| <b>distance to water + developed open</b>               | 5        | -675.70     | 2.86                            | 0.24            | 0.04          | 0.59          |
| <b>HUD + noise</b>                                      | 5        | -675.63     | 2.93                            | 0.23            | 0.04          | 0.62          |
| <b>noise + distance to water</b>                        | 5        | -675.61     | 2.95                            | 0.23            | 0.04          | 0.66          |
| <b>HUD + developed open</b>                             | 5        | -675.36     | 3.20                            | 0.20            | 0.03          | 0.69          |
| <b>distance to water + forest area</b>                  | 5        | -675.30     | 3.26                            | 0.20            | 0.03          | 0.72          |
| <b>HUD + forest area</b>                                | 5        | -675.12     | 3.44                            | 0.18            | 0.03          | 0.75          |
| <b>noise + forest area</b>                              | 5        | -674.80     | 3.76                            | 0.15            | 0.02          | 0.78          |
| <b>noise + developed open</b>                           | 5        | -674.77     | 3.79                            | 0.15            | 0.02          | 0.80          |
| <b>forest Area + developed open</b>                     | 5        | -674.70     | 3.86                            | 0.15            | 0.02          | 0.82          |
| <b>HUD + noise + distance to water</b>                  | 6        | -674.69     | 3.86                            | 0.14            | 0.02          | 0.84          |
| <b>HUD + distance to water + developed open</b>         | 6        | -674.60     | 3.96                            | 0.14            | 0.02          | 0.87          |
| <b>HUD + distance to water + forest area</b>            | 6        | -674.07     | 4.49                            | 0.11            | 0.02          | 0.88          |
| <b>distance to water + forest area + developed open</b> | 6        | -673.83     | 4.73                            | 0.09            | 0.01          | 0.90          |
| <b>noise + distance to water + forest area</b>          | 6        | -673.68     | 4.88                            | 0.09            | 0.01          | 0.91          |
| <b>noise + distance to water + developed open</b>       | 6        | -673.67     | 4.88                            | 0.09            | 0.01          | 0.92          |
| <b>HUD + noise + developed open</b>                     | 6        | -673.57     | 4.99                            | 0.08            | 0.01          | 0.94          |

|   |   |         |      |      |      |      |
|---|---|---------|------|------|------|------|
| <b>HUD + noise + forest area</b>                                | 6 | -673.56 | 5.00 | 0.08 | 0.01 | 0.95 |
| <b>HUD + forest area + developed open</b>                       | 6 | -673.27 | 5.28 | 0.07 | 0.01 | 0.96 |
| <b>HUD + noise + distance to water + developed open</b>         | 7 | -672.73 | 5.83 | 0.05 | 0.01 | 0.97 |
| <b>HUD + noise + distance to water + forest area</b>            | 7 | -672.65 | 5.91 | 0.05 | 0.01 | 0.98 |
| <b>HUD + distance to water + forest area + developed open</b>   | 7 | -672.57 | 5.99 | 0.05 | 0.01 | 0.99 |
| <b>noise + distance to water + forest area + developed open</b> | 7 | -671.90 | 6.66 | 0.04 | 0.01 | 0.99 |
| <b>HUD + noise + forest area + developed open</b>               | 7 | -671.51 | 7.05 | 0.03 | 0.00 | 1.00 |
| <b>global</b>   | 8 | -670.78 | 7.78 | 0.02 | 0.00 | 1.00 |

**Supplemental Table 5.** Model selection statistics for opossum density estimates and anthropogenic and environmental variables. Density is derived from motion-activated trail camera data and the REM. Models were ranked using Akaike's Information Criteria (AICc) and includes the number of parameters (K), difference from the top model ( $\Delta AICc$ ), model weight (AICcWt), and cumulative weight included for each model.

| model   | K | AICc    | $\Delta AICc$ | ModelLik | AICcWt | LL     | Cum.Wt |
|---|---|---------|---------------|----------|--------|--------|--------|
| <b>HUD + distance to water + forest area + developed open</b>   | 7 | -419.06 | 0.00          | 1.00     | 0.18   | 216.73 | 0.18   |
| <b>HUD + distance to water + developed open</b>                 | 6 | -418.20 | 0.85          | 0.65     | 0.12   | 215.25 | 0.30   |
| <b>distance to water + developed open</b>                       | 5 | -417.94 | 1.11          | 0.57     | 0.10   | 214.08 | 0.40   |
| <b>HUD + developed open</b>                                     | 5 | -417.82 | 1.23          | 0.54     | 0.10   | 214.02 | 0.50   |
| <b>distance to water + forest area + developed open</b>         | 6 | -417.63 | 1.43          | 0.49     | 0.09   | 214.96 | 0.59   |
| <b>HUD + forest area + developed open</b>                       | 6 | -417.31 | 1.75          | 0.42     | 0.08   | 214.80 | 0.66   |
| <b>Global</b>   | 8 | -417.09 | 1.97          | 0.37     | 0.07   | 216.80 | 0.73   |
| <b>developed open</b>   | 4 | -416.53 | 2.52          | 0.28     | 0.05   | 212.34 | 0.78   |
| <b>HUD + noise + distance to water + developed open</b>         | 7 | -416.14 | 2.91          | 0.23     | 0.04   | 215.27 | 0.82   |
| <b>noise + distance to water + developed open</b>               | 6 | -415.99 | 3.07          | 0.22     | 0.04   | 214.15 | 0.86   |
| <b>noise + distance to water + forest area + developed open</b> | 7 | -415.79 | 3.27          | 0.20     | 0.04   | 215.10 | 0.89   |
| <b>HUD + noise + developed open</b>                             | 6 | -415.78 | 3.28          | 0.19     | 0.04   | 214.04 | 0.93   |
| <b>HUD + noise + forest area + developed open</b>               | 7 | -415.33 | 3.73          | 0.16     | 0.03   | 214.86 | 0.96   |
| <b>forest Area + developed open</b>                             | 5 | -415.00 | 4.06          | 0.13     | 0.02   | 212.61 | 0.98   |
| <b>noise + developed open</b>                                   | 5 | -414.60 | 4.45          | 0.11     | 0.02   | 212.41 | 1.00   |
| <b>HUD + distance to water + forest area</b>                    | 6 | -405.66 | 13.39         | 0.00     | 0.00   | 208.98 | 1.00   |
| <b>HUD + noise + distance to water + forest area</b>            | 7 | -405.53 | 13.52         | 0.00     | 0.00   | 209.97 | 1.00   |
| <b>distance to water + forest area</b>                          | 5 | -405.16 | 13.90         | 0.00     | 0.00   | 207.68 | 1.00   |

|  |   |         |       |      |      |        |      |
|--|---|---------|-------|------|------|--------|------|
| <b>noise + distance to water<br/>+ forest area</b>                       | 6 | -404.71 | 14.35 | 0.00 | 0.00 | 208.50 | 1.00 |
| <b>noise + distance to water<br/>HUD + noise + distance<br/>to water</b> | 5 | -400.58 | 18.48 | 0.00 | 0.00 | 205.40 | 1.00 |
| <b>HUD + noise + forest<br/>area</b>                                     | 6 | -399.59 | 19.47 | 0.00 | 0.00 | 205.94 | 1.00 |
| <b>HUD + forest area</b>   | 6 | -399.18 | 19.88 | 0.00 | 0.00 | 205.74 | 1.00 |
| <b>Distance to water<br/>noise + forest area</b>                         | 5 | -398.26 | 20.79 | 0.00 | 0.00 | 204.24 | 1.00 |
| <b>forest Area</b>   | 4 | -398.03 | 21.03 | 0.00 | 0.00 | 203.08 | 1.00 |
| <b>HUD + distance to water<br/>HUD + noise</b>                           | 5 | -397.00 | 22.05 | 0.00 | 0.00 | 203.61 | 1.00 |
| <b>Noise</b>   | 4 | -396.40 | 22.65 | 0.00 | 0.00 | 202.27 | 1.00 |
| <b>Null</b>  | 5 | -396.30 | 22.75 | 0.00 | 0.00 | 203.26 | 1.00 |
| <b>HUD</b>   | 5 | -395.56 | 23.49 | 0.00 | 0.00 | 202.89 | 1.00 |
|  | 4 | -395.39 | 23.66 | 0.00 | 0.00 | 201.77 | 1.00 |
|  | 3 | -391.76 | 27.30 | 0.00 | 0.00 | 198.92 | 1.00 |
|  | 4 | -390.88 | 28.18 | 0.00 | 0.00 | 199.51 | 1.00 |

## CHAPTER II

### NINE BANDED ARMADILLO (*DASYPUS NOVEMCINCTUS*) OCCUPANCY AND DENSITY ACROSS AN URBAN TO RURAL GRADIENT

Leah E. McTigue and Brett A. DeGregorio

**Abstract** – The nine-banded armadillo (*Dasypus novemcinctus*, hereafter armadillo) is the only species of armadillo occurring in the United States and alters ecosystems due to its behavior of excavating numerous, extensive burrows that are used by many other species of wildlife. The armadillo has been expanding its range in the United States since the 1850s. However, relatively little is known about its habitat use, particularly in developed areas, which may be key to facilitating its range expansion. Here, we evaluated armadillo occupancy and density in relation to anthropogenic and landcover variables in the Ozark Mountain Ecoregion, Northwest Arkansas, USA, along an urban to rural gradient during two winter periods. Understanding habitat associations of armadillos can improve our understanding of how human development may be facilitating their range expansion and better predicting where wildlife-human conflicts might occur. Armadillo detection probability was best predicted by temperature (positively) and precipitation (negatively). Contrary to expectations, occupancy probability of armadillos was best predicted by slope and elevation rather than any landcover or development variables. Armadillos were less likely to occur on steeper slopes, likely because erosion and runoff may decrease foraging opportunities by reducing leaf litter accumulation. Armadillo occupancy probability increased as camera locations increased in elevation. This is counterintuitive, as higher elevations tend to have lower temperatures and armadillo are a cold intolerant species. However, this may be a result of a modest range in elevation between sites (214 – 541 m). We found that armadillo density varied considerably between study sites (ranging from a mean of 4.88 – 46.20 armadillos per km<sup>2</sup>) but was not predicted by any of the measured landcover or development variables. Compared to the small number of population density estimates published for the armadillo, our estimates were higher than those from the U.S., but were lower than

estimates from Brazil. Collectively, our results show that armadillos are widespread and can attain high densities in forested habitats in both natural and developed areas.

**Key words:** Armadillo, Ecosystem engineer, Urban-rural gradient, Detection, Occupancy, Random encounter Model, Density estimation

## Introduction

The nine-banded armadillo (*Dasypus novemcinctus*, hereafter armadillo) is a geographically widespread species in both North and South America that is considered an ecosystem engineer because it digs numerous and extensive burrows that are used by a wide variety of wildlife species (Sikes et al. 1990; Lamb et al. 2020; DeGregorio et al. 2022). Armadillos have been rapidly expanding their range within the United States since 1849 when the first individual was recorded in Texas (Fitch et al. 1952; Taulman and Robbins 1996; Feng and Papes 2014). Fitch et al. (1952) believed this range expansion was primarily due to changes in the landscape (timber cuts, agricultural expansion, livestock grazing), whereas Buchanan and Talmage (1954) attributed armadillo range expansion to the absence of large predators. The expansion of armadillos is also likely mediated by anthropogenic factors such as roads, translocation, and release from captive facilities (Humphrey 1974; Taulman and Robbins 1994; Haywood et al. 2021) and by warming temperatures (Taulman and Robbins 2014). Climate suitability models predict that armadillos could expand as far northward as parts of central Indiana and Ohio, the southeastern part of Pennsylvania, Delaware, and southern New Jersey (Feng and Papes 2014).

Human developed areas can facilitate the range expansion of species by providing subsidized resources, thermally buffered retreat sites, or altered thermal environments (Ordeñana et al. 2010; Dorak et al. 2016). This is particularly true for species that are limited by cold winter temperatures like the armadillo (McNab 1980). For instance, the Virginia opossum (*Didelphis virginiana*), has also been expanding its geographic range within the United States and human infrastructure and environments have played a pivotal role in this spread and survival during winter (Kanda et al. 2009; Walsh and Tucker 2018). Armadillos occur in suburban and urban

environments as well as natural areas (DeGregorio et al. 2021) but relatively little is known about their ecology and behavior in developed areas and how human subsidies might influence the species. As the armadillo expands its geographic range northwards, co-existing in human developed areas will be essential. However, relatively little is known about the habitat requirements and population densities of the armadillo in developed areas.

Armadillos are most frequently associated with riparian and forested habitats (McDonough, 2000; Rodrigues and Chiarello, 2018; Haywood et al. 2021). However, across their wide geographic range they have been documented using bottomland hardwood, upland hardwood, agricultural fields, riparian and grassland habitats (Thomas 1980; Zimmerman 1982; Breece and Dusi, 1985; Stallnecht et al. 1987; Layne and Glover 1997). Because of this flexibility, armadillos are often considered to be habitat generalists (McDonough, 2000; Rodrigues and Chiarello, 2018; Haywood et al. 2021) and are able to persist in both urban and suburban areas, though they may shift their activity to be more nocturnal in order to avoid humans (Taulman and Robbins 1996; Laughry et al 2013; DeGregorio et al. 2021). Little attention has been devoted to understanding how armadillo habitat use varies with surrounding human development. Because armadillos occurring in human developed areas are susceptible to a number of dangers including killing by dogs, collisions with vehicles, and disturbance by humans (Inbar and Mayer 1999; DeGregorio et al. 2021) the population dynamics of armadillos in natural and developed areas may be very different than those in natural areas. In addition to understanding habitat associations of armadillos along an urbanization gradient, understanding how density varies with development could also inform our understanding of how development facilitates or hinders range expansion.

Wildlife trail cameras are increasing in popularity due to their ability to effectively observe wildlife communities non-invasively 24 hours a day (Silveira et al. 2003, Trollet et al. 2014), allowing data to be collected on primarily nocturnal and elusive species such as the armadillo. Data from trail cameras can then provide data for a wide range of analytical methods, including density (Rowcliffe et al. 2008), community composition (Swann and Perkins, 2014), and occupancy (Gálvez et al. 2016). The Random Encounter Model (REM) is a method of density estimation that uses the field of motion and movement parameters of animals to estimate density from trail camera photographs and can be applied to species without individual markings (Rowcliffe et al. 2008). The REM has been validated in studies with known populations (Rowcliffe et al. 2008, Cusack et al. 2015, Kavčić et al., 2021), and is a promising approach for density estimation.

Here, we use a single species occupancy model and the REM to evaluate the habitat associations and density of armadillos along an urban to rural gradient in Northwest Arkansas. Armadillos have been present in this region of Arkansas since at least 1974 (Humphrey 1974), and the species is present along a continuum of landcover from undisturbed natural areas to urban areas within the greater Fayetteville metropolitan area (DeGregorio et al. 2021). The population growth in Northwest Arkansas has been dramatically increasing over the past 30 years, and the current human population of 546,725 is predicted to double by 2045 (NWARPC 2021). Understanding how the armadillo uses habitat along a gradient of development might provide insight into their use of habitats along the edge of their expansion where managers may have to mitigate conflict. Because the armadillo is often associated with developed areas (Chamberlain 1980; DeGregorio et al. 2021), we expected that anthropogenic variables (e.g., anthropogenic noise and developed open space) would increase armadillo occupancy probability.

We also predicted that density of armadillos would be greater in these developed areas because of expanded foraging opportunities associated with human development, particularly high moisture soils found in gardens and other developed open space (Chamberlain 1980). We also predicted that armadillo occupancy and density would be greatest in areas near water and with high forest cover as these variables have previously been shown to be important to this species (Loughry and McDonough, 2013).

## **Methods**

### *Site Selection*

Our study took place in Northwest Arkansas, USA, in the greater Fayetteville metropolitan area. We deployed trail cameras (Spypoint Force Dark (Spypoint Inc, Victoriaville, Quebec, Canada) and Browning Strikeforce XD cameras (Browning, Morgan, Utah, USA) over the course of two winter seasons, December 2020-March 2021, and November 2021-March 2022. We sampled 10 study sites in year one, and 12 in year two. All study sites were located in the Ozark Mountains ecoregion in Northwest Arkansas. Sites were all oak hickory dominated hardwood forests at similar elevation (213.6 – 541 m). Devils Eyebrow, Markham Hill, Sequoyah Woods, Ozark Natural Science Center (ONSC), and Kessler Mountain were sampled both years. Devils Eyebrow and ONSC are public natural areas managed by the Arkansas Natural heritage Commission (ANHC). Devil’s Den and Hobbs are managed by the Arkansas state park system. Markham Woods (Markham), Ninestone Land Trust (Ninestone) and Forbes, are all privately owned, though Markham has a publicly accessible trail system throughout the property. Lake Sequoyah, Mt. Sequoyah Woods, Kessler Mountain, Lake Fayetteville, and

Millsaps Mountain are all city parks and managed by the city of Fayetteville. Lastly, both Weddington and White Rock are natural areas within Ozark National Forest and managed by the Forest Service. We chose sites to represent a gradient of human development, based primarily on the distance to downtown Fayetteville with sites ranging from 2 – 60 km from city center of Fayetteville (Table 1).

### *Camera Placement*

We sampled ten areas in the first winter of the study. At each of the 10 study sites, we deployed anywhere between 5 and 15 cameras. Larger study areas received more cameras than smaller sites. All cameras were deployed a minimum of 150m between one another. We used a combination of Spypoint Force Dark and Browning Strike Force cameras for a total of 84 camera sites. We avoided placing cameras on roads, trails, and water sources to artificially bias wildlife detections. We also avoided placing cameras within 15m of trails to avoid detecting humans.

At each of the 12 study areas we surveyed in the second winter season, we deployed 12 to 30 Spypoint Force Dark and Browning Strikeforce XD cameras were deployed, for a total of 268 sites. We used recreational trails throughout each study area to facilitate semi-random camera deployment to meet the assumptions of the Random Encounter Model for estimating density (below). We used ArcGIS Pro (ArcGIS Pro; Esri Inc, Redlands, CA) to delineate trail systems and randomly placed cameras within a 150m buffer on each side of the trail. Trail densities at each site were often high, and this buffer typically encompassed most of the study sites. We then created random points using the Create Random Point tool in ArcGIS Pro. Cameras were spaced at least 150m from each other within 50m from the random point. A 50m buffer was allowed so

cameras were deployed on suitable topography and with a clear field of view, though cameras were not set in locations that would have increased animal detections (game trails, water sources, burrows etc.). Cameras were rotated between sites after 5 or 10 week intervals to allow us to maximize camera locations with a limited number of trail cameras available to us. Sites with more than 25 cameras were active for 5 consecutive weeks while sites with fewer than 25 cameras were active for 10 consecutive weeks. The length of deployment allowed for a goal of 1000 trap nights at each study area, though due to camera malfunction and theft this was not always possible but still allowed sampling efforts to exceed 600 trap nights per study area which is more than the minimum sampling effort needed to detect cryptic species (Carbone et al. 2001).

### *Camera Settings*

All cameras were placed on trees or tripods 50cm above ground and at least 15m from trails and roads. Cameras were set to take a burst of three photos when triggered. All photos were sorted using the Timelapse 2.0 software (Greenberg et al. 2019). We grouped photographs of a single species within single “episodes” of 5 minutes in length to avoid double counting individuals (Meek et al. 2014). The number of armadillos present within each episode was recorded.

### *Landcover Covariates*

To evaluate occupancy and density of armadillos based on environmental and anthropogenic variables, we used ArcGIS Pro (ArcGIS Pro 2.8.3, 2021; Esri Inc, Redlands, CA) to extract variables within 500m buffers placed around each camera (Table 3). This spatial scale

has been shown to hold biological meaning for armadillos and similarly sized species and minimizes overlap between cameras (Fidino et al. 2016, Magle et al. 2016, Gallo et al. 2017, DeGregorio et al. 2021). Elevation, slope, and aspect were all extracted from the base ArcGIS Pro map. We extracted maximum housing unit density (HUD) using the SILVIS housing layer (Radeloff et al. 2018, Table 3). We extracted anthropogenic noise from the layer created by Mennitt and Fristrup (2016; Buxton et al. 2017, Table 3) and used the “L50” anthropogenic sound level estimate, which was calculated by taking the difference between predicted environmental noise and the calculated noise level. Therefore, we assume that higher levels of L50 sound corresponded to higher human presence and activity, as prominent features projected by the estimated anthropogenic noise value reflect major U.S. cities and their surrounding transportation networks, reflecting human activity with areas having high noise values having high levels of human activity (voices, vehicles, and other sources of anthropogenic noise; Mennitt and Fristrup 2016; Buxton et al. 2017). Metrics for developed open landcover, forest area, and distance to forest edge were all derived from the 2019 National Land Cover Database (NLDC, Dewitz 2021, Table 3). Developed open landcover refers to open spaces with less than 20% impervious surface such as residential lawns, cemeteries, golf courses, and parks and has been shown to be important for medium-sized mammals (Poessel et al. 2012, Gallo et al. 2017). Forest area was calculated by combining all forest types within the NLDC layer (deciduous forest, mixed forest, coniferous forest), and summarizing the total area (km<sup>2</sup>) within the 500m buffer. Distance to forest edge was derived by creating a 30m buffer on each side of all forest boundaries and calculating the distance from each camera to the nearest forest edge. Distance to water was calculated by combining the waterbody and flowline features in the National Hydrography Dataset (U.S. Geological Survey) for the state of Arkansas to capture both permanent and

ephemeral water sources that may be important to wildlife. We measured the distance to water and distance to forest edge using the geoprocessing tool “near” in ArcGIS Pro which calculates the Euclidean distance between a point and the nearest feature. We used a search radius of 50 km when using the “near” tool to ensure features were not missed. We extracted Average Daily Traffic (ADT) from the Arkansas Department of Transportation database (Arkansas GIS Office). The maximum value for ADT was calculated using the Summarize Within tool in ArcGIS Pro.

We tested for correlation between all covariates with a Spearman correlation matrix and removed any variable with correlation greater than 0.6. Pairwise comparisons between ADT and HUD and between distance to forest edge and forest area were both correlated above 0.6; therefore, we dropped ADT and distance to forest edge from analyses as we predicted that HUD and forest area would have larger biological impacts on our focal species (Kretser et al. 2008).

### *Occupancy Analysis*

In order to better understand armadillo habitat associations while accounting for imperfect detections of armadillos, we used occupancy modeling (Mackenzie et al. 2002). We used a single-species single-season occupancy model (Mackenzie et al. 2002) even though we had two years of survey data. We chose to do this rather than using a multi-season dynamic occupancy model because most sites were not sampled during both years of the study. Even for sites that were sampled in both years, cameras were not placed in the same locations each year. Additionally, rather than exploring colonization and extinction rates at sites which multi-season models allow, we were only focused on better understanding habitat associations. We therefore combined all sampling into one single-season model and created unique site by year

combinations as our sampling locations and we used year as a covariate for analysis to explore changes in occupancy associated with the year of study.

For each sampling location, we created a detection history with 7 day sampling periods, allowing presence/absence data to be recorded at each site for each week of the study. This allowed for 16 survey periods between December 1<sup>st</sup>, 2020 and March 11<sup>th</sup>, 2021 for year 1 and 22 survey periods between November 1<sup>st</sup>, 2021 and March 24<sup>th</sup> for year 2. We treated each camera as a unique survey site, resulting in a total of 352 sites. Because not all cameras were deployed at the same time and for the same length of time, we used a staggered entry approach.

We used a multi-stage fitting approach in which we used Akaike's Information Criterion (AIC) to select for the best detection covariate. We modeled the survey period (to allow detection to vary over time), year (to evaluate detection across the two years of the study), weekly mean precipitation (to evaluate if precipitation influenced armadillo activity and thus detection), and weekly mean temperature (to evaluate if temperature influenced armadillo activity and thus detection) as covariates for detection against null occupancy parameters and selected the top covariate model with lowest AIC score. The top-ranked detection covariate(s) was then used in all subsequent analyses of occupancy. We acquired temperature and precipitation data from the NOAA weather station closest to each site for each detection date, and averaged temperature records across each 7-day survey period.

For occupancy covariates, we used distance to the nearest water source, distance to the nearest road, elevation, slope, aspect, maximum ADT, maximum anthropogenic noise developed open space), area of forest within each buffer, and maximum housing unit density. We then evaluated all single variable models using an AIC approach an apriori cutoff of 2  $\Delta$ AIC. (Burnham and Anderson 2002).

### *Density Estimation*

To evaluate armadillo density at each of the study sites, we used the Random Encounter Model (REM). The REM was developed to estimate density of unmarked animals through camera trap data (Rowcliffe et al. 2008). The three assumptions of the REM are: 1) that animals move randomly throughout their environment and are not set on any features that might increase their detection probability (e.g., trails, roads, bait etc.), 2) detection episodes are of individual animals, and 3) that the study population is closed (Rowcliffe et al. 2008). We used the REM equation to calculate armadillo density at each camera using Microsoft Excel (Microsoft corporation).

$$D = \frac{y}{t} \times \frac{\pi}{Vr(2 + \theta)}$$

In the REM, the  $y$  represents the total detections of armadillo at each camera. Total trap nights in hours (the measure of trapping effort) is represented by  $t$ .  $V$  refers to the day range (how far an individual travels in a 24-hour period) of the armadillo. We derived a mean day range for armadillo from day ranges reported in the literature (Table 2). Detection radius ( $r$ ) and detection angle ( $\theta$ ) were measured at each camera in the field through walk tests. The walk tests involved walking directly towards each camera to calculate the detection radius and from each side at 5m from the camera to calculate the detection angle in degrees. Detection was determined by whether or not the detection light on the camera was triggered during the walk test. We then converted the detection angle to radians for density calculations (Rowcliffe et al. 2008), Caravaggi et al. 2015). We were not able to calculate the detection angle and radius at 14 of the cameras due to camera malfunction (no detection light during walk test), and so we used the average detection angle for the given camera model (Schaus et al. 2020).

We evaluated if armadillo density correlated to anthropogenic or environmental variables. We used linear models in R, using the packages “lme4” and “AICcmodavg”. We only included data from the second year of sampling in our density calculations as detection radius and angle were not collected in year 1.. We evaluated armadillo density against HUD, anthropogenic noise, distance to water, forest area, development, and ADT. We modeled all single- and two-way combinations of these variables. However we did not include ADT and HUD in the same models due to high correlation between these covariates. Thus we evaluated 22 candidate models including the null and global models. In each model, we included site as a random effect to account for possible pseudoreplication when estimating density at each camera rather than each study site. We performed model selection was then preformed using an AIC approach with an apriori cutoff of 2  $\Delta$ AIC (Burnham and Anderson 2002).

## **Results**

### *Occupancy Results*

We conducted surveys at 352 survey locations and each location was surveyed during up to 22 7-day periods. Naïve occupancy (proportion of survey periods with armadillo detections) was 0.22. Armadillos were detected at least once at 243 of the 352 (69%) of sites. The max number of detections per site was 22 with a mean of 10.19 detections per site.

Of the 6 models assessing the individual and additive effects of detection covariates, armadillo detection was best predicted by the additive effects of precipitation (Fig 1) and temperature (Fig 2). The next best model for detection covariates was precipitation alone, with a

$\Delta$ AIC value of 64.68. Therefore, we used precipitation and temperature as detection covariates in all subsequent models evaluating armadillo occupancy.

Both elevation (Fig 3) and slope (Fig 4) were important in predicting armadillo occupancy. Elevation was present in all models within a  $\Delta$ AIC of 4 of the top model (Table 4). Furthermore no other models were within 2  $\Delta$ AIC of the additive effect of slope and elevation, which had a predicted occupancy probability of 0.70 (95% CI = 0.62-0.78). The degree of slope had a negative correlation with armadillo occupancy, though occupancy probability increased as elevation increased.

### *Density Results*

We used 287 camera locations across Northwest Arkansas for density analysis through the REM. Density estimates averaged across sites ranged from a low of 4.88 armadillos per km<sup>2</sup> at Devils Eyebrow to 46.20 armadillos per km<sup>2</sup> at ONSC (Table 5). Our top model relating density to environmental and anthropogenic variables was the null model indicating that none of our candidate models performed better than random at explaining variation in armadillo density (Table 6). While other models appeared to compete with the null, of the models within 2  $\Delta$ AIC, forest cover ( $\beta = 0.16$ , 95% CI = -0.15 to 0.49), distance to water, ( $\beta = 0.15$ , 95% CI = -0.22 to 0.39), ADT ( $\beta = 0.15$ , 95% CI = -0.22 to 0.35), and developed open space ( $\beta = 0.15$ , 95% CI = -0.24 to 0.34), each of these models had confidence intervals that overlapped with zero indicating considerable model uncertainty.

## Discussion

Armadillo were detected at all sites across both study years, including both natural and urban sites. We detected them during 69% of surveys, indicating that this species was relatively common along the studied urban to rural gradient. We found that detection probability of armadillos was most closely associated with temperature and precipitation. Despite our predictions, occupancy probability was best predicted by elevation and slope rather than any landcover variables. Occupancy probability increased with elevation and decreased on steep slopes. We did not see significant trends in any other anthropogenic or environmental landcover variables. We also found no influence of landcover or development variables on armadillo density.

The positive correlation between temperature and armadillo detection probability is intuitive given the physiology of armadillos. Armadillos are cold intolerant, have a low basal temperature, have a high rate of heat exchange with their environment, and take days to recover from exposure to suboptimal temperatures (McNab 1980). Thus, it makes sense that armadillos were most active during warmer periods of our winter study period. We also found that detection probability decreased during survey periods with precipitation. We had predicted the opposite trend assuming that rainfall would bring invertebrate prey closer to the soil surface for improved foraging (Humphrey 1974). It may be that some of the precipitation we recorded was snowfall and ice that could actually make foraging more difficult for armadillos. Precipitation may be more beneficial to armadillos during less thermally stressful periods of the year.

It was unexpected that slope and elevation would be the top ranked covariates explaining armadillo occupancy rather than any of the landcover or development variables. The negative correlation between armadillo occupancy and slope is intuitive as steeper slopes likely have less

foraging and burrowing potential for the armadillo due to higher levels of runoff and erosion and less accumulation soil and leaf litter (Warrington et al 1989). This finding is likely unique to mountainous areas where the armadillo occurs such as the Ozark Mountains, Ouachita Mountains, and Southern Appalachians. Our region of the Ozark Mountains has steep topography with some of our sites having slopes as steep as X% - Y%. Indeed, some of our steepest sites had the lowest densities of armadillos such as at Devil's Eyebrow. The Appalachian Mountains are likely a barrier to the range expansion of the armadillo on the East Coast of the United States (Feng and Papes 2015) and this may be due not only to harsher winter conditions but to large areas of unsuitable habitat due to steep slopes.

Because of the armadillo's intolerance to cold winter temperatures, we were surprised that occupancy increased at higher elevations within our study. Higher elevations are more thermally unpredictable (Willmott and Matsuura 1995) and thus likely more challenging for the cold intolerant armadillo. Elevation and slope have been reported to be associated with occupancy of eastern spotted skunks (*Spilogale putorius*: Eng and Jachowski 2019) and the authors believed this was a proxy for thermal conditions. There is also evidence that with climate change species have been expanding their range to higher elevations (Moritz et al. 2008). However, the direction of our reported effect is opposite of what we would expect if armadillos were preferentially found in warmer environments. However, we should note that the range of elevations of our study sites was minor (214 – 541m) and it's unclear how the relationship between armadillo occupancy and slope would behave if our sites encompassed a wider range of elevations. While the Ozark Mountains do not reach very high elevations, with the highest point being 751 m above sea level, our range of studied elevations do not encompass the full range of elevations available in the ecoregion.

We predicted that the probability of armadillo occurrence would increase in response to anthropogenic landcover, however we did not see any response to those variables in our analyses. Armadillos can shelter under sheds and other anthropogenic structures and will often forage in gardens, yards and other open spaces such as cemeteries, parks, and golf courses etc. (Chamberlain 1980). Despite these associations with urbanization, we found no relationship between development variables and occupancy or density. ADT also had no effect on armadillo occupancy or density, despite armadillos frequently being killed in vehicle collisions (Bond et al. 2002; Varela-Stokes et al. 2008; Hernandez et al. 2010).

Through the use of the REM, we were able to estimate armadillo density at 12 sites within the Ozark ecoregion. Overall, our density estimates are higher than other U.S based studies (McDonough 1994, 2000) and our highest density values align more closely with a density estimate from Brazil (Bovendorp and Galetti 2007). The higher densities in Arkansas could be related to the forested landscape of our region compared to more open habitats studied by McDonough in Texas (1994, 2000). Our highest density of armadillos occurred at ONSC (46.19 per km<sup>2</sup>). ONSC is a heavily forested natural area in Arkansas, created and managed to protect rare natural communities and provide vital habitat for plant and animal species by the Arkansas Natural Heritage Commission. ONSC does not allow dogs on any of the trails, which may allow armadillos to occur at higher densities (DeGregorio et al. 2021). Following ONSC, Lake Fayetteville (37.66 per km<sup>2</sup>), Markham Woods (34.95 per km<sup>2</sup>), and Millsaps (26.95 per km<sup>2</sup>), all urban sites with heavy human disturbance, had the highest armadillo densities. While we did not see any evidence based on landcover variables that armadillos occur in higher densities in urban areas, armadillos may be benefiting from anthropogenic resources which allow them to occur at higher densities in/around urban areas.

Our density estimates could be improved in the future by the incorporation of local movement parameters rather than using movement reports from other parts of their range (Table 7). It is also possible that the placement of some of our cameras near burrows could have led to high detection rates which can bias REM estimates (Rowcliffe et al. 2008). Ultimately, there are very few density estimates published for armadillos, which creates uncertainty regarding the accuracy of our estimates. However, it is encouraging that our mean density estimates for the 12 study sites fall within the range of reported density estimates from the 3 published density estimates available. Despite these shortcomings arising from limited data for this species, the REM has been successfully validated against known populations (Rowcliffe et al. 2008, Cusack et al. 2015, Kavčić et al., 2021), which lends support to our density estimates being valuable contributions to records of armadillo density across 12 different sites.

The expansion of armadillos is perceived as both a positive and negative thing. While their burrows provide habitat and shelter for an impressive number of different wildlife species (Clark 1951, Lamb et al. 2020; DeGregorio et al. 2022), they can also be seen as a nuisance species that threatens infrastructure and property. Their foraging and feeding habits have been known to cause property damage, and exclusion of armadillos is extremely difficult as they are excellent burrowers and are capable of climbing fences (Chamberlain 1980; Hawthorne 1994). Understanding the habitat and environmental conditions favored by this species will assist monitoring efforts as they continue north. While their detection probability increases in warmer temperatures, they may also have the capacity to occupy higher elevations, and be more widespread, particularly in areas like Tennessee and Virginia (Eichler and Gaudin 2011), though they are likely to avoid steep areas with little foraging opportunities. Additionally, a greater understanding of density and basic ecology of this species could impact success in monitoring

and managing the species. Further exploration of armadillo occupancy and density across a wider range of landcover could better inform our understanding of their resource needs. While we did find that population densities varied considerably across this study, we do not yet know what they vary in relation to. Additionally, the collection of location-specific movement parameters could increase the confidence of our density estimates using REM. The armadillo continues to rapidly expand and will continue to come into contact with people that have never co-existed with the species before, the more we understand about the species' habitat requirements and factors influencing their density, the better we will be able to manage their populations and interactions with humans.

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## TABLES

**Table 1.** Nature reserves located in Northwest Arkansas USA where cameras were set to survey for nine-banded armadillos (*Dasypus novemcinctus*) over two winter seasons, 2020/2021, and 2021/2022. Sites were chosen to represent a continuum of human activity. Sites farther from downtown Fayetteville were classified as more natural sites, and those closer to downtown more disturbed/urban. The number of cameras set at each site was determined by the size and trail density of the site as all cameras were placed away from trails and roads. Most sites with fewer cameras were active longer to allow a goal of 400 trap nights, though a minimum of five 7-day survey periods was ensured.

| Site                              | Study Year | Number of Cameras | Dates Active          | Total Trap Nights | Distance to Downtown Fayetteville (km) |
|-----------------------------------|------------|-------------------|-----------------------|-------------------|--|
| Markham Hill                      | 1          | 10                | 12/8/2020-3/8/2021    | 674               | 3                                      |
| Wilson Springs                    | 1          | 5                 | 1/8/2021-3/2/2021     | 257               | 4                                      |
| Mt. Sequoyah Woods                | 1          | 8                 | 12/30/2020-3/2/2021   | 372               | 2.1                                    |
| Kessler Mountain Park             | 1          | 15                | 12/1/2020-3/2/2021    | 517               | 5.7                                    |
| Lake Wilson Park                  | 1          | 10                | 12/10/2020-12/31/2020 | 198               | 9.8                                    |
| Forbes                            | 1          | 10                | 12/1/2020-1/4/2021    | 699               | 19.8                                   |
| Devils Den State Park             | 1          | 10                | 1/19/2021-3/2/2021    | 391               | 39.9                                   |
| Ozark Natural Science Center      | 1          | 10                | 12/5/2020-3/11/2021   | 1017              | 46.4                                   |
| Devils Eyebrow                    | 1          | 8                 | 1/17/2021-3/9/2021    | 355               | 50.6                                   |
| Mt. Sequoyah Woods                | 2          | 13                | 11/6/2021-1/8/2022    | 806               | 2.1                                    |
| Markham Hill                      | 2          | 25                | 11/1/2021-12/6/2021   | 853               | 3                                      |
| Centennial Park/Millsaps Mountain | 2          | 12                | 1/16/2022-3/21/2022   | 747               | 4.3                                    |
| Lake Fayetteville Park            | 2          | 12                | 1/15/2022-3/22/2022   | 682               | 9.6                                    |
| Kessler Mountain Park             | 2          | 28                | 2/16/2022-3/23/2022   | 996               | 5.7                                    |
| Lake Sequoyah Park                | 2          | 15                | 11/3/2021-1/9/2022    | 1005              | 9.6                                    |
| Ozark National Forest, Weddington | 2          | 30                | 12/8/2021-1/12/2022   | 1025              | 20                                     |
| Hobbs State Park                  | 2          | 29                | 1/14/2022-2/8/2022    | 1015              | 34.7                                   |
| Ozark National Science Center     | 2          | 28                | 12/9/2021-1/13/2022   | 1131              | 46.4                                   |
| Ozark National Forest, White Rock | 2          | 29                | 12/20/2022-3/24/2022  | 923               | 49.6                                   |
| Devils Eyebrow Natural Area       | 2          | 30                | 1/10/2022-2/14/2022   | 997               | 50.6                                   |
| Ninestone Land Trust              | 2          | 30                | 11/2/2021-12/7/2021   | 1086              | 58.1                                   |

**Table 2.** Literature derived day range values for the nine-banded armadillo (*Dasypus novemcinctus*). All values derived from literature were converted to kilometers traveled in a 24-hour period. We used the mean day range value from these literature derived values for the movement parameter in the Random Encounter Model to calculate population densities of armadillos in Northwest Arkansas, USA.

| <b>Citation</b>                          | <b>Day range<br/>(km/24h)</b> |
|--|-------------------------------|
| Vaughan, C., & Shoenfelder, S. 1999.     | 0.78                          |
| Loughry, W. J., & McDonough, C. M. 1998. | 0.16                          |
| Gammons et al. 2009                      | 0.49                          |
| <b>Mean Day Range Value</b>              | <b>0.47</b>                   |

**Table 3.** Variables included in occupancy and density analyses for the nine-banded armadillo (*Dasypus novemcinctus*). Variables were extracted using ArcGIS Pro (ArcGIS Pro; Esri Inc, Redlands, CA) within a 500m buffer surrounding each camera location. Table includes the minimum, maximum, and mean values for each variable across all 352 camera locations placed between the two winter study seasons.

| <b>Landcover Variable</b>                    | <b>Minimum</b> | <b>Maximum</b> | <b>Mean</b> |
|--|----------------|----------------|-------------|
| <b>Distance to road (km)</b>                 | 0.00           | 0.45           | 0.01        |
| <b>Elevation (m)</b>                         | 213.58         | 541.03         | 399.54      |
| <b>Slope (degrees)</b>                       | 0.21           | 39.16          | 11.12       |
| <b>Aspect (degrees)</b>                      | 0.06           | 354.33         | 174.54      |
| <b>Distance to water (km)</b>                | 0.00           | 0.08           | 0.00        |
| <b>ADT (daily traffic count)</b>             | 0.00           | 55,103.00      | 2,296.95    |
| <b>HUD (units/km<sup>2</sup>)</b>            | 0.00           | 5,335.91       | 277.36      |
| <b>Anthropogenic noise (dB)</b>              | 0.00           | 13.83          | 4.08        |
| <b>Developed open space (km<sup>2</sup>)</b> | 0.00           | 0.24           | 0.02        |
| <b>Forest area (km<sup>2</sup>)</b>          | 0.08           | 0.78           | 0.65        |

**Table 4.** Occupancy probability models for nine-banded armadillo (*Dasypus novemcinctus*) across an urban to rural gradient in Northwest Arkansas, USA, within 4  $\Delta$ AIC. Elevation and slope were in the top model, with 34% of overall weight of evidence. In each model, we used the additive effect of temperature and precipitation as detection covariates. Full AIC table is available as supplemental table 1.

| <b>Model</b>                         | <b>K</b> | <b>AIC</b> | <b>Delta<br/>AIC</b> | <b>AICwt</b> | <b>cumltvWt</b> |
|--------------------------------------|----------|------------|----------------------|--------------|-----------------|
| <b>elevation + slope</b>             | 6        | 3663.39    | 0.00                 | 0.30         | 0.30            |
| <b>elevation</b>                     | 5        | 3665.94    | 2.55                 | 0.08         | 0.38            |
| <b>distance to water + elevation</b> | 6        | 3666.74    | 3.34                 | 0.06         | 0.44            |
| <b>elevation + study year</b>        | 6        | 3666.87    | 3.48                 | 0.05         | 0.49            |
| <b>elevation + Noise</b>             | 6        | 3667.07    | 3.68                 | 0.05         | 0.54            |

**Table 5.** Mean density of Nine-banded armadillo (*Dasypus novemcinctus*) from 12 sites in the Ozark Mountains Ecosystem, Northwest Arkansas USA.

| Site                              | Density (ind./km <sup>2</sup> ) |       |
|-----------------------------------|---------------------------------|-------|
|                                   | Mean                            | SD    |
| Devils Eyebrow Nature Preserve    | 4.88                            | 2.56  |
| Hobbs State Park                  | 12.69                           | 3.51  |
| Kessler Mountain City Park        | 17.05                           | 9.92  |
| Lake Fayetteville City Park       | 37.66                           | 22.30 |
| Lake Sequoyah City Park           | 6.56                            | 2.37  |
| Markham Woods                     | 34.02                           | 7.94  |
| Millsaps Mountain/Centennial Park | 26.95                           | 12.05 |
| Ninestone Land Trust              | 10.81                           | 16.64 |
| Ozark Natural Science Center      | 46.20                           | 51.43 |
| Sequoyah Woods                    | 6.25                            | 2.12  |
| Ozark National Forest, Weddington | 24.16                           | 10.65 |
| Ozark National Forest, White Rock | 7.57                            | 2.84  |

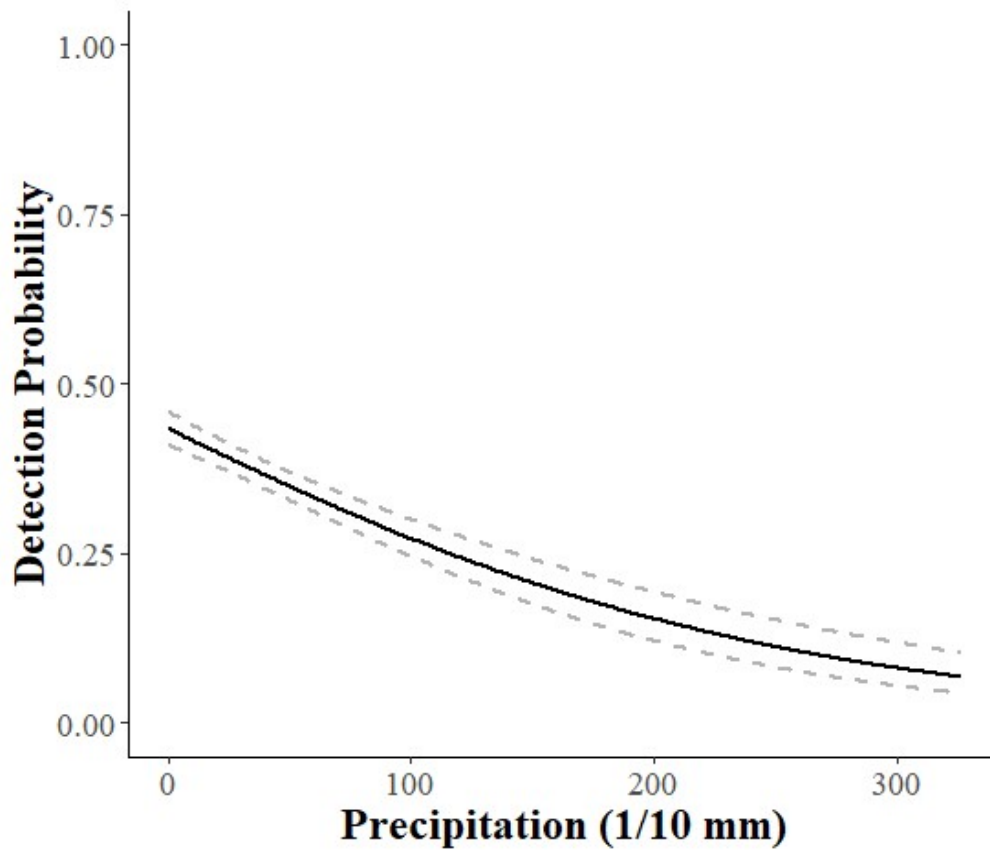
**Table 6.** Model selection statistics for nine-banded armadillo (*Dasypus novemcinctus*) density estimates in relation to environmental and anthropogenic factors. Table displays all individual models, not exceeding 3  $\Delta$ AIC. Density was calculated from motion activated trail camera data and the Random Encounter Model (REM). Models were ranked with Akaike's Information Criteria (AICc). The full AICc table is available (Supplementary Table 2).

| <b>Model</b>       | <b>K</b> | <b>AICc</b> | <b><math>\Delta</math>AICc</b> | <b>ModelLik</b> | <b>AICcWt</b> | <b>LL</b> | <b>Cum.Wt</b> |
|--------------------|----------|-------------|--------------------------------|-----------------|---------------|-----------|---------------|
| <b>null</b>        | 3        | 1319.70     | 0.00                           | 1.00            | 0.16          | -656.81   | 0.16          |
| <b>Forest</b>      | 4        | 1320.70     | 1.00                           | 0.61            | 0.10          | -656.27   | 0.26          |
| <b>Water</b>       | 4        | 1321.45     | 1.75                           | 0.42            | 0.07          | -656.65   | 0.33          |
| <b>ADT</b>         | 4        | 1321.58     | 1.88                           | 0.39            | 0.06          | -656.71   | 0.39          |
| <b>Development</b> | 4        | 1321.66     | 1.95                           | 0.38            | 0.06          | -656.75   | 0.45          |
| <b>Noise</b>       | 4        | 1321.73     | 2.02                           | 0.36            | 0.06          | -656.79   | 0.51          |
| <b>HUD</b>         | 4        | 1321.73     | 2.03                           | 0.36            | 0.06          | -656.79   | 0.57          |

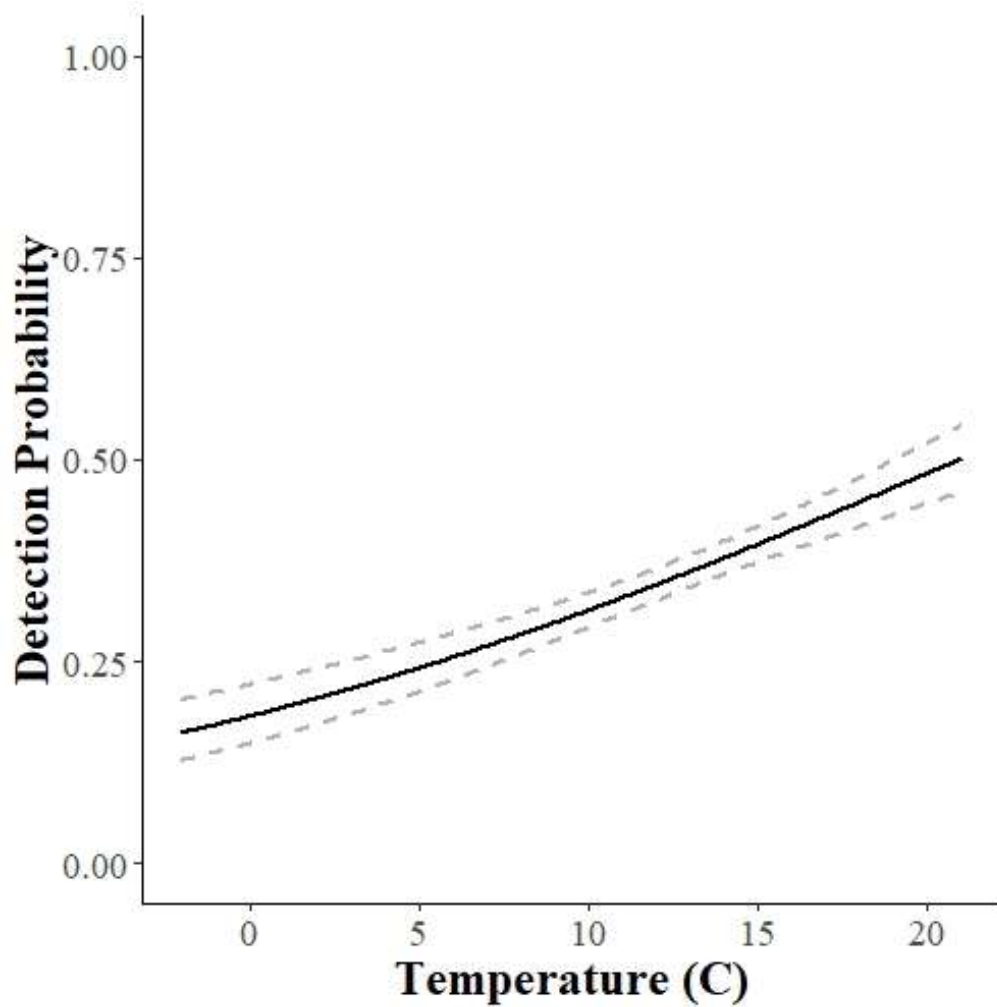
**Table 7.** Literature derived density estimates for the nine-banded armadillo (*Dasypus novemcinctus*). If multiple density estimates were provided in the literature for the same location, we averaged them together.

| <b>Citation</b>                      | <b>Location</b>               | <b>No. of<br/>Estimates</b> | <b>Density (ind./<br/>km<sup>2</sup>)</b> |
|--------------------------------------|-------------------------------|-----------------------------|---|
| Bovendorp, R. S., & Galetti, M. 2007 | Sao Paulo, Brazil             | 1                           | 45.23                                     |
| McDonough, C. M. 2000                | San Patricio County,<br>Texas | 12                          | 0.01                                      |
| McDonough, C. M. 1994                | San Patricio County,<br>Texas | 1                           | 0.01                                      |
| <b>Mean Density Value</b>            |                               | <b>4.66</b>                 | <b>15.08</b>                              |

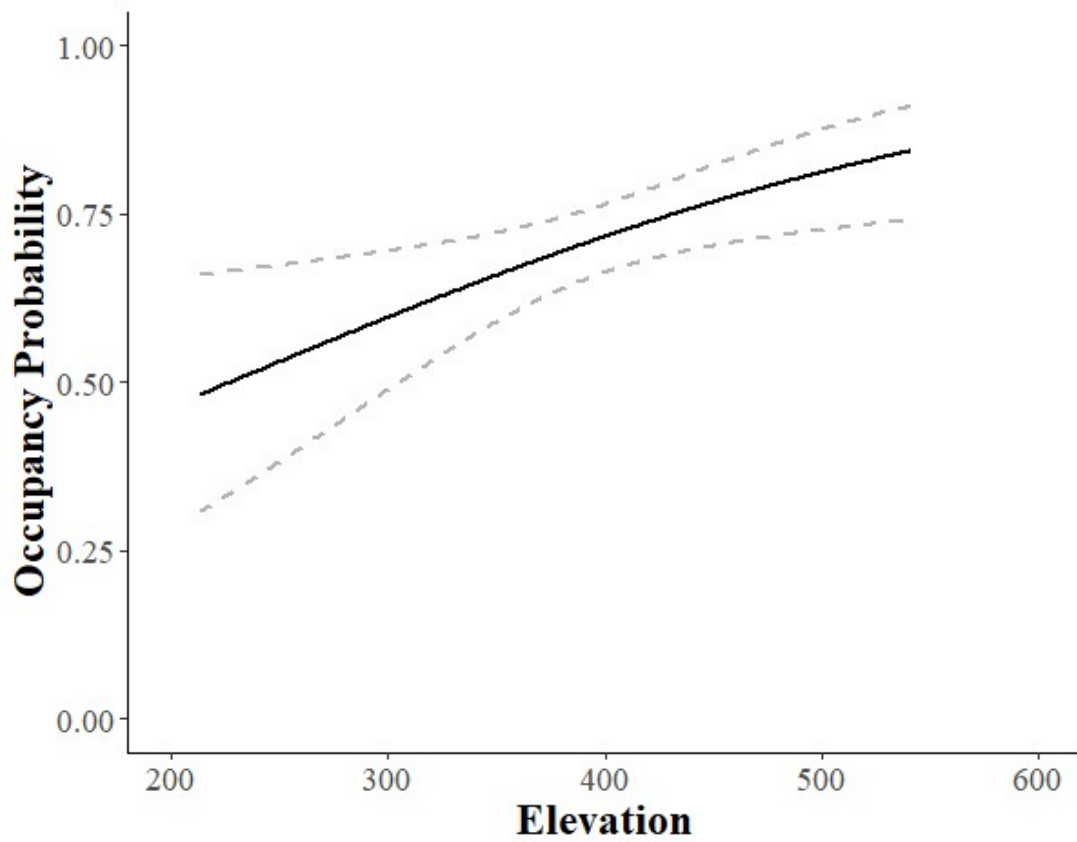
## FIGURES



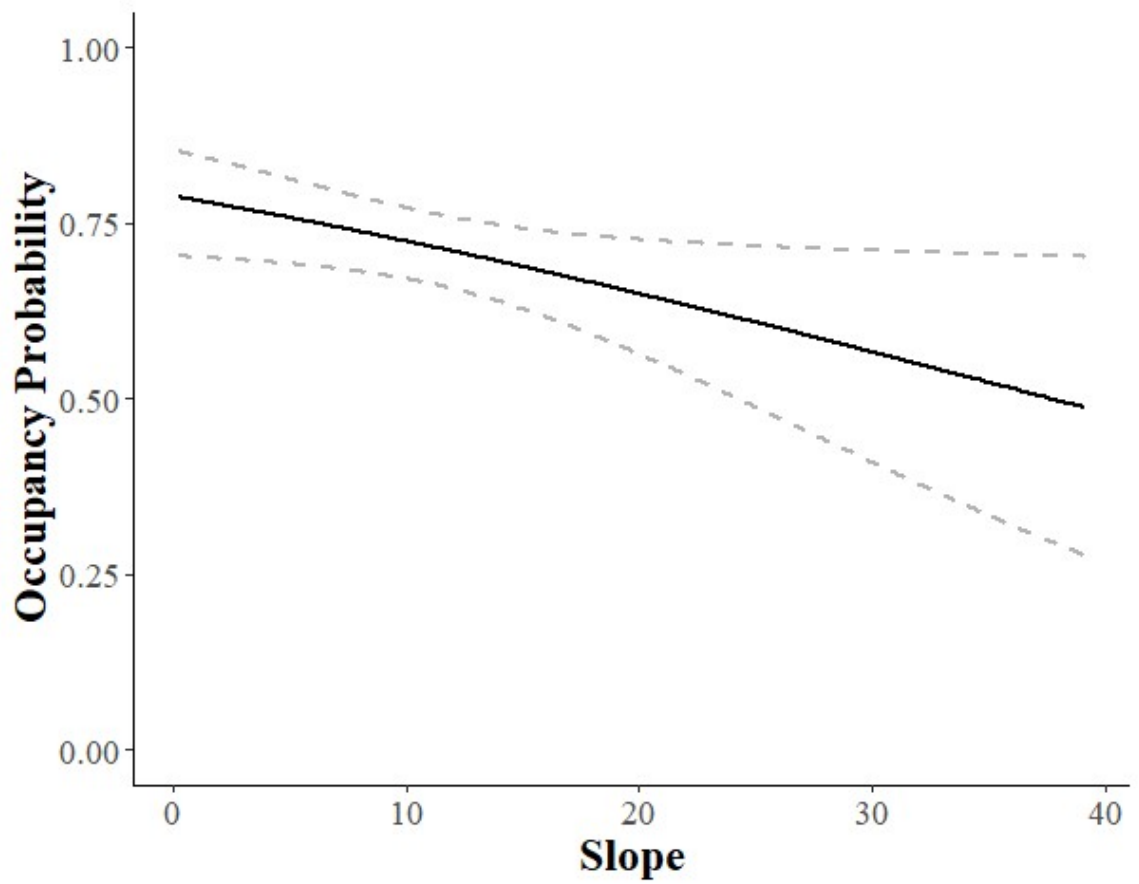
**Fig 1.** Detection probability for nine-banded armadillo (*Dasypus novemcinctus*) as predicted by precipitation across an urban to rural gradient in Northwest Arkansas. Detection probability decreases as the amount of precipitation (1/10 mm averaged over the 7-day survey period) increases.



**Fig 2.** Detection probability of nine-banded armadillo (*Dasypus novemcinctus*) as predicted by mean daily maximum temperature across an urban to rural gradient in Northwest Arkansas. Detection probability increases as maximum average temperature (degrees Celsius) averaged over the 7-day survey period) increases.



**Fig 3.** Occupancy probability of nine-banded armadillo (*Dasypus novemcinctus*) across an urban to rural gradient in Northwest Arkansas as predicted by elevation. As elevation increased, the probability of armadillos occurring also increased.



**Fig 4.** Occupancy probability for nine-banded armadillo (*Dasypus novemcinctus*) across an urban to rural gradient in Northwest Arkansas as predicted by slope. Occupancy probability decreased as the degree of slope increased.

# SUPPLEMENTARY MATERIALS

Supplemental Table 1. Full occupancy probability AIC table for the nine-banded armadillo

(*Dasypus novemcinctus*) across an urban to rural gradient in Northwest Arkansas, USA.

Elevation and slope were in the top model, with 34% of overall model weight. Other models

below the apriori cutoff of 2  $\Delta$ AIC show a high cumulative weight, however all contain

elevation, so no model averaging was performed.

| <i>Model</i>                                   | <i>nPars</i> | <i>AIC</i> | <i>delta</i> | <i>AICwt</i> | <i>Rsq</i> | <i>cumltvWt</i> |
|--|--------------|------------|--------------|--------------|------------|-----------------|
| <b><i>elevation + slope</i></b>                | 6            | 3663.39    | 0.00         | 0.30         | 0.40       | 0.30            |
| <b><i>elevation</i></b>                        | 5            | 3665.94    | 2.55         | 0.08         | 0.40       | 0.38            |
| <b><i>distance to water + elevation</i></b>    | 6            | 3666.74    | 3.34         | 0.06         | 0.40       | 0.44            |
| <b><i>elevation + study year</i></b>           | 6            | 3666.87    | 3.48         | 0.05         | 0.40       | 0.49            |
| <b><i>elevation + Noise</i></b>                | 6            | 3667.07    | 3.68         | 0.05         | 0.40       | 0.54            |
| <b><i>distance to water + slope</i></b>        | 6            | 3667.50    | 4.11         | 0.04         | 0.40       | 0.58            |
| <b><i>elevation + developed open space</i></b> | 6            | 3667.66    | 4.27         | 0.04         | 0.40       | 0.62            |
| <b><i>elevation + HUD</i></b>                  | 6            | 3667.68    | 4.28         | 0.04         | 0.40       | 0.65            |
| <b><i>elevation + aspect</i></b>               | 6            | 3667.72    | 4.32         | 0.03         | 0.40       | 0.69            |
| <b><i>elevation + forest area</i></b>          | 6            | 3667.80    | 4.40         | 0.03         | 0.40       | 0.72            |
| <b><i>slope + study year</i></b>               | 6            | 3667.98    | 4.59         | 0.03         | 0.40       | 0.75            |
| <b><i>ADT</i></b>                              | 5            | 3668.59    | 5.19         | 0.02         | 0.39       | 0.77            |
| <b><i>slope</i></b>                            | 5            | 3668.72    | 5.33         | 0.02         | 0.39       | 0.79            |
| <b><i>slope + Noise</i></b>                    | 6            | 3668.96    | 5.57         | 0.02         | 0.40       | 0.81            |
| <b><i>Noise + study year</i></b>               | 6            | 3669.21    | 5.82         | 0.02         | 0.39       | 0.83            |
| <b><i>distance to water + Noise</i></b>        | 6            | 3669.50    | 6.11         | 0.01         | 0.39       | 0.84            |
| <b><i>distance to water + study year</i></b>   | 6            | 3669.66    | 6.27         | 0.01         | 0.39       | 0.86            |
| <b><i>Noise</i></b>                            | 5            | 3669.87    | 6.48         | 0.01         | 0.39       | 0.87            |
| <b><i>distance to water</i></b>                | 5            | 3670.03    | 6.64         | 0.01         | 0.39       | 0.88            |
| <b><i>Noise + forest area</i></b>              | 6            | 3670.25    | 6.86         | 0.01         | 0.39       | 0.89            |
| <b><i>slope + forest area</i></b>              | 6            | 3670.31    | 6.92         | 0.01         | 0.39       | 0.90            |
| <b><i>slope + HUD</i></b>                      | 6            | 3670.37    | 6.97         | 0.01         | 0.39       | 0.91            |
| <b><i>study year</i></b>                       | 5            | 3670.46    | 7.07         | 0.01         | 0.39       | 0.92            |
| <b><i>slope + aspect</i></b>                   | 6            | 3670.49    | 7.10         | 0.01         | 0.39       | 0.92            |
| <b><i>slope + developed open space</i></b>     | 6            | 3670.71    | 7.31         | 0.01         | 0.39       | 0.93            |
| <b><i>Noise + developed open space</i></b>     | 6            | 3670.76    | 7.37         | 0.01         | 0.39       | 0.94            |
| <b><i>distance to water + HUD</i></b>          | 6            | 3671.40    | 8.01         | 0.01         | 0.39       | 0.95            |
| <b><i>aspect + Noise</i></b>                   | 6            | 3671.46    | 8.06         | 0.01         | 0.39       | 0.95            |
| <b><i>HUD + study year</i></b>                 | 6            | 3671.75    | 8.36         | 0.00         | 0.39       | 0.96            |

|   |    |         |       |      |      |      |
|---|----|---------|-------|------|------|------|
| <b>distance to water + aspect</b>               | 6  | 3671.81 | 8.41  | 0.00 | 0.39 | 0.96 |
| <b>Noise + HUD</b>                              | 6  | 3671.85 | 8.45  | 0.00 | 0.39 | 0.96 |
| <b>aspect + study year</b>                      | 6  | 3671.87 | 8.47  | 0.00 | 0.39 | 0.97 |
| <b>distance to water + developed open space</b> | 6  | 3671.94 | 8.55  | 0.00 | 0.39 | 0.97 |
| <b>distance to water + forest area</b>          | 6  | 3672.03 | 8.63  | 0.00 | 0.39 | 0.98 |
| <b>forest area + study year</b>                 | 6  | 3672.41 | 9.01  | 0.00 | 0.39 | 0.98 |
| <b>developed open space + study year</b>        | 6  | 3672.46 | 9.07  | 0.00 | 0.39 | 0.98 |
| <b>HUD</b>                                      | 5  | 3672.78 | 9.39  | 0.00 | 0.38 | 0.99 |
| <b>aspect</b>                                   | 5  | 3673.07 | 9.67  | 0.00 | 0.38 | 0.99 |
| <b>forest area</b>                              | 5  | 3673.38 | 9.98  | 0.00 | 0.38 | 0.99 |
| <b>developed open space</b>                     | 5  | 3673.45 | 10.06 | 0.00 | 0.38 | 0.99 |
| <b>global</b>                                   | 13 | 3673.47 | 10.07 | 0.00 | 0.41 | 0.99 |
| <b>aspect + HUD</b>                             | 6  | 3674.44 | 11.05 | 0.00 | 0.39 | 1.00 |
| <b>forest area + HUD</b>                        | 6  | 3674.55 | 11.15 | 0.00 | 0.39 | 1.00 |
| <b>developed open space + HUD</b>               | 6  | 3674.76 | 11.37 | 0.00 | 0.38 | 1.00 |
| <b>aspect + forest area</b>                     | 6  | 3675.02 | 11.62 | 0.00 | 0.38 | 1.00 |
| <b>aspect + developed open space</b>            | 6  | 3675.07 | 11.67 | 0.00 | 0.38 | 1.00 |
| <b>developed open space + forest area</b>       | 6  | 3675.33 | 11.94 | 0.00 | 0.38 | 1.00 |
| <b>null</b>                                     | 2  | 3837.86 | 174.4 | 0.00 | 0.00 | 1.00 |

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Supplemental Table 2. Full AIC table for nine-banded armadillo (*Dasypus novemcinctus*) density across an urban to rural gradient in Northwest Arkansas, USA. The top model for density was null. While other covariates appear to compete with the null, all other models are insignificant, with beta values overlapping 0.

| <b>Model</b>  | <b>K</b> | <b>AICc</b> | <b>ΔAICc</b> | <b>ModelLik</b> | <b>AICcWt</b> | <b>LL</b> | <b>Cum.Wt</b> |
|---------------|----------|-------------|--------------|-----------------|---------------|-----------|---------------|
| <b>null</b>   | 3        | 1319.70     | 0.00         | 1.00            | 0.16          | -656.81   | 0.16          |
| <b>Forest</b> | 4        | 1320.70     | 1.00         | 0.61            | 0.10          | -656.27   | 0.26          |
| <b>Water</b>  | 4        | 1321.45     | 1.75         | 0.42            | 0.07          | -656.65   | 0.33          |
| <b>ADT</b>    | 4        | 1321.58     | 1.88         | 0.39            | 0.06          | -656.71   | 0.39          |

|                        |   |         |      |      |      |         |      |
|------------------------|---|---------|------|------|------|---------|------|
| <b>Develop</b>         | 4 | 1321.66 | 1.95 | 0.38 | 0.06 | -656.75 | 0.45 |
| <b>Noise</b>           | 4 | 1321.73 | 2.02 | 0.36 | 0.06 | -656.79 | 0.51 |
| <b>HUD</b>             | 4 | 1321.73 | 2.03 | 0.36 | 0.06 | -656.79 | 0.57 |
| <b>ADT + Forest</b>    | 5 | 1322.11 | 2.41 | 0.30 | 0.05 | -655.94 | 0.62 |
| <b>Forest +</b>        | 5 | 1322.19 | 2.48 | 0.29 | 0.05 | -655.97 | 0.67 |
| <b>Develop</b>         |   |         |      |      |      |         |      |
| <b>Noise + Forest</b>  | 5 | 1322.22 | 2.52 | 0.28 | 0.05 | -655.99 | 0.71 |
| <b>HUD + Forest</b>    | 5 | 1322.48 | 2.77 | 0.25 | 0.04 | -656.12 | 0.75 |
| <b>Water + Forest</b>  | 5 | 1322.64 | 2.93 | 0.23 | 0.04 | -656.20 | 0.79 |
| <b>ADT + Water</b>     | 5 | 1323.33 | 3.63 | 0.16 | 0.03 | -656.55 | 0.82 |
| <b>HUD + Water</b>     | 5 | 1323.47 | 3.77 | 0.15 | 0.02 | -656.62 | 0.84 |
| <b>Water +</b>         | 5 | 1323.50 | 3.79 | 0.15 | 0.02 | -656.63 | 0.86 |
| <b>Develop</b>         |   |         |      |      |      |         |      |
| <b>Noise + Water</b>   | 5 | 1323.53 | 3.82 | 0.15 | 0.02 | -656.65 | 0.89 |
| <b>ADT + Develop</b>   | 5 | 1323.61 | 3.90 | 0.14 | 0.02 | -656.68 | 0.91 |
| <b>ADT + Noise</b>     | 5 | 1323.66 | 3.95 | 0.14 | 0.02 | -656.71 | 0.93 |
| <b>HUD + Develop</b>   | 5 | 1323.73 | 4.02 | 0.13 | 0.02 | -656.75 | 0.96 |
| <b>Noise + Develop</b> | 5 | 1323.74 | 4.03 | 0.13 | 0.02 | -656.75 | 0.98 |
| <b>HUD + Noise</b>     | 5 | 1323.79 | 4.09 | 0.13 | 0.02 | -656.78 | 1.00 |
| <b>global</b>          | 8 | 1328.26 | 8.56 | 0.01 | 0.00 | -655.84 | 1.00 |

## CONCLUSION

For my master's thesis research, I evaluated the effects of anthropogenic and environmental variables on mammal density and occupancy along an urban to rural gradient. I found that density estimations for raccoon, coyote, red fox, and opossum were consistent with the expectations for urban exploiter species, though they differed in which landcover variables they responded to.

Coyote and raccoons had higher densities with anthropogenic noise, indicating their ability to co-occur near humans. Opossum and red fox both showed a positive relationship between density and developed open space and were absent (red fox) or rare (opossum) in natural forested areas.

While bobcats were widespread, we found little support for landscape variables correlating with bobcat density. In Arkansas, bobcats have large home ranges ( $64.2\text{km}^2$  for adult males,  $24.5\text{km}^2$  for adult females; Rucker et al. 1989), and therefore it is possible our spatial scale was inappropriate to evaluate which landcover variables impact density.

In my second chapter, I focused on the nine-banded armadillo (*Dasypus novemcinctus*). I evaluated armadillo occupancy and density along an urban to rural gradient. Density was estimated through the Random Encounter Model (REM). Temperature and precipitation impacted armadillo detection probability, while occupancy probability was impacted by slope and elevation. While we were able to estimate the density of armadillos, similarly to bobcat density did not align with any landcover variables used in analysis. While past studies have shown armadillos to be impacted by urbanization, we did not see any correlation between the occupancy and density of armadillos in association with anthropogenic resources (DeGregorio et al. 2021). The positive correlation between armadillos and elevation could indicate their potential

to expand their range, encompassing the entirety of more northern mountainous states like Tennessee and Virginia (Eichler and Gaudin 2011).

By using only motion-triggered game cameras, we were able to successfully calculate the density of 6 species at 12 different study sites using the REM. Density estimates were comparable to values found in the literature, which is encouraging and shows the robustness of the REM. The REM is particularly valuable for cryptic species, as it uses the species movement parameters for density estimation rather than continuous timelapse data.

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