MAMMAL REACTIONS TO NOVEL OBJECTS IN THEIR ENVIRONMENT

by

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Bachelor of Science
George Mason University, 2022

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DEDICATION

I dedicate this work to my family and friends. Extreme gratitude to my loving parents, Richard and Patricia Wood, who have continually supported and encouraged me. Special gratitude to my partner, Adam Caraballo, for continually loving and supporting me throughout my entire degree process.

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ABSTRACT

MAMMAL REACTIONS TO NOVEL OBJECTS IN THEIR ENVIRONMENT

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The way in which mammals respond to novel objects can inform experts and managers about how urbanization is impacting species. The behaviors of three common North American mammal species with great behavioral adaptability, raccoons (*Procyon lotor*); red foxes (*Vulpes vulpes*); and white-tailed deer (*Odocoileus virginianus*), were observed using remotely triggered wildlife cameras and novel objects. The amount of time an individual spent within view of the camera, the number of behaviors exhibited, and the time it took an individual to approach novel objects and control sites were analyzed as a function of canopy cover, impervious cover, and human population density. Correlations between canopy cover, impervious cover, and population density and response variables, and the direction of effects differed between species, but trends emerged among similar taxa (carnivores). This study can inform plans and protocols to mitigate human-wildlife conflicts while considering how different species respond to urbanization.

CHAPTER ONE

INTRODUCTION & BACKGROUND

The world's human population has been increasing at an exponential rate since the industrial revolution, with the current population precariously close to 8 billion (Cleland, 2013; Goujon, 2019). As human population levels continue to increase, people are increasingly moving to cities (Ritchie & Roser, 2018). To accommodate rising populations, urban development happens quickly, is often ill-designed, and ultimately reduces or eliminates natural spaces (Benedict & McMahon, 2002). Decreasing natural space results in less habitat for wildlife and requires wild animals to exist and live in increasingly human-dominated spaces. This circumstance can lead to an increased likelihood of humans interacting with wild species, and potentially causing human-wildlife conflicts (Barrett et. al, 2018).

While people often assume that species avoid urban spaces, this is not inherently true. In some cases, urbanization may increase the number of species living within cities (Ditchkoff et al., 2006). For example, human maintenance of vegetation creates novel and more heterogenous habitats that allow for more niches, and thus the potential for more species (Faeth et al, 2011). There are a number of factors that influence an animal's ability to adapt to new surroundings, but resource availability, the presence of predators, and the condition of the physical environment are the greatest factors (Bateman & Fleming, 2012; Luniak, M., 2004; Schell et al, 2020).

Cities provide supplemental resources (e.g. landscaping, fruit trees, human refuse) that allow animals access to food and shelter throughout the year (Bateman & Fleming, 2012). A large portion of the supplemental food resources in urban settings are easy to find and have higher nutritional content than most resources in rural settings (Bateman & Fleming, 2012). Many successful urban adapted animals are generalists and can utilize the variety of anthropogenically provided food sources found within a city (Ditchkoff et al., 2006).

Urban spaces also have different predator-prey dynamics than rural locations (Faeth et al, 2005; Rodewald & Gehrt, 2014). Human presence has greatly altered the predator-prey dynamics through the introduction of nonnative species and extirpation of other native species (Faeth et al., 2005; Prange & Gehrt, 2004). In urban and suburban space there is often a distinct lack of apex predator species (Faeth et. al, 2005; Ryan & Partan, 2014). The lack of predatory presence may result in a greater abundance of prey species or change the behavior of prey and mesocarnivores, which could lead to an increase in human wildlife interactions (Ryan & Partan, 2014; Crooks & Soulé, 1999).

The ever-changing and increasing infrastructure of urban and suburban spaces can also create new and novel spaces for species to use as shelter. For example, racoons will utilize crawl spaces under houses as dens (Bateman & Fleming, 2012), red foxes will often utilize trash bins or compost containers as food sources (Bateman & Fleming, 2012), and white-tailed deer will often utilize lawns and gardens as food sources

(McShea, 2012). While the built environment can create shelter for particular species, these types of human-wildlife shared spaces are often what leads to human-wildlife conflict.

While not all species do well within urban settings, those with some sort of behavioral innovation or adaptability tend to persist in these human-dominated environments (Bateman & Fleming, 2012). Many studies have found that urban animals are more explorative than their rural counterparts (Gil-Fernández et al, 2020; Ritzel & Gallo, 2020), and species or individuals that demonstrate greater innovation are more successful at establishing themselves in a new environment (Bergman & Kitchen, 2009; Stanton et al, 2022; Thompson et al, 2018). Species that demonstrate greater innovation are oftentimes those that are better able to change their behavior under changing circumstances. In urban settings an individual's flexibility and ability to use novel resources in beneficial ways is paramount to survival (Caspi et. al, 2022).

As urbanization encroaches on natural habitats, persisting animals are increasingly exposed to new or novel objects and food sources, and may ultimately develop a tolerance to these novel things (Barrett et. al, 2018). Studies have found that observed behavioral differences between urban and rural populations can be attributed to the individuals' ability to change their behaviors (Caspi et al, 2022). Behavioral changes can be viewed as an entry point to adaptations and evolution (Caspi et al, 2022). Three common urban species with great flexibility in their behaviors – that I study here – are raccoons, red foxes, and white-tailed deer (Prange et al, 2004; Walton et al, 2018; Wolff et al, 2020).

HUMAN-WILDLIFE CONFLICT: CARNIVORES AND UNGULATES

Human-wildlife conflict, in the United States, is an issue not only in urban areas, but also rural areas. Human-wildlife conflict can take many forms and vary in their degree of harm. For example, ungulates are responsible for vehicle collisions, and feeding on home landscaping; small mammals and birds can cause nuisance actions such as getting into trash cans, into homes chimneys, or destroying vegetation; and carnivores can cause direct harm to humans from attacks; and many species can transmit diseases to humans (Ryan & Partan, 2014).

Raccoons and red foxes are both carnivores that utilize urban spaces. Carnivores, particularly those in urban settings, are often viewed in a negative light because the negative interactions, even when they are infrequent, outweigh the positive services they provide to the ecosystem (Skogen & Krange, 2003). Carnivore-human conflicts can take on many different forms, such as property damage, or injury or death to livestock, pets, or people (Klees van Bommel et. al, 2020). Thus, carnivores are often viewed as species that need to be eradicated to allow other animal populations to thrive or to increase human safety (Klees van Bommel et. al, 2020). However, carnivores provide many ecosystem services, such as mitigation of disease, and carcass removal (Expósito-Granados, et. al, 2019; Gilbert et al, 2016). Therefore, it is important that a way if found for carnivores and humans to co-exist in all landscapes, including urban.

While ungulates, like deer, are not as persecuted as carnivores, they do experience similar issues in urban environments and can oftentimes be considered a nuisance species

(Brown et. al, 2012). Anthropogenic disturbances, such as roads and development, can cause habitat fragmentation that results in less connected populations and more developed areas in which deer must disperse. Many residents in urban and suburban areas are concerned about deer-vehicle collisions or deer related plant damage (Storm et al 2007). It was reported in 1995 that there were an estimated 1 million deer-vehicle collisions, in the United States, that resulted in 200 human deaths, and an estimated 1.5 million deer-vehicle collisions in the United States resulting in greater than 200 human deaths in 2001 (Conover et al 1997; Mastro et al, 2008). These common concerns and problems have led deer and other ungulates to be viewed as nuisance species, and a species that needs to be controlled. Previous research found that the best solution to controlling deer populations was sharpshooting to cull the population (DeNicola, 2008).

Human-wildlife conflict can be difficult to manage without knowledge about how species react to anthropogenic urbanization and novel environments. Understanding the way in which species respond to novel objects could aid wildlife managers in creating strategies to decrease human-wildlife conflicts.

PURPOSE OF STUDY AND VARIABLES EXAMINED

Being able to understand a species' immediate response to a new object in their environment can help to decrease human-wildlife conflicts by understanding how a species interacts with anthropogenic objects around them. Knowing whether a species will exhibit more neophobic or exploratory behavior will allow for new sustainability practices to be created so that more wildlife-friendly development can occur.

The purpose of this study is to assess how three common urban mammal species – white-tailed deer, red fox, raccoon – interact with novel objects across an urban to suburban gradient. The goal of this project is to assess how behaviors change as a response to urbanization. I used a combination of remotely triggered wildlife cameras and novel objects to examine neophobia towards a novel object and exploratory behaviors when in the presence of a novel object.

This study has the potential to help land and/or wildlife managers understand species' behaviors and reactions to increasing urbanization. The results from this study could also aid managers in developing strategies to decrease human-wildlife interactions.

METHODS

Study Area

I conducted my study throughout the Metropolitan Statistical Area of District of Columbia, Virginia, and Maryland, which has a population of approximately 6,358,652 residents (~968.2 people /mi^2) (Census Profile, 2021). The area of District of Columbia, Virginia, and Maryland has a temperate/tropical climate with an average of 110 centimeters of annual precipitation and annual average temperatures ranging from 21.6 to 6.9◦C (National Oceanic and Atmospheric Administration, 2021)

Site Selection

Within the Washington, D.C. metro area, 20 greenspaces were randomly selected from a comprehensive list of greenspaces in the region. The final list of 16 greenspaces were chosen based on accessibility and permission from landowners (Fig. 1). Sites were checked using NLCD impervious cover data to ensure that they covered a gradient with impervious cover as a metric for urbanization (Wickham et al 2021). At each site 2 camera stations, a treatment (with novel object) and a control, were placed an average of 373 meters apart with a range of 52 – 1297 meters. While these distances are within a species home range, I was not concerned about capturing the same individual at the same paired control/treatment sites as this information might increase the variability among individuals. Camera set ups were placed within green space and off trails to minimize the visibility from public spaces and decrease human disturbances.

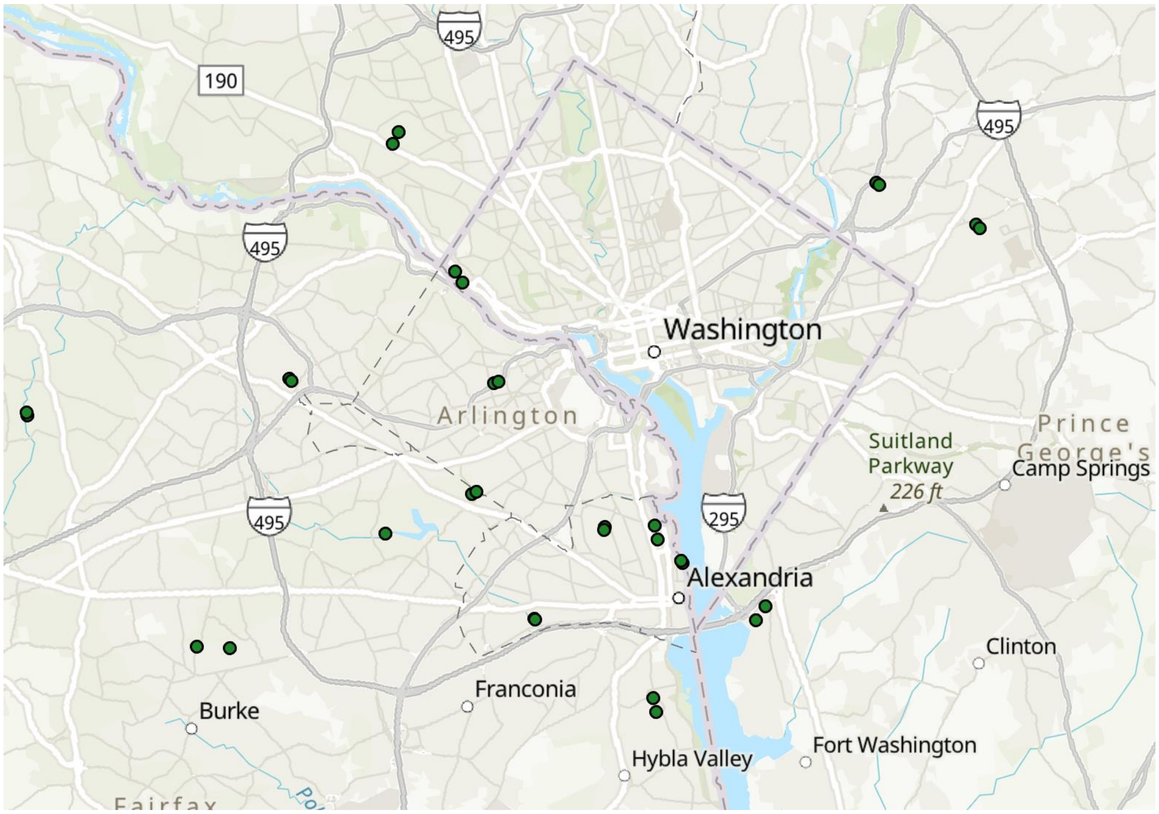

Figure 1. Locations in the Washington, D.C. metropolitan area where study sites were set to study the reactions of three common urban mammals to novel objects.

Camera Site Set-up

At each site a nylon strap and cable lock were used to place an infrared, remotely triggered Reconyx Hyperfire (Reconyx, Holmen, WI, USA) camera on a tree approximately 80 cm off the ground at an approximate 75° angle towards the ground. Once the camera was triggered it recorded a thirty second video and had a one second delay before recording any subsequent videos. Approximately 5 meters in front of each camera, one tablespoon of Sweet Meat Predator bait was placed in a small dug hole and then covered by leaves. At treatment sites, a novel object was placed directly behind the bait. (Fig. 2) The novel object consisted of a piece of rebar placed into the ground and an approximately two-foot tall pvc “t” covered in purple pool noodles placed over the rebar (Fig. 2). At control stations, no novel object was placed behind the bait. Each camera set up remained in place for approximately two weeks or until at least one video of each species was recorded (Table 1).

Table 1. The dates and the amount of time that each study site was observed

Site	**Deployed at Site**	**Removed from Sites**	**Total Days Out**
Betty Blum/Oxon Hill	6/16/22	7/28/22	42
John Carroll	6/16/22	7/28/22	42
Cheverly Nature Center	6/16/22	7/28/22	42
Barcroft Knolls	6/30/22	8/11/22	42
Holmes Run	6/30/22	8/9/22	40
Tide Lock	8/18/22	9/1/22	14
Potomac Yard	8/18/22	9/1/22	14
Monticello	8/18/22	9/1/22	14
Mount Vernon District	8/18/22	9/1/22	14
Custis Trail	8/18/22	9/1/22	14
Spring Lane	9/6/22	9/19/22	13
Difficult Run	9/6/22	9/19/22	13
Long Branch	10/20/22	11/7/22	18
C&O Lock 5	10/20/22	11/7/22	18
Whittier Woods	10/20/22	11/7/22	18
Lemon Road	11/2/22	11/21/22	19

Figure 2. Novel object placed at treatment sites to study the behavioral reaction of three common urban mammals in the Washington, D.C. region

Data Collection and Processing

All videos of raccoons, red foxes, and white-tailed deer were downloaded from SD cards to a computer. Videos were then organized by species, site, and between control and treatment stations. Individual animals could not be determined via the camera trap approach. Therefore, to reduce the likelihood that a single individual was captured multiple times a day I conducted the following thinning procedure: if more than three videos for the same species were present within the same day all videos were assigned a randomly generated number. The two videos that had the lowest randomly generated number were kept, while all others were removed.

Response Variables

Three metrics that can be used to study animal boldness and/or neophobia are time spent in the vicinity of a novel object (Lueptow, 2017), the diversity of behaviors displayed while exploring a novel object (Thompson et al, 2018), and how quickly an animal approaches and touches a novel object (Robertson, 2018).

For my study, the amount of time each individual spent within the camera's field of vision (seconds) was used as a proxy for the amount of time each species spent in the vicinity of the novel object. I then calculated the number of behaviors (Table 2) that an individual displayed while in view of the camera (count) as a proxy for behavioral diversity and used amount of time that an individual took to approach the bait (seconds) as a metric for how quickly an animal approached and touched a novel object. Individual behaviors were coded using a previously developed ethogram for urban mammals (Stanton et al, 2015) and then counted (Table 1). The number of behaviors was recorded as presence or absence of each individual behavior within a single 30 second video and summed to get a diversity of behaviors. Time to approach the bait was measured once the camera was triggered and an individual entered the frame; if an individual never came into contact with the bait area it was coded as 31 seconds to indicate that an individual never came into contact within the video time frame. These variables were recorded for each 30-second video analyzed.

The amount of time that an individual spends within the camera's field of vision can serve as an indicator of either how cautious or curious an individual is based on the environmental factors and the presence of a novel object. The number of behaviors an individual displayed can indicate how explorative or cautious an individual is based on environmental factors and presence of a novel object. The amount of time that an individual took to approach the bait illustrates the boldness or cautiousness of an individual based on environmental factors and the presence of a novel object. I calculated a Pearson's correlation between each variable using R to test whether dependent variables were correlated and found that they were not highly correlated ($|r| < 0.60$).

Table 2. Previously developed ethogram (Stanton et al, 2015) used to code behaviors of raccoons, red foxes, and white-tailed deer at control and novel object sites in the Washington, D.C. region

Behavior	**Definition**	**Behavior Code**
Affiliative interaction	Play, grooming, food sharing, etc. with conspecifics	AF
Aggressive interaction	Charging, baring teeth, etc. with conspecifics	AG
Back away	Approach novel	BA

	object (within arm's length) then back away	
Bite	Open mouth and close teeth on novel object	BI
Climb	Raise body vertically along novel object	CL
Dig	Use paws to dig at the ground in view of novel object	DI
Eat	Place bait into mouth	EA
Hang	Use limbs to hang on novel object	HA
Lick	Open mouth and move tongue on novel object	LI
Jump	Jump away from novel object or bait location	JU

Look away	Pause/sniff and look away from the novel object	LA
Move through	Walk or run through camera frame within view of novel object	MT
Pace	Move back and forth repetitively within arm distance of novel object	PA
Pause	Approach novel object on all fours, pause then continue in direction of novel object	PS
Push/Pull	Use mouth or paws to push or pull novel object	PU
Reach	Extend nose, neck, or paws towards novel object	RE
Rest	Lay within view of	RS

	novel object	
Sniff	Lift head in sniffing posture to detect scent (towards object)	SN
Stop	Stop (1 second or longer) within the periphery of novel object	SP
Touch	Place nose or paw on novel object	TO

Independent Variables

To assess the influence of characteristics of urban habitats on the behaviors of each species, I used proportion of canopy cover, proportion of impervious cover, and mean human population density as independent variables. These three variables generally represent available habitat for animals in cities. Canopy cover and impervious cover were included as independent variables because together they represent either natural habitat (canopy cover) or the conversion of natural habitats to impervious surfaces (Grimm et al, 2008; Gallo et al, 2018). Human population density was included as it represents human activity and the inherent human element of urban areas (Foley et al, 2005; Grimm et al, 2008; Gallo et al, 2018).

Habitat covariates were calculated in ARCGIS (ESRI, Redlands, California, USA) by creating a species-dependent spatial-buffer around each site – white-tailed deer – 0.66km, red fox – 4km, racoon – 8km. Buffer sizes were determined by the home range of the respective species (SUNY ESF, 2023; Tesky, Julie, 1995; Animal and Plant Health Inspection Service, 2023). The mean of canopy cover and impervious cover was calculated within each buffer using the zonal statistics tool in ArcMap. Total human population was calculated within each buffer using 2010 census data (United States Census Bureau, 2010) that was divided by the area of the buffer to get human population density.

I tested for correlation between independent variables using a Pearson's correlation test in R and found that canopy cover and impervious cover were highly correlated across all three scales (Table 3) and population density and impervious over were highly correlated across the two smallest scales (Table 3). Therefore, I only fit univariate models and did not include multiple environmental variables in the same model (Table 4).

Table 3. Correlations between independent variables at the differing buffer sizes of raccoons, red foxes, and white-tailed deer

Habitat covariate pairing	**8km Buffer**	**4km Buffer**	**660m Buffer**
Human population density/Impervious	0.782	0.710	0.273

cover			
Human population density/Canopy cover	-0.547	-0.486	-0.273
Impervious cover/Canopy cover	-0.819	-0.817	-0.944

Modeling Approaches

I used a Poisson regression model to assess the influence that each continuous variable and the novel object had on 1) time spent in frame, 2) number of behaviors exhibited within the video, and 3) time to approach the bait. To help reduce the likelihood of pseudo-replication and account for the potential that not all observations at a site were wholly independent, I included a random effect on site. For each species I developed a model set for each response variable that included additive models of each independent variable and treatment together, plus an interaction model between each independent variable and treatment (Table 2). A null model that only contained the random effect was also included in each model set. I used Akaike Information Criterion (AICc) model selection to determine the best model for each species (Burnham et al, 2011). I considered any model that was less than 2 ΔAICc values from the lowest AICc to be a top model. For each model, I considered a variable to be significant if the coefficient had a p-value less than 0.05. All analysis was done in R ver. 4.1.2 (R Core Team, 2021).

Table 4. Model set used to analyze the influence of treatment, canopy cover, impervious cover, and human population density on time spent in frame, the number of behaviors exhibited within the video, and time to approach bait (y). All models were fit with a Poisson regression.

Model set
y ~ (1 | Site)
y ~ (1 | Site) + treatment
y ~ (1 | Site) + treatment + canopy cover
y ~ (1 | Site) + treatment + canopy cover*treatment
y ~ (1 | Site) + treatment + impervious cover
y ~ (1 | Site) + treatment + impervious cover*treatment
y ~ (1 | Site) + treatment + population density
y ~ (1 | Site) + treatment + population density*treatment

Potential Impact

Raccoon, red fox, and white-tailed deer are three common generalist species in urban spaces. When these species and humans exist in the same space, they tend to be the culprits of human-wildlife conflict. Assessing time within frame; number of behaviors; and time to approach – when in the presence of a novel object will aid in understanding how species react to novel stimuli and if those reactions differ across a gradient of urbanization. Being able to understand how species respond to novel objects can aid in understanding how urbanization impacts survival and persistence and how certain species are able to co-exist in human-dominated landscapes.

CHAPTER TWO: CARNIVORE INTERACTIONS WITH A NOVEL OBJECT

INTRODUCTION

Human wildlife conflict from carnivore species has been around as long as humans have been developing natural spaces (Bateman & Fleming, 2012). Carnivores, in both rural and urban spaces, create conflict with humans by invading human dwellings, or by causing a loss of life (Klees van Bommel et. al, 2020). Being able to understand how carnivores respond to novel objects can inform managers how to prevent some carnivore-human conflicts by making informed decisions on wildlife deterrent strategies. I studied two common carnivores in an urban environment, as the increased number of people in cities has increased the likelihood of human-wildlife interactions between these two species.

Raccoons have been found within cities across the entire United States since the early 1900s (Bateman & Fleming, 2012). Raccoons have a keen interest in novel objects and are notoriously smart and look to humans and human objects for food (Stanton et al, 2022). In many cases, raccoons are considered a nuisance species in cities as they have been found to get into or destroy trashcans, homes, and other property (Daniels et al, 2019; Barrett et al, 2019). With less natural spaces in cities, raccoons are forced to explore the more developed areas of cities for resources. Due to raccoons' exploratory nature, they oftentimes utilize anthropogenic items for sources of food and come into contact with humans, increasing the chances for disease transmission, direct harm, or household damage (Bateman & Fleming, 2012). Raccoons are a well-suited species to study for this particular project as they are well known for their intelligence, innovation, and curiosity and have flourished in urban settings (Stanton et al, 2022; Pettit, 2010).

Red foxes are also a common urban species, but whose presence is hidden from view within urban settings. Red foxes are oftentimes nocturnal and found in areas with more greenspace (Gallo et al, 2022). Red foxes are one of the most adaptable wild carnivores (Stanton et al, 2022). Due to their generalist nature, red foxes utilize anthropogenic food sources and shelter that are available within cities (Stanton et al, 2022). A study conducted in Australia on rural and urban red foxes found that urban red foxes were, on average, bolder than their rural counterparts (Gil-Fernández et al, 2020). However, red foxes are an introduced species in Australia and very few if any studies have been conducted on fox boldness in their native range, especially in urban areas (Ritzel & Gallo, 2020). While this increase in boldness can mean success for red foxes in urban areas, it does pose a greater risk for human-wildlife conflict. Red foxes are known for their intelligence and highly adaptive behavior, which has allowed them to thrive in a variety of settings. Thus, studying how they react to novel stimuli could aid in understanding what allows them to persist in urban areas (Crosby et al, 2020).

Using the methods described in Chapter 1, I studied how characteristics of the urban environment influenced how these two species reacted to novel objects. I used remotely triggered wildlife cameras and a novel object to study the correlation between canopy cover, impervious cover, and human population density and the time each species stayed within the vicinity of the novel object, the number of behaviors displayed while interacting with the novel object, and the time it took for each species to approach and touch the novel object.

RESULTS

Summary Statistics

Cameras were deployed from June 2022 to November 2022 (Table 1). On average, a camera remained in place for 23 days. A total number of 815 videos across 15 sites were used for data analysis. 178 videos of raccoons were utilized for data analysis and 378 videos of red foxes.

Raccoon Model Results

I found two top models for the amount of time a raccoon spent within frame. The model containing an interaction between impervious cover and treatment, the presence or lack of a novel object, was the top model and the interaction model between human population density and treatment was within 2 ΔAICc (Table 3).

Table 5. AICc model selection results for Raccoon Time within Frame with the presence or lack of a novel object models

Model	K	AICc	ΔAICc	AICcWt	Cum.Wt	LL
Impervious Cover * Treatment	5	2023.53	0.00	0.63	0.63	-1006.59
Population Density * Treatment	5	2024.59	1.06	0.37	1.00	-1007.12
Impervious Cover +	4	2065.81	42.29	0.00	1.00	-1028.79

Treatment						
Canopy Cover * Treatment	5	2066.82	43.29	0.00	1.00	-1028.23
Population Density + Treatment	4	2067.44	43.92	0.00	1.00	-1029.60
Canopy Cover + Treatment	4	2071.58	48.05	0.00	1.00	-1031.67
Treatment	3	9849.01	7825.48	0.00	1.00	-4921.49
Intercept	2	10071.47	8047.95	0.00	1.00	-5033.73

When further evaluating the interaction model between impervious cover and treatment, I found that all model terms were significant. Impervious cover had a significant positive effect on time raccoons spent in frame ($\beta = 0.128$, p-value = 0.0128), treatment had a significant negative effect ($\beta = -1.881$, p-value = <0.001), and the interaction term was significantly positive ($\beta = 0.072$, p-value = <0.001, Fig. 4).

In my second top model (Table 2), all model terms were again significant. Population density had a positive effect on the time that raccoons spent in frame (β = 0.001, p-value = .027), but treatment again had a negative effect on time spent in frame ($\beta = -1.869$, p-value = <0.001). In this model the interaction term was also significantly positive ($\beta = 0.001$, p-value = <0.001, Fig. 5). These results indicate that on average the amount of time spent within frame increased with impervious cover and canopy cover, but increased less in the presence of a novel object. However, the presence of a novel object had a stronger effect on time spent in frame as impervious cover and canopy cover increased (Fig. 4 and 5).

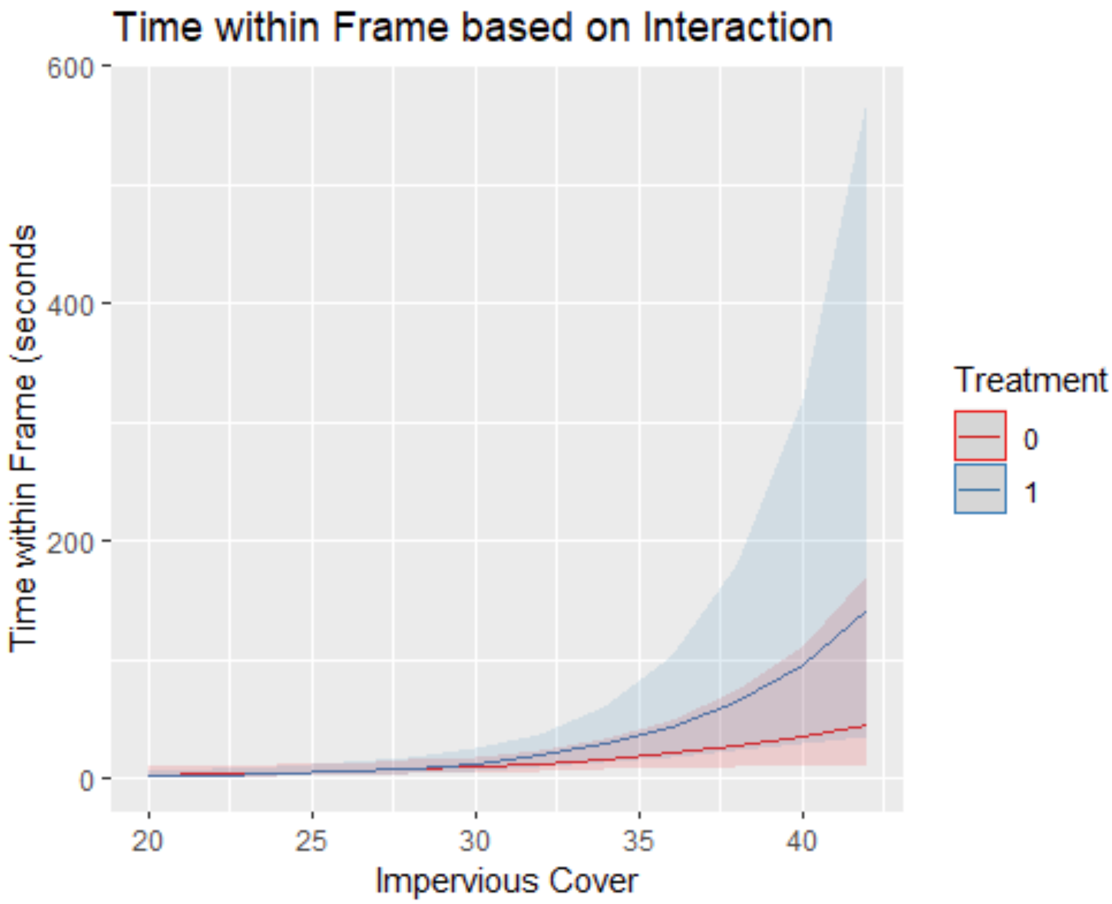

Figure 3. Predicted raccoon time within frame using the top model (impervious cover interaction model). Solid lines are the predicted estimated values and shaded areas represent the 95% confidence intervals.

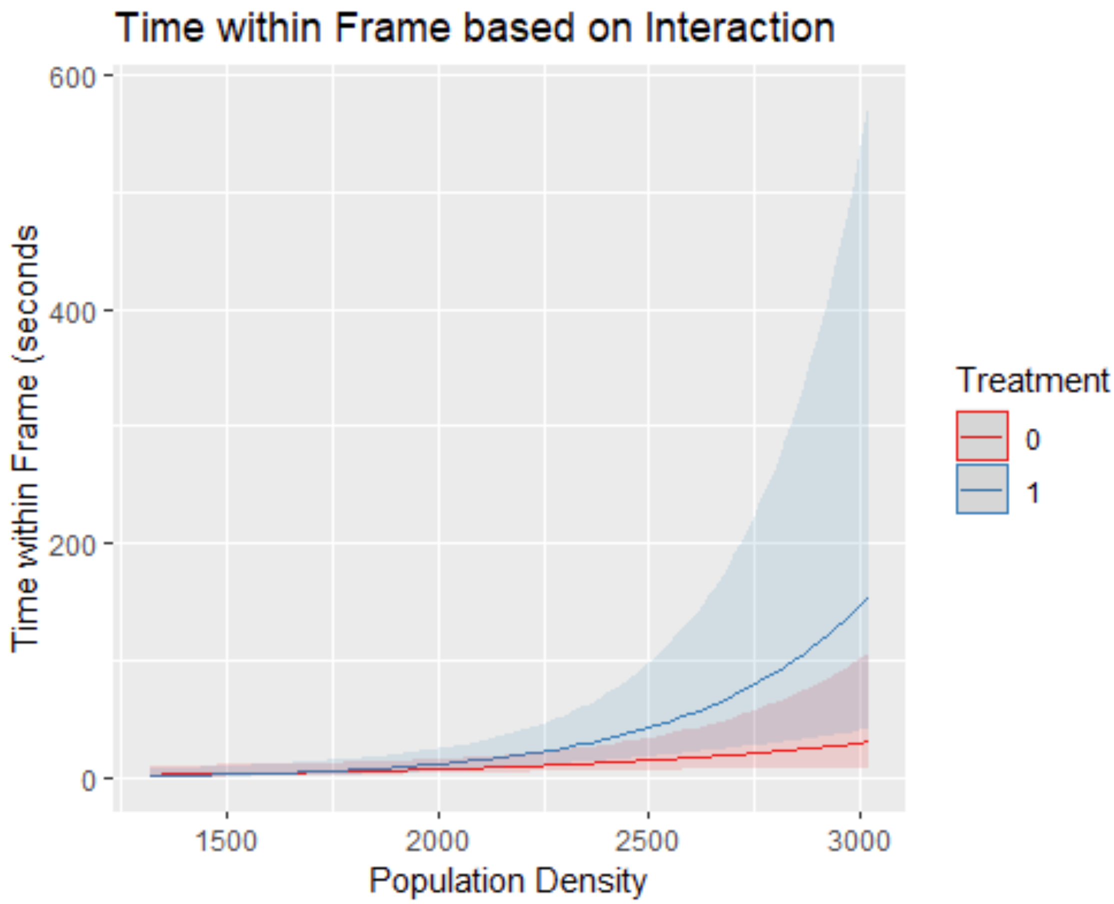

Figure 4. Predicted raccoon time within frame using the second model (population density interaction model). Solid lines are the predicted estimated values and shaded areas represent the 95% confidence intervals.

The top model for the number of behaviors exhibited by raccoons was the model that contained an interaction between canopy cover and treatment. There was no other model within two ΔAICc (Table 4).

Table 6. AICc model selection results for Raccoon Number of Behaviors exhibited with the presence or lack of a novel object models

Model	**K**	**AICc**	**ΔAICc**	**AICcWt**	**Cum.Wt**	**LL**

Canopy Cover * Treatment	5	575.87	0.00	0.74	0.74	-282.76
Impervious Cover * Treatment	5	578.45	2.58	0.20	0.94	-284.05
Impervious Cover + Treatment	4	582.53	6.66	0.03	0.97	-287.15
Canopy Cover + Treatment	4	583.45	7.58	0.02	0.98	-287.61
Population Density + Treatment	4	584.49	8.61	0.01	0.99	-288.13
Population Density * Treatment	5	585.75	9.88	0.01	1.00	-287.70
Treatment	3	2461.28	1885.41	0.00	1.00	-1227.63
Intercept	2	2517.18	1941.30	0.00	1.00	-1256.58

The interaction model demonstrated a significant positive effect of canopy cover (β = 0.027, p-value = 0.055 Fig. 6) on the number of behaviors displayed by raccoons. Treatment and the interaction term also had significant effects (β = 2.429, p-value = <0.001, β = -0.059, p-value = <0.001 respectively). These results indicate that, on average, the number of behaviors increased as canopy cover increased and was greatest at sites with a novel object. However, due to a negative interaction term the number of behaviors displayed was significantly greater at sites with less canopy cover, but decreased significantly as canopy cover increased (Fig. 5).

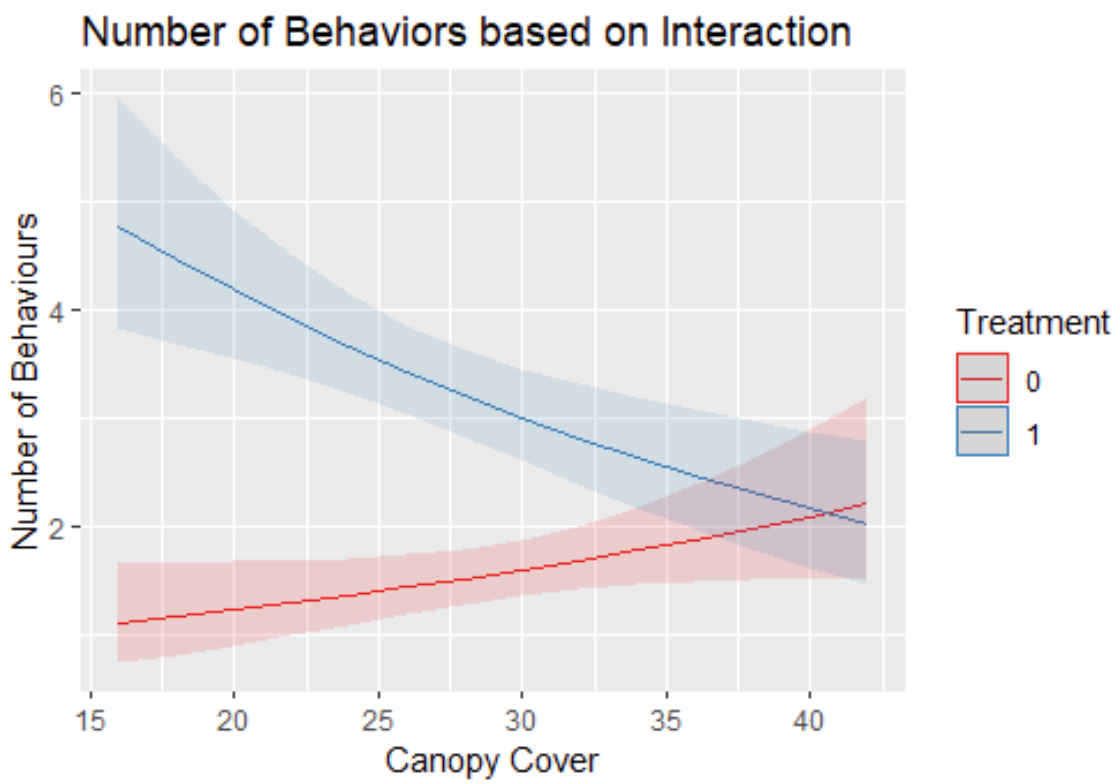

Figure 5. Predicted raccoon number of behaviors using the top model (canopy cover interaction model). Solid lines are the predicted estimated values and shaded areas represent the 95% confidence intervals.

The top model for raccoon time to approach a bait station contained an interaction between canopy cover and treatment, there was no other model within two ΔAICc (Table 5).

Table 7. AICc model selection results for Raccoon Time to Approach with the presence or lack of a novel object models

Model	**K**	**AICc**	**ΔAICc**	**AICcWt**	**Cum.Wt**	**LL**
Canopy Cover * Treatment	5	2453.41	0.00	0.96	0.96	-1221.53
Impervious Cover *	5	2459.65	6.24	0.04	1.00	-1224.65

Treatment						
Population Density * Treatment	5	2490.02	36.61	0.00	1.00	-1239.83
Canopy Cover + Treatment	4	2513.12	59.71	0.00	1.00	-1252.44
Population Density + Treatment	4	2513.16	59.76	0.00	1.00	-1252.46
Impervious Cover + Treatment	4	2514.22	60.81	0.00	1.00	-1252.99
Treatment	3	10140.84	7687.43	0.00	1.00	-5067.40
Intercept	2	10301.51	7848.11	0.00	1.00	-5148.75

Canopy cover and treatment had significant negative effects on the time for raccoons to approach the bait station (β = -0.033, p-value = <0.001 and β = -1.807, p-value = <0.001 respectively). The interaction term was significantly positive (β = 0.065, p-value = <0.001; Fig. 7). These results indicate that, on average, the time to approach the bait station decreased as canopy cover increased and was lower at sites with a novel object. However, the positive interaction term indicates that the number of behaviors decreased significantly at control sites but increased significantly with the presence of a novel object as canopy cover increased – switching the direction of effect (Fig 6).

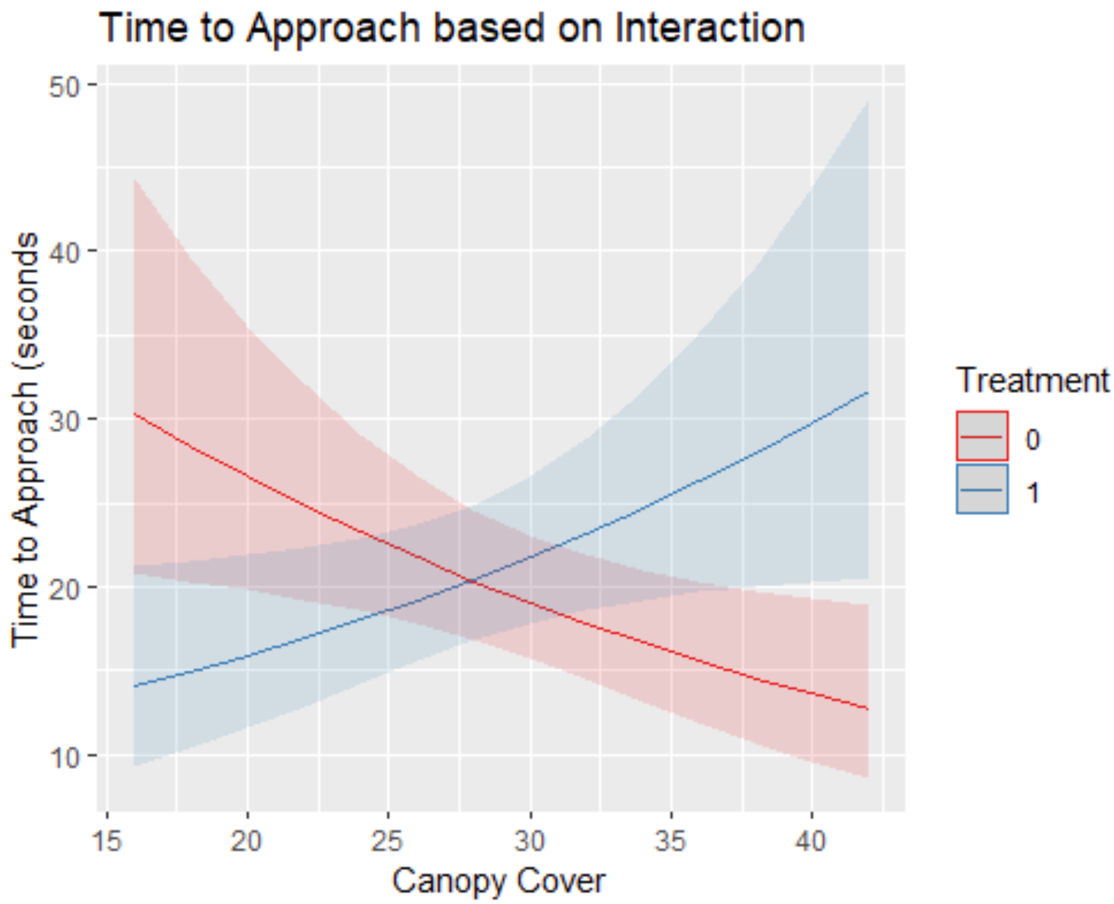

Figure 6. Predicted raccoon Time to Approach using the top model (canopy cover interaction model). Solid lines are the predicted estimated values and shaded areas represent the 95% confidence intervals.

Red Fox Model Results

The top model for time spent within frame for red foxes was the model that contained an interaction between canopy cover and treatment. There was no other model within two ΔAICc (Table 6).

Table 8. AICc model selection results for Red Fox Time within Frame with the presence or lack of a novel object models

Model	K	AICc	ΔAICc	AICcWt	Cum.Wt	LL
Canopy Cover * Treatment	5	4083.78	0.00	0.93	0.93	-2036.81
Canopy Cover + Treatment	4	4090.67	6.88	0.03	0.96	-2041.28
Impervious Cover + Treatment	4	4091.00	7.22	0.03	0.98	-2041.45
Impervious Cover * Treatment	5	4092.21	8.43	0.01	0.99	-2041.03
Population Density + Treatment	4	4094.97	11.19	0.00	1.00	-2043.34
Population Density * Treatment	5	4096.33	12.54	0.00	1.00	-2043.08
Treatment	3	9849.01	5765.23	0.00	1.00	-4921.49
Intercept	2	10071.47	5987.69	0.00	1.00	-5033.73

When further evaluating the interaction model between canopy cover and treatment, I found that only two model terms were significant, treatment and interaction. Treatment, the presence or lack of a novel object, had a significant positive effect on time that red foxes spent in frame ($\beta = 0.395$, p-value = 0.003) and the interaction term had a significant negative effect ($\beta = -0.012$, p-value = 0.003). Canopy cover was negative but insignificant ($\beta = -0.022$, p-value = 0.160; Fig. 8). These results indicate that, on average, time spent in frame was greatest at novel object sites and did not vary significantly across canopy cover. However, the direction of effect of the novel object on time spent in frame did switch across a gradient of canopy cover from positive in more urban sites (less canopy cover) to negative in more suburban sites (more canopy cover).

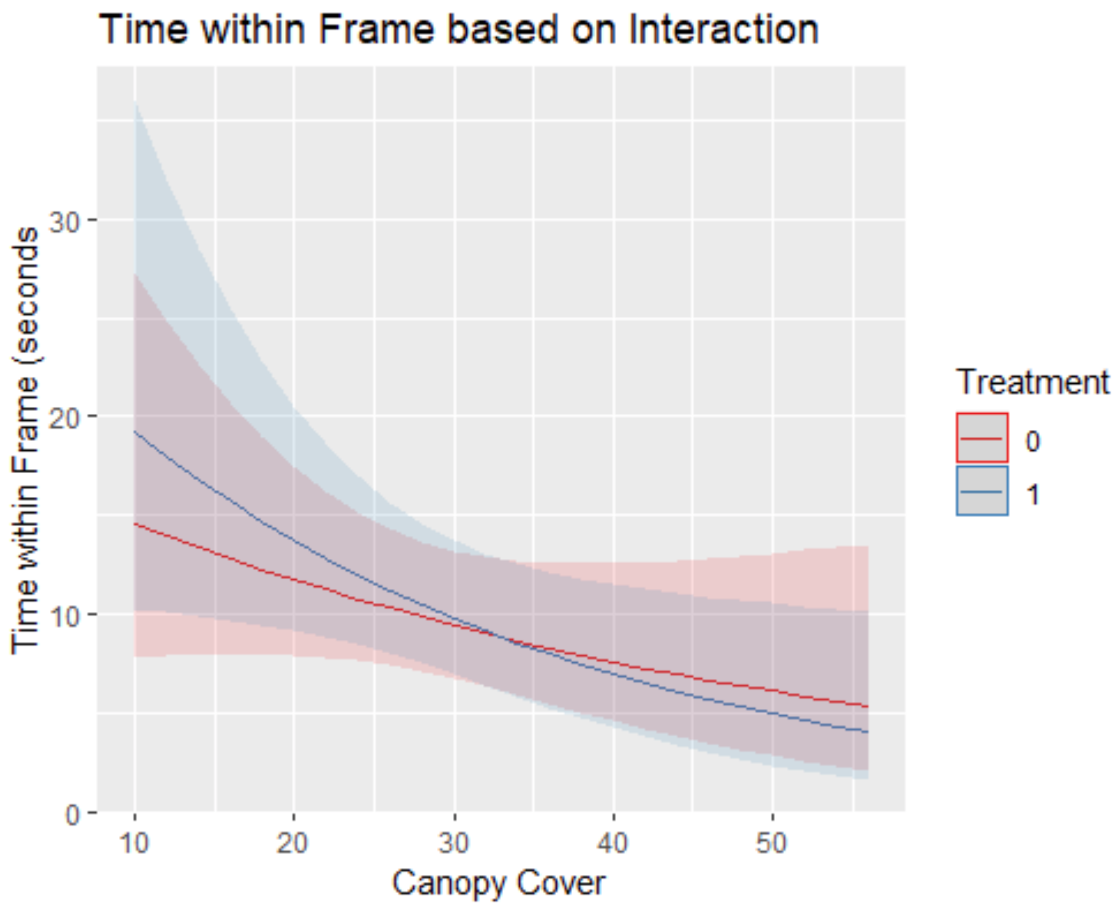

Figure 7. Predicted Red Fox Time within Frame using the top model (canopy cover interaction model). Solid lines are the predicted estimated values and shaded areas represent the 95% confidence intervals.

I found five top models for red fox number of behaviors, the additive model with impervious cover and treatment, the additive model with canopy cover and treatment, the additive model with population density and treatment, the interaction model between canopy cover and treatment, and the interaction model between population density and treatment (Table 7).

Table 9. AICc model selection results for Red Fox number of behaviors exhibited with the presence or lack of a novel object models

Model	K	AICc	ΔAICc	AICcWt	Cum.Wt	LL
Impervious Cover + Treatment	4	1071.72	0.00	0.23	0.23	-531.81
Canopy Cover + Treatment	4	1071.77	0.05	0.23	0.46	-531.83
Population Density + Treatment	4	1071.86	0.15	0.22	0.68	-531.88
Canopy Cover * Treatment	5	1072.89	1.17	0.13	0.81	-531.37
Population Density * Treatment	5	1073.33	1.61	0.10	0.91	-531.58
Impervious Cover * Treatment	5	1073.73	2.01	0.09	1.00	-531.78
Treatment	3	2461.28	1389.56	0.00	1.00	-1227.63
Intercept	2	2517.18	1445.46	0.00	1.00	-1256.58

When further evaluating the top additive model with impervious cover and treatment, I found that only the treatment model term was significant ($\beta = 0.342$, p-value = 0.0002; Fig. 9). Similarly, in the additive model containing canopy cover and treatment, treatment was the only significant model term ($\beta = 0.344$, p-value = 0.0002), as well as in the additive model of population density and treatment, treatment was the only significant model term ($\beta = 0.342$, p-value = 0.0002). Finally, in the fourth model that contained an interaction term between canopy cover and treatment, only the treatment model term proved significant (β = 0.599, p-value = 0.032). Canopy cover and the interaction model term were both insignificant (β = 0.0008, p-value = 0.902 and β = -0.009, p-value = 0.334). The final model, an interaction between population density and treatment, had no significant model terms. These results indicate that the novel object had a significant positive effect on the number of behaviors, but it did not vary across any environmental variables.

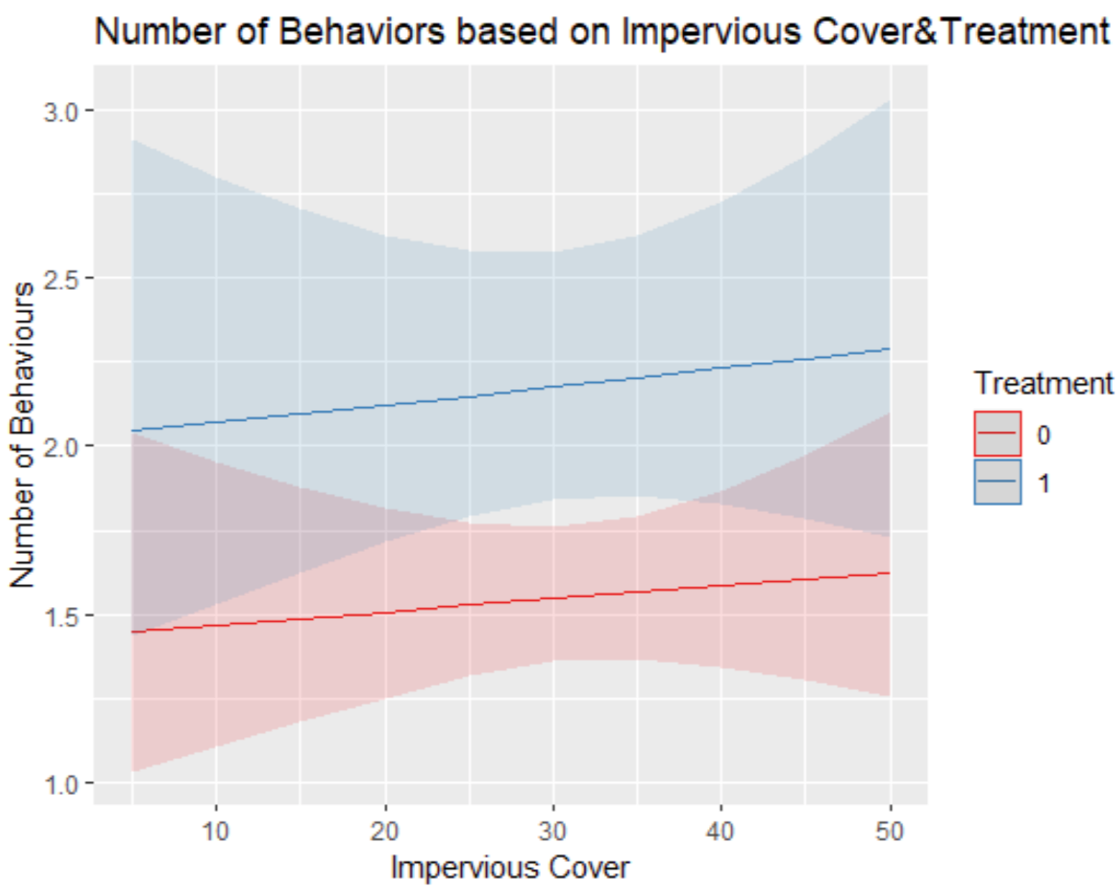

Figure 8. Predicted Red Fox Number of Behaviors using the top model (impervious cover additive model). Solid lines are the predicted estimated values and shaded areas represent the 95% confidence intervals.

The top model for red fox time to approach the bait was an additive model between canopy cover and treatment. There was no other model within two ΔAICc of the top model (Table 8).

Table 10. AICc model selection results for Red Fox Time to Approach with the presence or lack of a novel object models

Model	**K**	**AICc**	**ΔAICc**	**AICcWt**	**Cum.Wt**	**LL**
Canopy Cover + Treatment	5	4534.47	0.00	1	1	-2262.16
Population * Treatment	5	4549.72	15.25	0	1	-2269.78
Impervious Cover * Treatment	5	4554.98	20.51	0	1	-2272.41
Canopy Cover + Treatment	4	4595.32	60.85	0	1	-2293.61
Impervious Cover + Treatment	4	4596.54	62.06	0	1	-2294.21
Population Density + Treatment	4	4598.65	64.18	0	1	-2295.27
Treatment	3	10140.84	5606.37	0.00	1.00	-5067.40
Intercept	2	10301.51	5767.04	0.00	1.00	-5148.75

In this model, I found that all model terms were significant. Canopy cover had a significant negative effect on time for red foxes to approach the bait station (β = -0.013, p-value = 0.024), and treatment had a significant positive effect on time to approach (β = 0.385, p-value = 0.001; Fig. 10). These results indicate that, on average, time to approach decreased as canopy cover increased, and was significantly greater at sites with novel objects (Fig. 9).

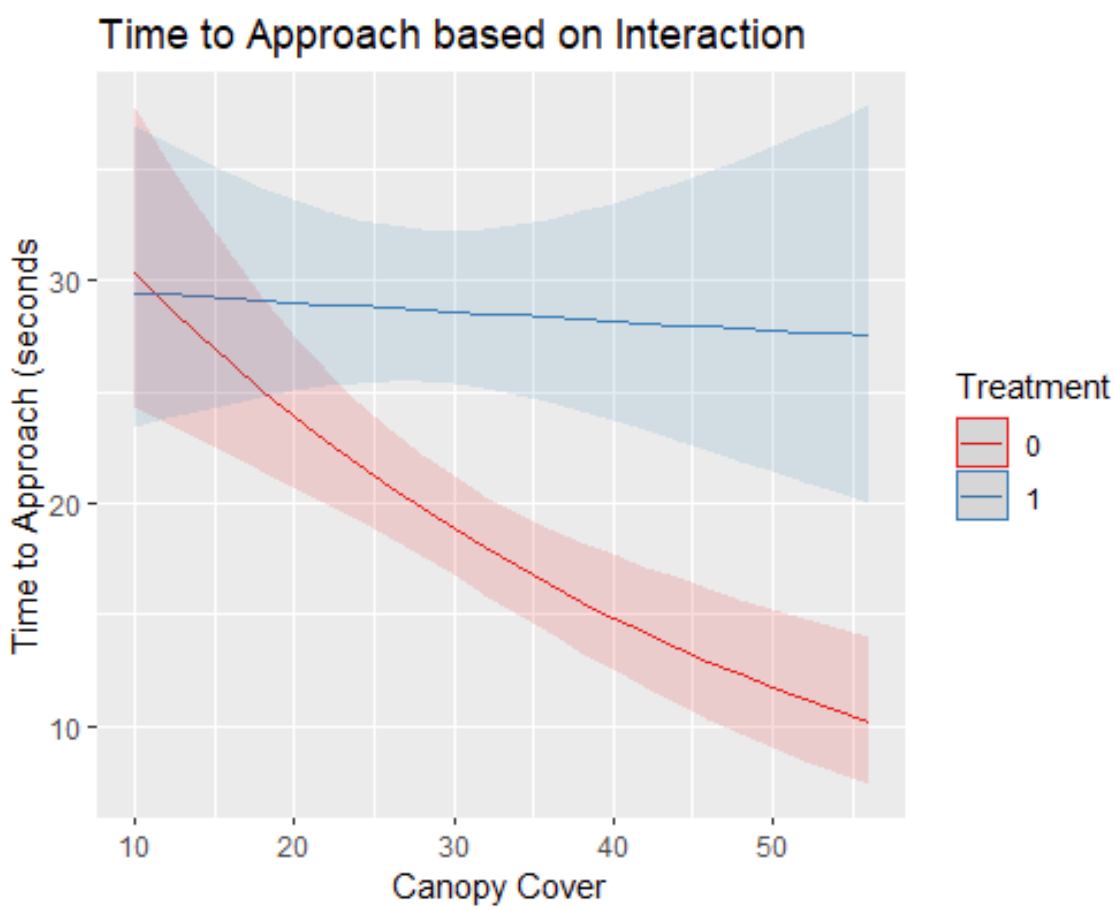

Figure 9. Predicted Red Fox Time to Approach using the top model (canopy cover additive model). Solid lines are the predicted estimated values and shaded areas represent the 95% confidence intervals.

Discussion

Raccoon and red fox behaviors were analyzed through videos obtained from remote camera traps. I found that raccoon time spent within frame increased in more urban settings, the number of behaviors increased in settings of higher canopy cover, and time to approach decreased in urban settings but these behaviors changed in the presence of a novel object. Raccoon time within frame did not increase or decrease in a substantial way but did increase with the presence of a novel object. The number of behaviors exhibited in the presence of a novel object decreased as canopy cover increased. The amount of time that it took a raccoon individual to approach the bait station increased with increasing canopy cover, counter to a control site.

I also found that red fox time spent within frame and the number of behaviors displayed was impacted by the presence of a novel object, more than urbanization. However, red fox time to approach was most impacted by canopy cover and the presence of a novel object, but in opposite ways. With the presence of a novel object the amount of time an individual spent within frame decreased at a greater rate than at a control site. The number of behaviors an individual exhibited demonstrated a similar pattern, wherein the number of behaviors increased at a greater rate with the presence of a novel object. The amount of time it took a red fox to approach also demonstrated a similar pattern type. At control sites time to approach decreased at a greater rate with increasing canopy cover than treatment sites with novel objects. These findings demonstrate the different ways that two common urban carnivores respond to increasing urbanization, and how anthropogenic items in their environments may influence their behavior.

The amount of time raccoons spent within the video frame increased with an increase in both impervious cover and population density (both indicative of more urban sites), and the presence of a novel object. I also found that in general, the number of behaviors increased as canopy cover increased, however the greatest number of behaviors was displayed at sites with low canopy cover (more urban) when a novel object was present. I also found that raccoons approached the bait stations quicker in urban sites (less canopy cover) when a novel object was present compared to control sites, but that relationship switched as canopy cover increased (less urban). Thus, raccoons in urban sites spend longer in the vicinity of a novel object, display more behaviors, and approach the object quicker. These combined results could indicate bolder and more adaptive individuals living in urban spaces. Raccoon individuals living in urban spaces may be bolder as there are greater novel spaces and objects present in their home range, and they have become desensitized to them or they have learned to utilize anthropogenic resources (Stanton et al, 2022; Barrett et al, 2019). These findings have been corroborated by Ritzel and Stanton and provide further evidence that raccoons are superb urban adapters (Ritzl & Gallo, 2020; Stanton, 2022).

The amount of time red fox individuals spent within frame and the number of behaviors foxes displayed was largely impacted by the presence of a novel object, but I found no correlation with characteristics of the urban environment. Foxes spent more time in the video frame when a novel object was present, but that difference was negated at sites with more canopy cover. Foxes also displayed more behaviors at sites with novel objects. These results may indicate that foxes, in general, are curious but their behaviors do not change along an urban gradient. Red foxes generally avoid highly populated areas (Gallo et al, 2022), which may cause the lack of change along the urban-rural gradient. Additionally, I found no difference in time to approach between treatment and control sites in more urban environments (less canopy cover), but the time to approach decreased significantly in more rural sites (more canopy cover) when no novel object was present. Red fox individuals in urban settings could already be adapted to novel stimuli (Handler et al, 2019). Therefore, the lack of difference between treatment and control sites could be explained by habituation to anthropogenic settings (Stanton et al, 2022). A decreased time to approach in less urban sites (greater canopy cover) and with no significant response to a novel object could indicate that individuals are more comfortable in more covered and secluded settings. Similarly, Gallo et al, (2022) and Díaz-Ruiz et al (2015) found more expected daily patterns of red foxes in more forested areas indicating that canopy cover may offer a sense of protection under novel circumstances.

Management Implications

My findings indicate that raccoons are superb urban exploiters and that foxes are curious but cautious or shy of novel stimuli regardless of the habitat they are in. These findings can help park and neighborhood managers create species management programs based on the species' reactions to novel objects. For example, those that manage raccoons should probably not consider novel objects as a deterrent since they seemed to be curious and explore the object more. Whereas those managing red foxes might use novel objects to discourage individuals from unwanted spaces, especially for those in less urban settings.

Conclusion

Raccoons and red foxes both responded to increasing urban spaces and novel stimuli in varying ways. Raccoons changed their behaviors along environmental gradients (impervious cover, population density, and canopy cover), and the presence of a novel object added complexity to those behavioral changes. Whereas red fox behaviors changed based on the presence of a novel object in all cases but changed in response to environmental factors to a lesser degree, if at all. These results can be used by wildlife managers to develop deterrent protocols depending on the level of urbanization or habitat types, by considering behavioral responses to novel stimuli in these environments. This study could have impacts that greatly alter the way in which urban managers and developers create wildlife-friendly spaces.

CHAPTER THREE: AN HERBIVORE'S INTERACTIONS WITH NOVEL OBJECTS

INTRODUCTION

White-tailed deer are one of the most widespread ungulates in North America (Wolff et al, 2020). As human populations continue to change the natural world, deer have demonstrated the ability to change with their changing habitat (Wolff et al, 2020). Urban and suburban areas offer deer refuges by having green spaces to serve as shelter, supplemental and various food sources, and a decreased threat of predation (Potratz et al, 2019). Increased deer abundance can change the ecological balance of an ecosystem through overgrazing, disease transmissions, and direct conflict with humans (i.e. vehicle collisions) (Potratz et al, 2019). As increased urbanization continues, wildlife managers will need to change tactics for managing white-tailed deer populations.

Increased available vegetation within urban and suburban settings has allowed deer populations to increase, however some urban obstacles may actually play a role in decreasing population levels (McShea, 2012). Studies have found that increasing the number of barriers, fencing or domestic animals (i.e. dogs) decreases deer access to vegetation, overall controlling population levels (McShea, 2012). In increasingly urban settings, different tactics will need to be utilized to minimize deer-human conflict. Being able to understand how white-tailed deer react to novel objects will allow managers to come up with novel approaches to managing the population.

Using the methods described in Chapter 1, I studied how characteristics of the urban environment influence how white-tailed deer react to novel objects. I used remotely triggered wildlife cameras and novel objects to study the correlation between canopy cover, impervious cover, and human population density and the time deer stayed within the vicinity of the novel object, the number of behaviors displayed while interacting with the novel object, and the time it took for deer to approach and touch the novel object.

RESULTS

Summary Statistics

Cameras were placed in the green spaces from June 2022 to November 2022 (Table 1). On average, a camera remained in place for 23 days. 260 white-tailed deer videos were used in data analysis.

White-tailed deer Model Results

I found three top models for deer time within frame. The model that contains an interaction between population density and treatment, the additive model with canopy cover and treatment, and the model that contains an interaction between canopy cover and treatment (Table 9).

Table 11. AICc model selection results for White-tailed Deer time within frame with the presence or lack of a novel object models

Model	**K**	**AICc**	**ΔAICc**	**AICcWt**	**Cum.Wt**	**LL**
Population Density * Treatment	5	2908.25	0.00	0.39	0.39	-1449.01
Canopy Cover + Treatment	4	2909.26	1.01	0.23	0.62	-1450.55
Canopy Cover * Treatment	5	2909.76	1.51	0.18	0.80	-1449.76
Population Density + Treatment	4	2911.33	3.08	0.08	0.88	-1451.59
Impervious Cover + Treatment	4	2911.35	3.10	0.08	0.97	-1451.59
Impervious Cover * Treatment	5	2913.18	4.93	0.03	1.00	-1451.47
Treatment	3	9849.01	6940.76	0.00	1.00	-4921.49
Intercept	2	10071.47	7163.22	0.00	1.00	-5033.73

When further evaluated, only the interaction term was positively significant (β = 1.885×10^{-4}, p-value = 0.025; Fig. 11) in the model containing the interaction between human population density and the presence or lack thereof of a novel object (top model). Population density and treatment were both not significant (β = -1.039×10^{-4}, p-value = 0.507, and β = 0.062, p-value = 0.585) respectively on their own. The second top model, the additive model with canopy cover and treatment, had only the treatment model term as significant (β = 0.307, p-value = <0.001). Canopy cover was not significant (β = 0.007, p-value = 0.142). In the third and final top model, the presence or lack thereof of a novel object had a significant positive effect on the amount of time white-tailed deer spent within frame (β = 0.475, p-value = 0.0007). However, canopy cover and the interaction term were not significant (β = 0.009, p-value = 0.077, and β = -0.004, p-value = 0.212, respectively). These results indicate that on average, the presence of a novel object had a greater influence on the time spent in frame and that time spent in frame did not vary across any environmental variables.

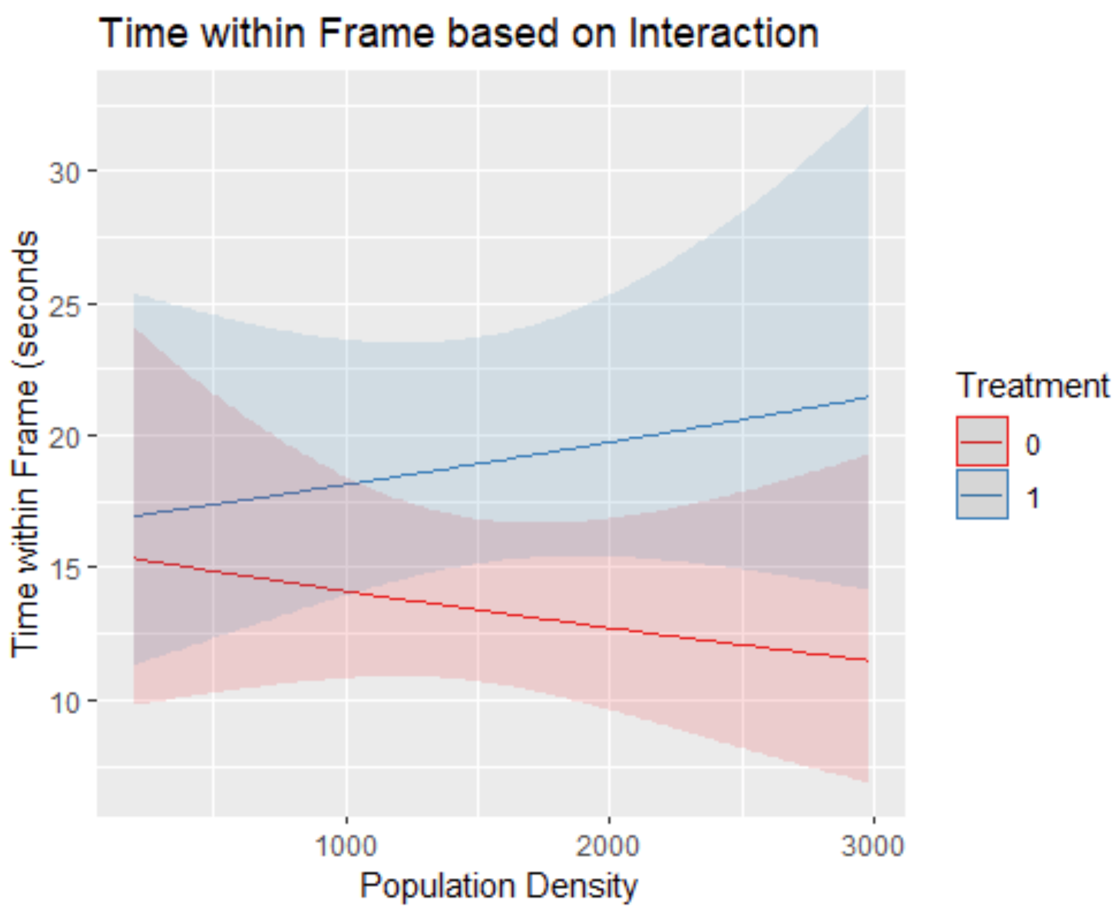

Figure 30. Predicted White-tailed Deer time within frame using the top model (population density interaction model). Solid lines are the predicted estimated values and shaded areas represent the 95% confidence intervals.

For the number of behaviors displayed, I found two top models, an additive model with human population density and treatment, and an interaction model between population density and treatment (Table 10).

Table 12. AICc model selection results for White-tailed Deer number of behaviors exhibited with the presence or lack of a novel object models

Model	K	AICc	ΔAICc	AICc_Wt	Cum.Wt	LL
Population Density + Treatment	4	788.54	0.00	0.40	0.40	-390.19
Population Density * Treatment	5	789.72	1.17	0.22	0.62	-389.74
Impervious Cover + Treatment	4	790.88	2.34	0.12	0.75	-391.36
Canopy Cover + Treatment	4	790.92	2.38	0.12	0.87	-391.38
Impervious Cover * Treatment	5	792.09	3.55	0.07	0.94	-390.93
Canopy Cover * Treatment	5	792.27	3.73	0.06	1.00	-391.02
Treatment	3	2461.28	1672.74	0.00	1.00	-1227.63
Intercept	2	2517.18	1728.64	0.00	1.00	-1256.58

The top model, an additive model with population density and treatment, had only treatment as a significant model term ($\beta = 0.208$, p-value = 0.045; Fig. 12). Population density was not significant ($\beta = 0.0002$, p-value = 0.086). The second model, an interaction between population density and treatment, contained no significant variables (population density β = $8.619x10^{-5}$, p-value = 0.527, treatment β = -0.027, p-value = 0.919, interaction β = $1.594x10^{-4}$, p-value = 0.335). These results indicate, that on average, the presence of a novel object had a greater influence on the number of behaviors displayed, and that population density explained more variability than any other environmental variables, but the number of behaviors did not increase or decrease significantly across population density (Fig. 11).

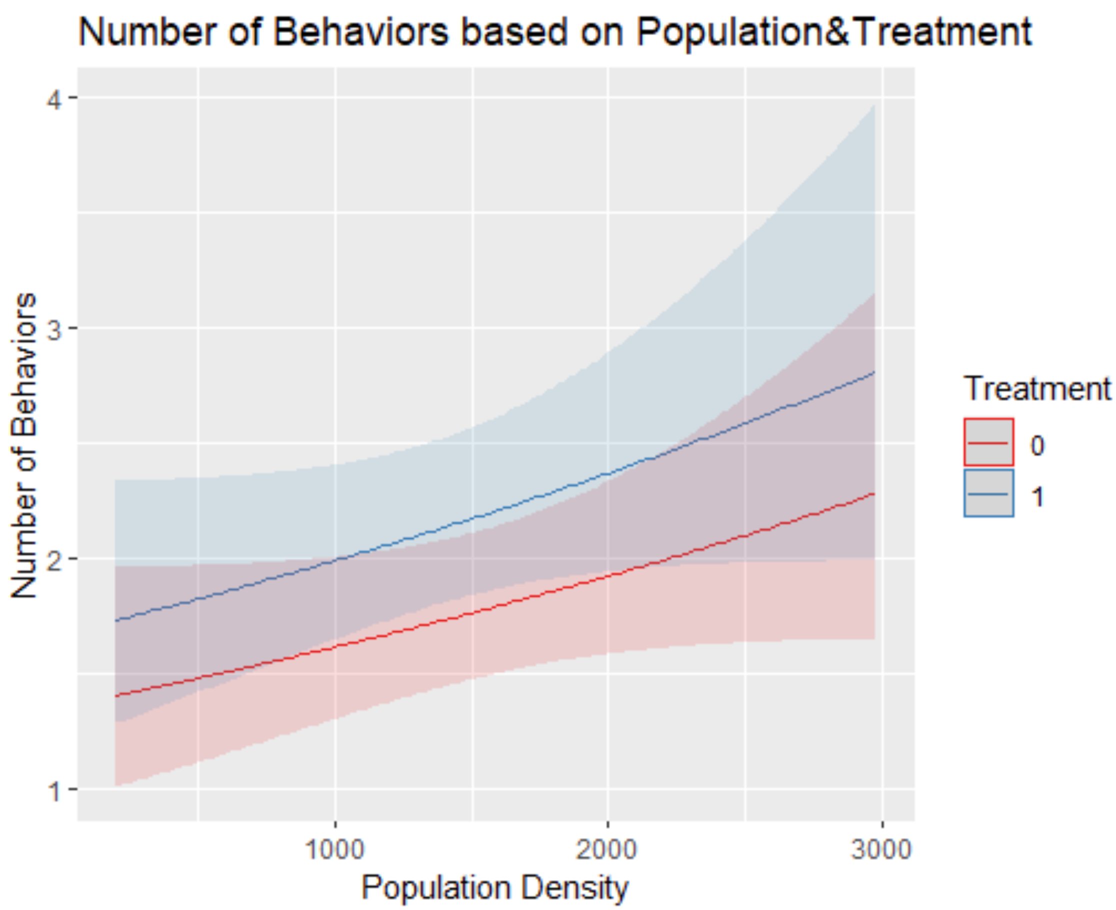

Figure 11. Predicted White-tailed Deer number of behaviors using the top model (population density additive model). Solid lines are the predicted estimated values and shaded areas represent the 95% confidence intervals.

Finally, I found only one top model for deer time to approach the bait station, the model that contains an interaction between canopy cover and treatment. There were no other models within two ΔAICc (Table 11).

Table 13. AICc model selection results for White-tailed Deer time to approach with the presence or lack of a novel object models

Model	K	AICc	ΔAICc	AICcWt	Cum.Wt	LL
Canopy Cover * Treatment	5	2717.55	0.00	1	1	-1353.66
Canopy Cover + Treatment	4	2730.13	12.58	0	1	-1360.99
Population Density * Treatment	5	2757.85	40.30	0	1	-1373.81
Impervious Cover * Treatment	5	2761.64	44.09	0	1	-1375.70
Population Density + Treatment	4	2765.08	47.53	0	1	-1378.46
Impervious Cover + Treatment	4	2765.76	48.21	0	1	-5067.40
Treatment	3	10140.84	7423.29	0	1	-5067.40
Intercept	2	10301.51	7583.96	0	1	-5148.75

For the top model in this analysis, all variables were significant. Canopy cover had a significant positive effect on the amount of time it took a white-tailed deer to approach the bait ($\beta = 0.029$, p-value = <0.001), the presence of a novel object had a significant negative effect on time to approach ($\beta = -0.241$, p-value = 0.037), and the interaction of the two model terms had a significant positive effect on time to approach (β = 0.010, p-value = <0.001; Fig. 12). These results indicate that, on average, time to approach increased as canopy cover increased, but was significantly lower at novel object sites. However, as canopy cover increased, time to approach increased more significantly at novel object sites (Fig. 12).

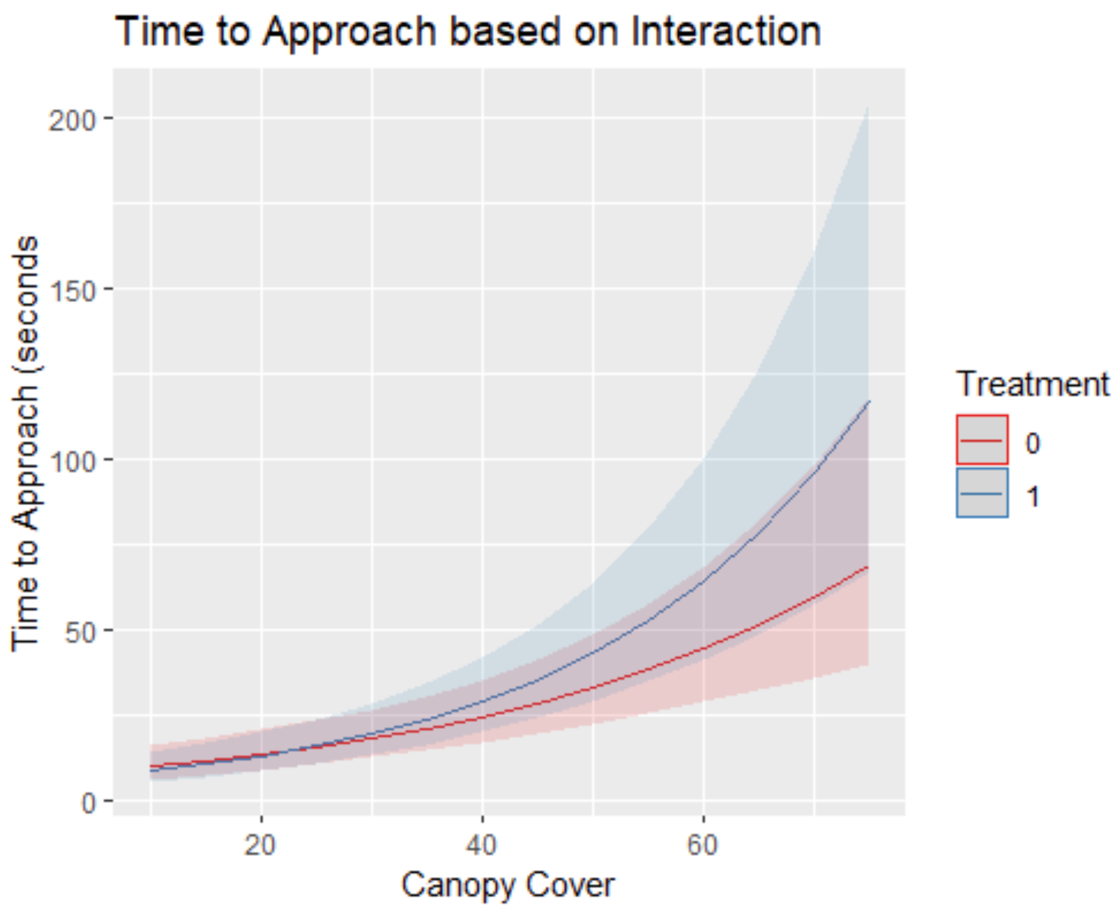

Figure 42. Predicted White-tailed Deer time to approach using the top model (canopy cover interaction model). Solid lines are the predicted estimated values and shaded areas represent the 95% confidence intervals.

DISCUSSION

White-tailed deer behaviors and reactions to novel stimuli were recorded through remotely triggered cameras. The amount of time an individual spent within view of a camera was affected mainly by the presence of a novel object, but that effect had an interaction with human population density. The number of behaviors an individual exhibited was positively correlated to the presence of a novel object but was not correlated to any environmental variables, and I found no significant correlation between the time it took a deer to approach the bait site and treatment or environmental variables. In general, I found that deer were more influenced by the novel object and less so by characteristics of the urban environment.

The amount of time a white-tailed deer spent within frame of a camera increased with the presence of a novel object, and as human population density increased the effect of the novel object became greater, and urban deer spent more time around novel objects in more urban environments. Additionally, the presence of a novel object increased the number of behaviors a white-tailed deer exhibited. Together these results may indicate that urban deer are more curious in the presence of a novel object. Previous research found that fallow deer (*Damad ama*), have greater exploratory tendencies in the presence of novel objects, but a separate study found that roe deer (*Capreolus* capreolus) demonstrated neophobic behaviors in the presence of a novel object (Bergvall et al, 2011; Monestier, et al, 2017). To determine if these behaviors are indicative of increased curiosity or the deer being more cautious, future studies should focus on giving up densities and finer scale titration studies to tease apart different types of behaviors, time spent conducting particular types such as fear response, or a curiosity response (Altendorf et. al, 2001; Stephens et al, 2007).

I did find evidence of boldness in urban white-tailed deer. The amount of time it takes an individual to approach the bait was lowest in more urban sites (less canopy cover) regardless of the presence of a novel object. However, time to approach increased as canopy cover increased and was significantly higher at sites with more canopy cover and a novel object. These results indicate that individuals at less urban sites are shyer and approach a novel object slower than those in more urban settings. Generally, animals that inhabit more novel spaces, such as urban environments, tend to be bolder and exhibit more explorative behaviors (Honda et al, 2018), and my results show similar patterns. This is likely due to the fact that individuals in more urban spaces are adapted to many novel objects and stimuli (Honda et al, 2018). I only used a single type of novel object, but future studies could use a variety of novel objects to test whether there is a difference between the “novelty” of an object in individual’s environments.

Similar to raccoon and red fox, time spent within frame and time to approach both increased with the presence of a novel object, regardless of the level of urbanization and environmental factors. Across all species there was a distinct difference between both urban and rural settings in the amount of time it took to approach a novel object. A major difference between the two groups is that white-tailed deer were impacted by more natural variables (i.e. canopy cover), whereas both carnivore species were impacted by anthropogenic variables (impervious cover and human population density). Perhaps white-tailed deer are more sensitive to changes in canopy cover as they use forested spaces to hide from predators (Gulsby et al, 2017) and forage (Johnson et al, 1995). Vegetation cover may provide a sense of protection for herbivores and mitigate their response to novel objects. Raccoons and red foxes on the other hand, are generally top predators in urban environments and do not need to be as alert to other predator species (Castañeda et al, 2018; Gehrt et al, 2010). However, their greatest threats are humans and therefore are more sensitive to anthropogenic changes (Gehrt, 2004).

Being able to understand that white-tailed deer respond to novel objects with caution or curiosity can aid in creating deterrent practices. Deterrent practices for white-tailed deer could entail placing novel objects in or around gardens, along roadways, or highly trafficked areas. Furthermore, knowing that white-tailed deer across an urban-rural gradient respond similarly can allow managers to generalize population management practices. Taking into account how an animal will respond to anthropogenic features and novel objects in their specific environment is important when considering how to mitigate human-wildlife conflict with deterrents.

CHAPTER FOUR: CONCLUSION

With this study I planned to observe the ways in which species change behaviors in response to a novel object along an urban-rural gradient. However, what was actually captured was the varying levels of exploration that raccoons, red foxes, and white-tailed deer displayed in the presence of a novel object. While this study has the potential to provide great insights into how a species reactions to a novel object may change across an urban gradient, individual animals were not followed throughout the study. Therefore, individual personalities were not considered, and inference was made at the population level for each species. Further, I did not examine the proportion of time each type of behavior was displayed during each video therefore, I was limited in making inferences about boldness and shyness. To fully understand whether species differ in their boldness due to urbanization, each type of behavior – aggressive, exploratory, or shyness – should be studied more deeply as all behaviors are not equal in the information that they provide. Future research could also utilize tracking devices or individual markings to study individuals and gain a greater insight into heterogeneity among individuals, herds/groups, and personalities.

An additional limitation to my study was that I did not sample truly rural or remote areas. There is the potential that individuals in more urban and suburban settings have become desensitized and adapted to anthropogenic objects and therefore I could not detect major changes. Future research should include more sites along the urban-wild gradient to better compare habitat features. Additionally, my project was limited temporally, as I only studied a snapshot of time (~2 weeks) and did not account for potential habituation to novel objects. Knowing whether species become habituated to a novel object, or the amount of time that it takes a species to become habituated could aid wildlife managers for designing deterrent protocols (Oswick & Robertson, 2009; Sunnucks, 1998; Uchida et al, 2019). To assess whether individuals become habituated to novel objects, future research should conduct longer studies with the inclusion of temporal variables, such as the amount of time that a novel object was in place, in their modeling approach.

As camera traps were used in this study to observe the ways individual animals respond to a novel object, I was unable to differentiate individuals which could mean that the same individuals visited the sites multiple times and were recorded as repeated measures. Repeated measures of individuals within the data could skew away from the population mean if an individual was recorded several times and considered an independent observation. I attempted to limit the number of repeated individuals by conducting a thinning procedure for videos and including a random effect on sites in the models.

The variance explained by the random effect in the amount of time an individual spent in frame model was relatively high for each species (raccoon = 1.46, red fox = 0.388, and white-tailed deer = 0.145), as was the variance explained for the random effect in the time to approach model (raccoon = 0.115 and white-tailed deer = 0.442) except for red foxes (0.045). While the variance explained by the random effect in the behavior diversity model was relatively low for each (raccoon: < 0.001, red fox: 0.018, and white-tailed deer: 0.032) these combined results demonstrate that, in general, there was variation between sites. This variation could be indicative of repeated individuals in the data as the site level variance did not trend towards a mean with low variation. Therefore, I cannot guarantee that there were no repeat individuals present in the data. Future research should take into consideration repeated individuals. Additional steps could be taken by noting identifying features like antler patterns (Vanpé et al, 2007), unique injuries (Gomez-Salazar et al, 2011), diseases (Murray et al, 2021), or by marking and tracking individuals.

Finally, there are a variety of potential weather and environmental factors that could confound the data collected within this study. Rain and/or wind could play a role in the number of individuals that visited the bait and camera locations (Ikeda et al, 2015) and how they react to novel objects (Habberfield & St. Clair, 2015). This study was conducted over a short period of time as an effort to limit the variability in temperature. However, future research could include a greater number of sites, as a way to increase site diversity and the amount of data, as well as increase the amount of time that cameras remained in the field to capture variation in climatic variables. With enough data, climatic variables could be included in the modeling procedure to better understand their affect.

I found that environmental factors that are indicative of the urban environment had a significant impact on the amount of time that both carnivores and ungulates spent within view of a camera and approaching bait. All species, regardless of taxa, were found to respond to the presence of a novel object, indicating some sort of exploratory response associated with anthropogenic options for resources. This study can enable both managers and the public to be aware of how mammals are responding to increasing urbanization and anthropogenic sources. Wildlife managers can use these findings to create well-informed plans on how to deter species in urban spaces and/or manage them within urban environments.

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BIOGRAPHY

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