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Free-Roaming Cat Abundance Across a Habitat Gradient

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FREE-ROAMING CAT ABUNDANCE ACROSS A HABITAT GRADIENT

by

RACHEL BIRD

(Under the Direction of Ray Chandler)

ABSTRACT

There are an estimated 172 million owned and feral cats in the United States, and wildlife enthusiasts and cat owners are often at odds over how best to manage free-roaming cats. Management is needed because of the documented impacts of free-ranging cats on wildlife. Targeting these management efforts, however, is hampered by an imperfect understanding of cat distribution in the landscape. My study used game cameras and capture-recapture sampling to estimate abundance of free-roaming cats across a habitat gradient in Bulloch County, Georgia, USA. In all, I detected cats at 51% (25/49) sites with a mean of 2.1 cats per site. Cat abundance was significantly related to percentage of forest, distance to buildings, and density of buildings. Ultimately, density of buildings was the single best predictor of free-ranging cat abundance. Free-roaming cats had a significant, positive relationship with density of human buildings, and the free-roaming cat population of Bulloch County was found mostly in urbanized zones. As urbanization increases, current management strategies must be revised based on this data to target areas with high structural density to mitigate free-roaming cat impacts and hasten the removal of the species from the environment.

INDEX WORDS: Free-roaming, Cat, Game camera, Feline, Habitat, Capture-recapture, Camera trapping, *Felis catus*

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by

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CHAPTER 1

INTRODUCTION

Invasive species are organisms that cause ecological or economic harm in a new environment where they are not native, and they typically originate from intentional or accidental introductions by humans (Mooney et al., 2001). Increased globalization through transportation vectors such as cargo ships and airplanes has increased the frequency, prevalence, and intensity of invasive species movement and unintentional disease outbreak (Crowl et al., 2008). Nearly any species that becomes established outside of its native range can be invasive, but invasive predators seem to pose a heightened risk. To date, 30 species of invasive predators have caused the extinction or endangerment of 738 vertebrate species and contributed to 58% of all bird, mammal, and reptile extinctions worldwide (Doherty et al., 2016). Among invasive predators, invasive mammalian predators are considered the most harmful in their new environments (Hamer et al., 2021). Some of these species have wild origins, while other invasive species originate from domestication (Slater and Shain, 2005). Domestic cats (Duffy and Capece, 2012), dogs (Home et al., 2017), and pigs (Pedrosa et al., 2015) have all been implicated in ecosystem damage when they become feral. Free-roaming cats damage native ecosystems as a novel predator (Lepczyk et al., 2004), via competition in food webs, increasing disease transmission (Taetzsch et al., 2018), and indirect landscape alterations (Medina et al., 2014).

It is estimated that domestic cats kill at least 1.3 billion birds and 6.3 billion mammals annually in the United States, and cats are considered to be the single greatest source of anthropogenic mortality for U.S. birds and mammals (Loss and Marra, 2017). In New Zealand, birds were the most abundant victims of free-roaming cats, but in the United Kingdom, Australia, United States, and Switzerland, free-roaming cats mainly kill mammals (Loyd et al., 2013; Piontek et al., 2020). Cat predation on native wildlife can often lead not only to native species decline, but extinction (Burbidge and Manly, 2002; Nogales et al., 2004; Bonnaud et al., 2009; Loyd et al., 2013; Hardman et al., 2016; Davies et al., 2016; Algar et al., 2019). Because cats prey on a variety of small to medium prey species (Loyd et al., 2013; Read et al., 2015) and possess few potential predators themselves, they can decimate small animal populations in many habitats (Turner et al., 2000). Worldwide, cats are responsible for 14% of global bird, mammal, and reptile extinctions and are the greatest threat to 8% of critically endangered birds (Medina et al., 2011, 2014).

Free-roaming cats elicit behavioral changes in prey species in the new habitat, and this can lead to decreased reproductive success (Trouwborst et al., 2020). Even briefly displaying a taxidermy cat near Blackbird (*Turdus merula*) nests decreased provisioning of nestlings by 33% (Bonnington et al., 2013). This drop in provisioning and parental nest attendance made the Blackbird nests more likely to be attacked by corvids, further decreasing fledgling success. The fear induced by outdoor cats can also alter foraging, defense behaviors, stress responses, body condition, vulnerability to predators, and reproductive investment of prey species (Loss and Marra, 2017).

Secondary effects of free-roaming cats can change entire landscapes as well. Free-roaming cats and invasive red foxes (*Vulpes vulpes*) together have led to the decline or extinction of 66% of Australia's digging mammal species over the past 200 years (Doherty et al., 2016). The reduced topsoil disturbance due to the lack of digging mammals creates landscapes where little organic matter accumulates and rates of seed germination are low, causing dramatic changes in shrub cover. Free-roaming cat predation can reduce populations of seed-dispersing rodents (Corlett, 2011). This reduction indirectly impacted the herbaceous plants and trees of the area that rely on this method of seed dispersal and altered habitat complexity due to the cascading effects of cat predation.

Free-roaming cats can introduce endo- and ectoparasites, zoonotic diseases, and mammalian viruses to humans, pets, and wildlife (Foley and Stojanovic, 2011). Roundworms, hookworms, and tapeworms are endoparasites that affect up to 75% of cats, both domestic and feral. These worms can be passed to humans, and contact with contaminated soil such as playground sand that has been used as a free-roaming cat litterbox or exposure to infected cat fleas (*Ctenocephalides felis*) are possible routes of transmission (Abdullah et al., 2019). Free-roaming cats can also transmit toxoplasmosis, which can be especially dangerous for the immunocompromised or pregnant. As with other mammals, cats can host the rabies virus, although this is uncommon (Mutinelli, 2010). Cat fleas are known to carry typhus (*Rickettsia typhi*), *Bartonella* (cat-scratch fever), and the plague (*Yersinia pestis*) (McElroy et al., 2010). These illnesses and parasites can be spread through direct or indirect contact with free-roaming cats by allowing them into households or backyards, petting, receiving bites or scratches, touching feces-contaminated soil, allowing indoor cats access to outdoors without supervision, or direct handling. (Luria et al., 2004).

The negative effects of free-roaming cats can be exacerbated by the fact that they can be found in remarkably high densities. Free-roaming cats can average densities of approximately 1 – 15 cats/km^2 (Page et al., 1992; Hansen et al., 2017). Native predators such as coyote (*Canis latrans*) average only 3 individuals/km^2 in similar habitats (Bateman and Fleming, 2012). Free-roaming cat density can be even higher near feeding stations where cats form into colonies (Hatley, 2003). A study in Italy demonstrated that cat colonies can range from 3 - 80 individuals, and the number of colonies has been steadily increasing (Natoli et al., 2006). Supplemental food stations for free-roaming cat colonies allow cat densities to become unnaturally high, lead to a decrease in prey density (Hawkins et al., 1999), and can increase density-dependent disease transmission rates (Hwang et al., 2018). Supplemental feeding stations for free-roaming cat colonies do not decrease predation rates because cats are opportunistic predators known to hunt even in the absence of hunger (Loyd et al., 2013).

Outdoor cats also can have large home ranges. Male cats have much larger home ranges (6.2 km^2) than females (1.7 km^2) (Jones and Coman, 1982). Free-roaming cats are active during all hours but tend to do most (and farthest) wandering activities nocturnally. Home range sizes typically are determined by the density and spatial distribution of cats using separate food resources, personality and social dominance of individual cats, location of favored hunting and resting sites, and barriers such as busy roads (Barratt, 2006).

Mitigating the many problems created by free-roaming cats is challenging because of conflicting public opinion about cat management techniques. Possible solutions include laws prohibiting free-roaming pet cats, habitat management, culling, keeping pet cats strictly indoors, and Trap-Neuter-Return (TNR) to reduce population size. Finding common ground between stakeholders regarding these management options is difficult. Although free-roaming cats can be managed through state and federal legislation as in Italy and Czech Republic (Voslárˇvá and Passantino, 2012), owned-cat management tends to fall onto cat owners. In 2021, 63% of owned American cats were kept strictly indoors, while other owners promote either an indoor-outdoor or outdoor-only lifestyle for their pets. These alternatives remain a heavily debated subject worldwide with implications for cat welfare and enrichment, human health and wellness, the cat-owner bond, and the survival of native wildlife.

For example, feral cats are typically trapped in locations where they have been physically seen, typically in colonies, in order to begin management techniques. Given the large home ranges of outdoor cats, they might range (and cause wildlife problems) well beyond areas where they are visible. Alternatively, there may be habitats or landscape features that cats avoid. Given that time and money are always limiting factors in management efforts, predicting where cats will occur improve the efficiency of free-roaming cat control efforts. There is a need for data on how cat abundance varies with landscape features in a human-dominated landscape.

Therefore, the objective of my study is to quantify the abundance of free-roaming cats as a function of habitat in Bulloch County, Georgia, USA. Similar studies regarding cat population abundance not as a function of habitat have been conducted in other parts of the world and can be related to the data gathered here (Bengsen et al., 2011, 2012; Marra et al., 2021), but this study is the first of its kind in southeastern Georgia. Other studies in Bulloch County have used free-roaming cats as a target species as well. One tracked movement and genetic relationships in free-roaming cats on the Georgia Southern University campus and surrounding areas using GPS harnesses and DNA analysis and provided information regarding the large possible home ranges of free-roaming cats (Plummer, 2018). Another touched on the subject of free-roaming cats scavenging bird window-strike carcasses on the same campus (McLain, 2019). The purpose of my study is to answer two questions. First, does the abundance of free-roaming cats vary across an urban-rural gradient? Second, if cat abundance does vary across the gradient, is it associated with specific features of the habitat? I quantified several characteristics of the habitat to determine if free-roaming cat population estimates could be predicted based on one or more habitat characteristics (distance to buildings, density of buildings, percentage of forest, mesopredator frequency, and predator frequency). Distance to buildings, density of buildings, and percentage of forest were selected due to other studies indicating that free-roaming cats were less influenced by land cover types but were directly tied to anthropogenic features and was more localized to urban areas (Morin et al., 2018; Bennett et al., 2021). Similarly, mesopredator and predator species were analyzed because native wildlife may limit free-roaming cat distribution due to competition and/or predation (Pollack, 1951; Grubbs and Krausman, 2010).

I predicted that free-roaming cat population estimates will vary across the urbanization gradient, and that the highest populations of cats will be in close proximity to buildings due to high cover and a limited number of predator species (coyotes, bobcats, and dogs) and mesopredators (opossum, raccoon, gray fox, and red fox) in urbanized areas. Game cameras allow these data to be collected in a non-intrusive way and are a common method used to determine abundances of elusive or nocturnal mammals. Game cameras were the chosen tool for this study in order to mitigate problems posed by live trapping such as zoonotic diseases, low capture rates, and low recapture probabilities (Bengsen et. al, 2011; Kilshaw et al., 2014; Comer et al., 2018; Palmer et al., 2020). By using these cameras to improve understanding of the preferred habitat characteristics and use by free-roaming cats, management techniques can be targeted to specific locations that hold the most cats to increase trap rates, hasten the removal of this species from the ecosystem to mitigate issues presented, and encourage wildlife conservation. Whatever management methods are directed at outdoor, free-roaming cats, the efficacy of management is hampered by an imperfect understanding of cat distribution in human-dominated landscapes (Bengsen et al., 2011, 2012; Marra et al., 2021).

CHAPTER 2

METHODS

The study site was Bulloch County on the coastal plain of southeastern Georgia. The county is primarily rural and includes 798 km^2 of agriculture, 41 km^2 of water, and 66 km^2 of urbanized areas (United States Department of Agriculture, 2017). The towns of Portal, Stilson, Nevils, and Brooklet surround Statesboro, the most populous city. Statesboro is home to the Georgia Southern University campus and a population of 74,722 people (United States Census Bureau, 2018).

The landscape characteristics described above create an urban-to-rural habitat gradient (Figure 1). This gradient is defined by variation in density of buildings, distance to nearest building, and area of forest. I estimated free-roaming cat populations across this gradient using game cameras. Nine game cameras (four Campark Mini 16 MP 1080P HD Game Cameras and five Browning Strike Force Pro XD Trail Cameras) were deployed at 49 locations that had varying distances to buildings (0.23 – 1244.50 meters), density of buildings (0 – 2.46 structure/ha), and percentage of forest (0.86 – 87.07) (Figure 2). Habitat at all sites was quantified using Google Earth 2019 and its Measure tool and compared to Apple Maps 2021 to ensure no discrepancy in number of buildings. After possible study sites were located on Google Earth, landowners were contacted to request permission if the sites fell on private lands. After being granted permission, I deployed the cameras to the first nine sites, starting on February 6, 2021.

Before setting cameras every month, sites were inspected for game trails, clues for any wildlife, proximity to urbanization, and thickness of underbrush to determine site viability.

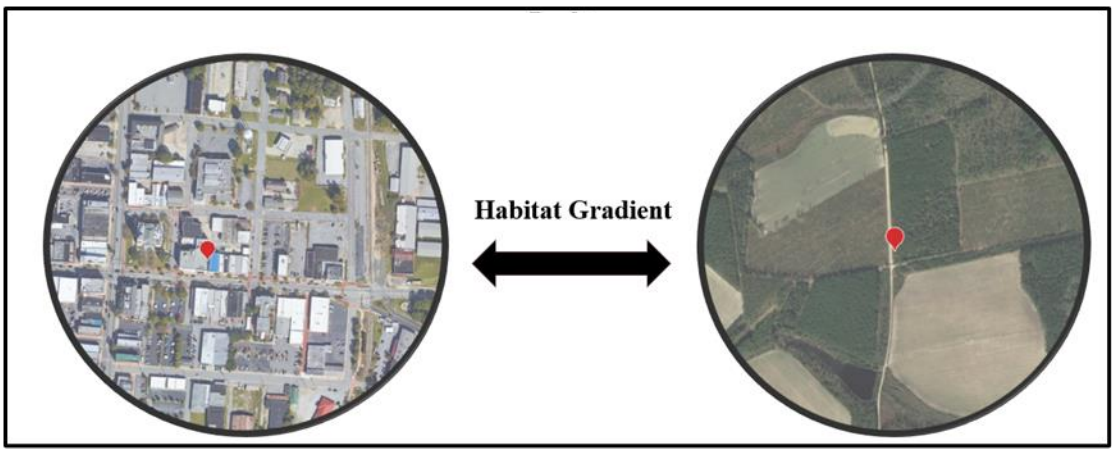

Figure 1. Example of endpoints of the habitat gradient sampled in this study.

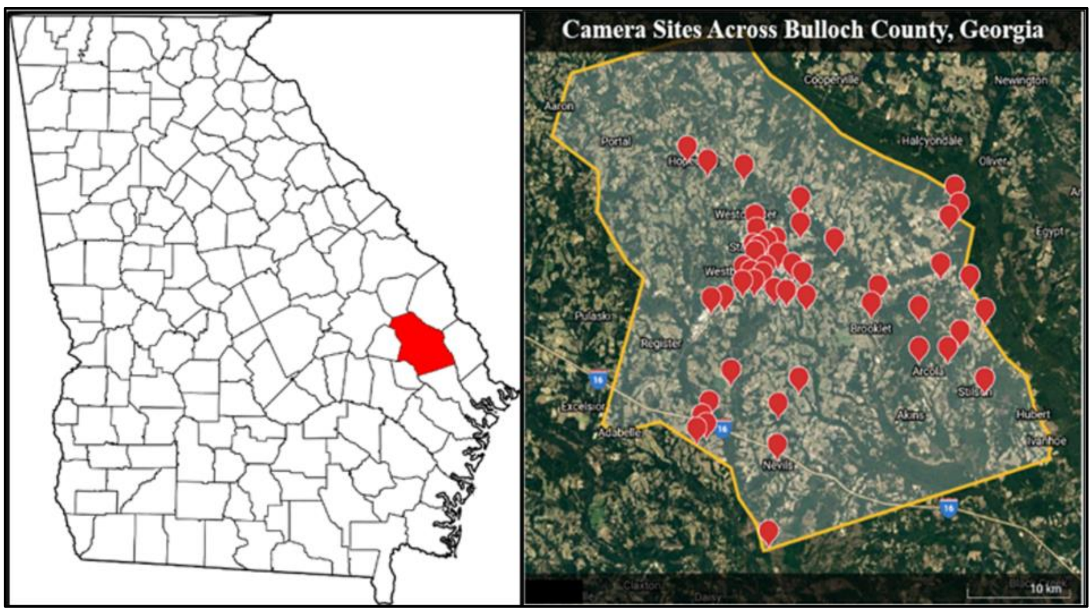

Figure 2. Study area and location of the 49 camera sites in Bulloch County, Georgia, USA.

The immediate area around each camera was cleared of any dangling branches, vines, or growing vegetation to reduce pictures of moving vegetation that would prematurely fill up space on the SD card of the camera. Each site needed weekly access through a roadway or on foot. Considering that free-roaming cats have tendencies to wander and large home ranges (Bengsen et al., 2016), cameras were placed at least 1.28 kilometers apart to decrease the chances of double-counting individuals.

Eight cameras remained in a location for one month and then were moved to the next location. The ninth camera (Site #8), selected due to landowner permission for long-term use of the site and predicted presence of cats (due to its close proximity to buildings), stayed at one location throughout the entire study. It functioned as a reference to determine if the one month timespan for other camera sites was an adequate timespan to capture photographs of the majority of cats at each site.

I placed three lures in front of each camera at each site to encourage wildlife to venture into view of the camera lens. The lures used at each site included roughly 0.5 cup of various brands of dry cat kibble (Kitten Kaboodle© or Meow Mix©), used litterbox clumps, and tufts of brushed fur collected from a long-haired pet cat. All three lures were placed simultaneously and roughly 1-1.5 m in front of the cameras. The kibble was mixed in with the leaf litter to encourage animals to stay longer at the site to facilitate photography, fur tufts were secured using nearby sticks and rocks, and used litter clumps were placed on the ground or smeared on nearby trees (within view of the camera lens) roughly 1-1.5 m above the ground to discourage disturbance by wildlife.

I checked cameras weekly to download pictures, replace batteries, and refresh lures. Each camera was securely fastened to objects available at sites such as trees, roughly 0.5 m above the ground (Figure 3). Each camera was labeled with a waterproof ownership tag with contact information, university affiliation, and “Biological Research” to discourage theft. Later, habitat features (distance to buildings, density of buildings, percentage of forest, frequency of mesopredators, and frequency of predators) and wildlife relative abundance indices (number of camera images per species divided by total trap nights) were quantified within a 500-m radius of each site (a circle of 78 ha).

Figure 3. Example of a deployment of a game camera in this study.

Camera Settings and Photo Analysis

In order to maximize the number of images of cats and preserve battery life in the cameras, each camera was programmed with settings optimized for the methods and goals of the study. The four Campark Mini 16 MP 1080P HD Game Cameras had settings of: photo mode on, 16 MP resolution, three photos taken in a row, no video or audio used, 5-sec shot lag, middle sensitivity, and target recording and time lapse off. The Browning Strike Force Pro XD Trail Cameras had settings of: trail mode, 5-sec capture delay, medium picture size, two-shot multishot, smart IR on, long range night exposure, 10-sec TL frequency, and 3-hour TL period. I downloaded and analyzed photos weekly to ensure no malfunctions with the cameras had occurred.

Mesopredators and predators captured in photos were quantified by frequency per site (number of days photographed divided by number of camera days per site), detection rate (total number of photos of a species divided by the total number of nights), and relative abundance indices (total number of photo captures divided by total trap nights). Abundance of cats was estimated using a capture-recapture approach where previously photographed cats ("marked") were "recaptured" when photographed again. Similar to studies conducted on tigers and jaguars (Wang and McDonald, 2009; Maffei et al., 2014), each image of a cat was carefully inspected for uniquely identifying marks such as color pattern, characteristics of striping, injuries, status of neutering, shape of the ears/jowls/nose, body proportions, presence of collar, age, or body condition. Individual identification provides the option of estimating cat relative abundance using capture-recapture methods. (Karanth, 1995; Soisalo and Cavalcanti, 2006; Tobler and Powell, 2012) (Figure 4). For this, it is assumed each population estimate is a relative estimation used to determine patterns – not an absolute number of exact population of cats at each site.

Figure 4. Example of free-roaming cats photographed during this study.

Landscape Criteria

Using a 500-m radius buffer, I quantified three habitat variables and two variables related to other wildlife. Distance to nearest building was the linear distance to the closet building to the camera at each site. Sites ranged across a gradient of 0.2 - 1244.5 m to the nearest building. Density of buildings (number of buildings divided by area of the 500-m radius) and percentage of forest (percentage of forested area out of total area of the surrounding 500-m radius) were recorded and compared to cat population estimates. Some locations were surrounded by high urbanization density, some were in wooded areas with heavy urbanization (such as housing complexes) nearby, and others were completely devoid of all urbanization in heavily isolated areas in large plots of fields and woodlands. For this study, animals that were classified as mesopredators were raccoons (*Procyon lotor*), gray foxes (*Urocyon cinereoargenteus*), red foxes (*Vulpes vulpes*), and opossums (*Didelphis virginiana*). Animals that were classified as potential predators of cats were dogs (*Canis familiaris*), coyotes (*Canis latrans*), and bobcats (*Lynx rufus*).

Data Analysis

Because an outdoor pet cat can be just as harmful to the local ecosystem as a feral cat (Baker et al, 2008), I made no distinction between feral (unowned) and free-range (owned) cats in terms of data analysis. To estimate population size at each site, Lincoln-Peterson capture-recapture sampling was used. This method is dependable in estimating populations and is a common, noninvasive method for sampling wildlife over large areas (Rich et al., 2014). Capture-recapture sampling is a powerful analytical tool to estimate populations and derive information on space use and behavior of elusive animals. This uses a proportion of the real number of animals in a given area, assuming that each animal has an equal probability of being captured. To use this method, I divided the one-month sampling period at each site into two survey periods:

the first half of the month and the second half of the month. Cats photographed in the first survey period were defined as “marked”. Cats photographed again in the second period were defined as “recaptured”. The capture-recapture formula is:

$$N = M(n)/m$$

N = cat population estimate per site

M = number of cats photographed in the first survey period (“marked”)

n = total number of cats photographed in the second survey period

m = proportion of cats photographed in the second period that were “recaptures” (photographed during the first period)

Cats photographed during the first period remained in the population, which is then resampled in the second survey period, and the proportion of previously photographed animals is used to estimate the population size per site. In this study, Site #8 was used to evaluate the reliability of the one-month capture-recapture sampling for this study. Because each camera remained at its specified site for only one month, I used the longer-term camera at Site #8 to see if cat frequency and the presence of unmarked cats changed after the one month period. This allowed me to determine if the one-month timespans of each deployment were long enough to allow adequate documentation of cats at each site. All wildlife documented in the collected game camera images were counted to provide a frequency of species found at each site (Appendix 1). Data were analyzed through Microsoft Excel and JMP Pro 16 using linear and multiple regressions.

CHAPTER 3

RESULTS

I obtained 64,222 images of wildlife over the duration of the study. Across all sites, I captured 16,158 photos of cats, 25,249 photos of opossums, 10,872 photos of raccoons, 8,266 photos of gray foxes, 2,275 photos of dogs, 756 photos of red foxes, 569 photos of coyotes, and 77 photos of bobcats. (Appendix 1). Most individual animals were photographed multiple times at each encounter.

Based on the site with continuous camera operation, the number of unmarked cats (ones not previously photographed) decreased to zero after the second month (Figure 5). Thus, two months appears to be a suitable timespan for capture-recapture estimates at other sites. Cat frequency decreased throughout the duration of the study showing that even marked (previously photographed) cats were seen in images increasingly less often than in the initial month.

Relation to Habitat

I photographed cats at 51% of sites (25/49) and population estimates ranged from 0 – 13.4 cats per site (Appendix 2). The largest cat populations occurred at sites within 440 m of a building, below 50% forest cover, and with more than 0.02 buildings/ha. Cats constituted 25% of all images of animals captured and had a relative abundance index of 22.96 – the second most abundant species recorded behind opossums (Figure 6). I recorded no instances of the same cat at more than one site, indicating no double-counting of cats.

Estimated cat populations showed a significant, positive relationship with density of buildings ($F_{1,47}$ = 37.3, P = <0.0001) (Figure 9). As structure density increased, the estimated cat populations increased significantly as well. There are significant, negative relationships between the estimated cat populations per site and distance to buildings ($F_{1,47}$ = 15.9, P = 0.0002) (Figure 7) and percentage of forest ($F_{1,47}$ = 10.6, P = 0.002) (Figure 8). Sites farther from buildings with more forest had fewer cats.

In a multiple regression holding other variables constant, estimated cat populations had no relationship to distance to buildings or percentage of forest (Table 1). Estimated cat populations did have a significant, positive relationship with density of buildings (Table 1). As density of buildings increased, cat population estimates increased significantly.

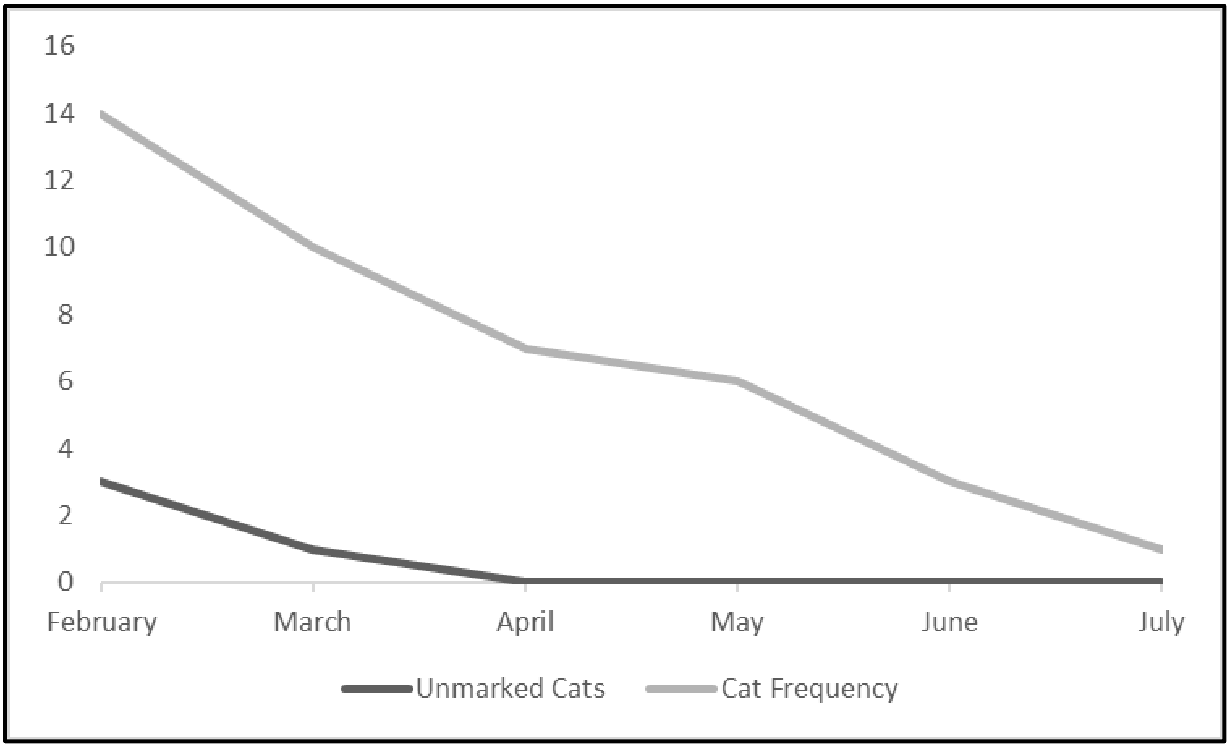

Figure 5. The camera at Site #8 remained in place throughout the study to serve as a comparison to the one-month sample period at other sites. The number of “unmarked” (unphotographed) cats declines rapidly, and the frequency of cat photos declined over time.

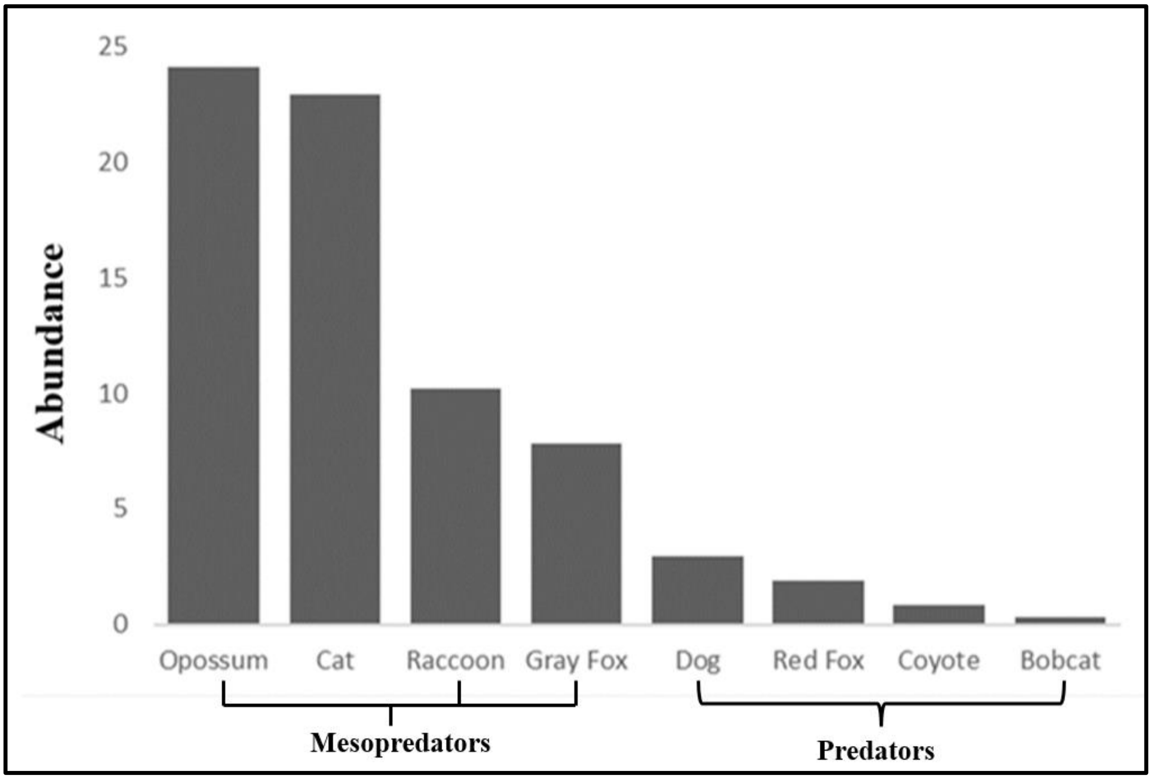

Figure 6. Relative abundance of predators and mesopredators photographed in this study.

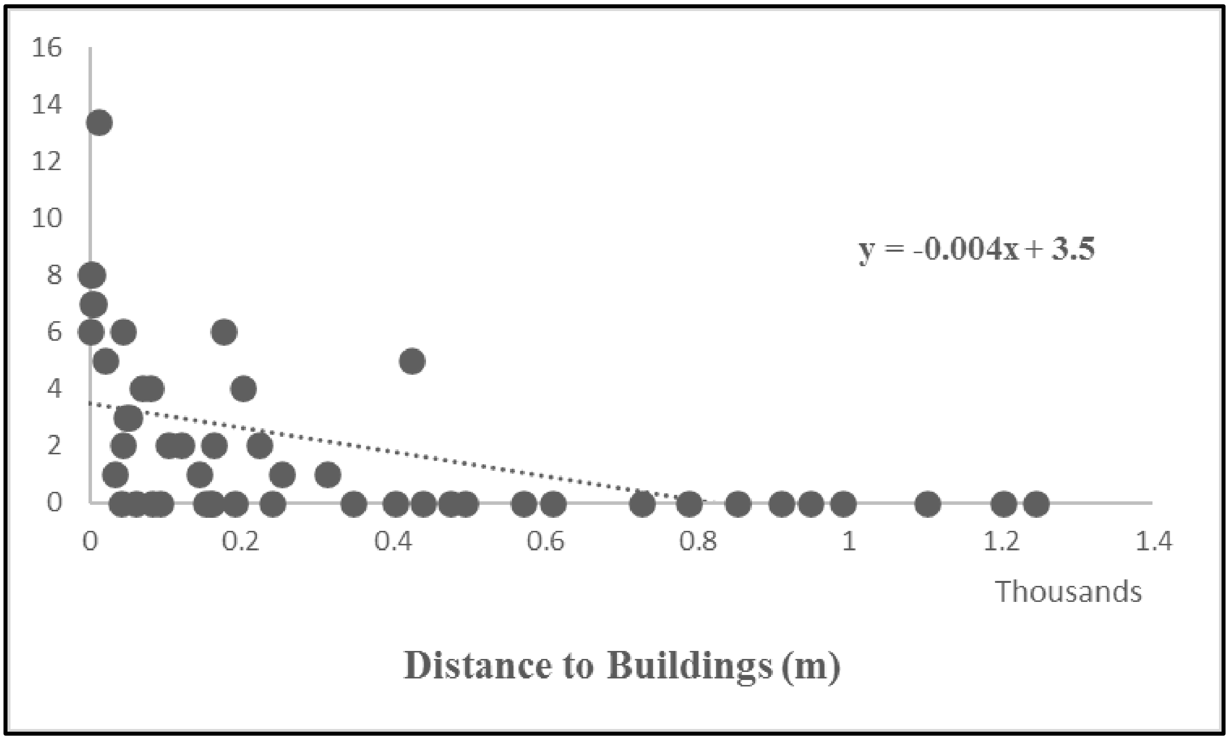

Figure 7. Cat abundance decreased at sites farther from buildings.

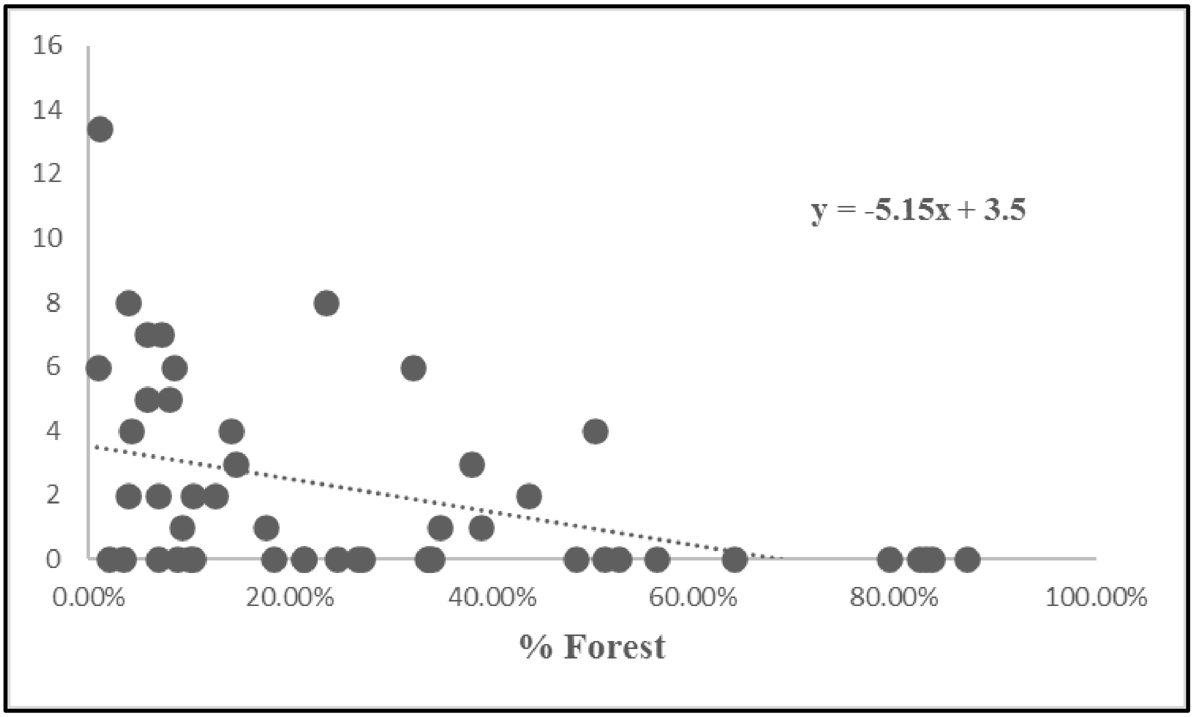

Figure 8. Cat abundance decreased with increasing forest cover.

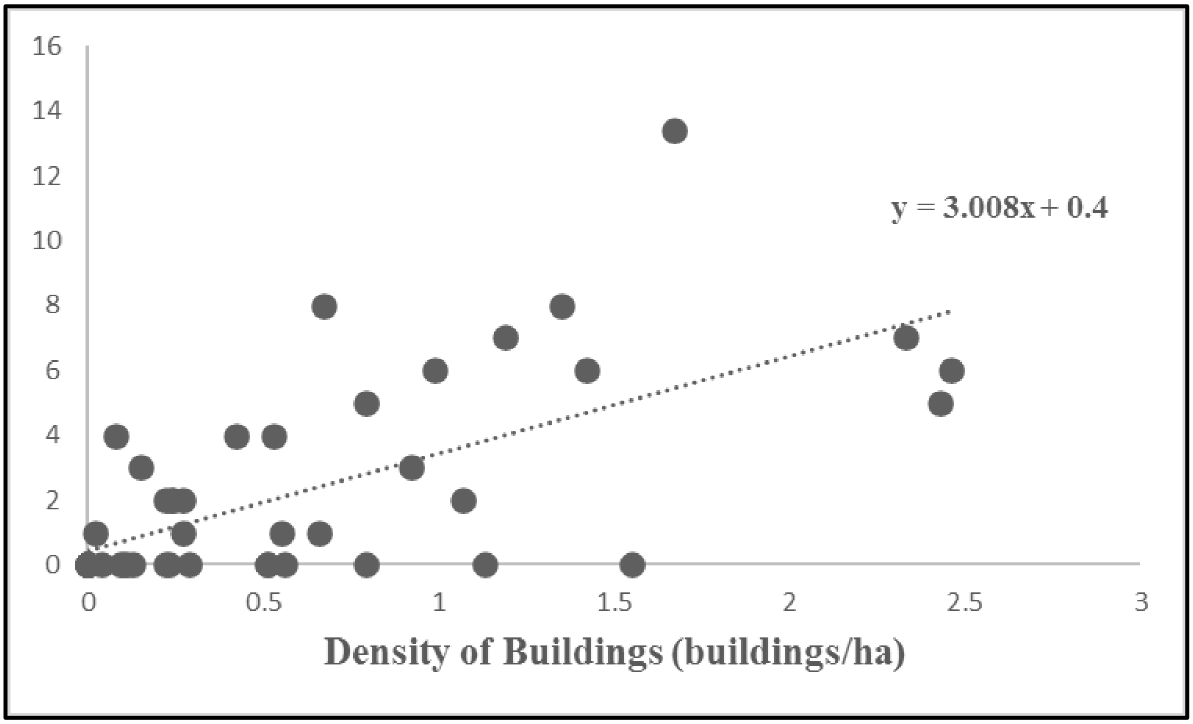

Figure 9. Cat abundance increased with increasing density of buildings.

Table 1. Results of multiple regression on the ability of habitat variables to predict cat abundance (R^2 = 0.47, $F_{3,45}$ = 13.1, P = <0.0001).

	Std Beta	**t ratio**	**Prob > t**
Distance	-0.20	-1.15	0.26
Density	0.56	4.19	0.0001
% Forest	0.02	0.14	0.89

Relation to Predators

One or more potential predator species were photographed at 30% of all sites with dogs being the most abundant at a 2.92 relative abundance index. Dogs made up 3% of all wildlife images captured. The least abundant predator was bobcat with a relative abundance index of 0.29, found at 6% of all sites, and representing less than 1% of all wildlife photos. Coyotes were found at 8% of sites, had a relative abundance index of 0.80, and represented less than 1% of all wildlife photos.

Cats had no relation to the frequency of coyotes ($F_{1,47} = 1.7$, $P = 0.15$), dogs ($F_{1,47} = 0.04$, $P = 0.56$), or bobcats ($F_{1,47} = 0.004$, $P = 0.61$). In multiple regressions, there was still no relationship between cats and combined predator frequencies (Table 2). Additionally, the frequency of dogs ($F_{1,47} = 1.6$, $P = 0.22$), bobcats ($F_{1,47} = 1.7$, $P = 0.22$), and coyotes ($F_{1,47} = 0.11$, $P = 0.74$) had no relationship to forest percentage. The frequency of dogs ($F_{1,47} = 0.31$, $P = 0.58$), bobcats ($F_{1,47} = 0.86$, $P = 0.36$), and coyotes ($F_{1,47} = 2$, $P = 0.16$) had no relationship to the density of buildings. The frequency of dogs ($F_{1,47} = 0.98$, $P = 0.33$), bobcats ($F_{1,47} = 0.62$, $P = 0.43$), and coyotes ($F_{1,47} = 0.91$, $P = 0.35$) had no relationship to the distance to buildings.

Relation to Mesopredators

Mesopredators were found at 79% of sites with opossums being the most common with a relative abundance index of 24.13 – the highest out of all wildlife (Figure 6). Opossums were found at 69% of sites and constituted 39% of all wildlife photos. Raccoons were found at 36% of sites, had a relative abundance index of 10.20, and constituted 17% of all wildlife photos. Gray foxes were found at 26% of all sites, had a relative abundance index of 7.80, and constituted 13%

of all wildlife photos. Lastly, red foxes were the least common mesopredator found with a relative abundance index of 1.90, found at 8% of sites, and constituted 1% of all wildlife photos.

Cats had no relationship to the frequency of opossums ($F_{1,47}$ = 0.02, P = 0.99), raccoons ($F_{1,47}$ = 0.002, P = 0.67), gray fox ($F_{1,47}$ = 0.07, P = 0.97), or red foxes ($F_{1,47}$ = 0.02, P = 0.43). Similarly, in a multiple regression, cats still had no relationship to mesopredator frequency (Table 2). Additionally, the frequency of opossums ($F_{1,47}$ = 0.07, P = 0.8), gray foxes ($F_{1,47}$ = 0.2, P = 0.67), raccoons ($F_{1,47}$ = 0.6, P = 0.44), or red foxes ($F_{1,47}$ = 1.2, P = 0.28) had no relationship to the percentage of forest. The frequency of opossums ($F_{1,47}$ = 0.22, P = 0.64), gray foxes ($F_{1,47}$ = 0.24, P = 0.62), raccoons ($F_{1,47}$ = 0.8, P = 0.39), or red foxes ($F_{1,47}$ = 0.75, P = 0.39) had no relationship to the density of buildings. The frequency of opossums ($F_{1,47}$ = 0.01, P = 0.92), gray foxes ($F_{1,47}$ = 2, P = 0.17), raccoons ($F_{1,47}$ = 1.7, P = 0.20), or red foxes ($F_{1,47}$ = 1.1, P = 0.29) had no relationship to the distance to buildings.

Table 2. Results of multiple regression on the ability of wildlife to predict cat abundance.

Model		**Mesopredators**		**Predators**
R^2		0.02		0.06
F Ratio		1.49		0.29
		Std Beta	**T ratio**	**Prob > t**
Mesopredators	Opossum	-0.06	-0.34	0.74
	Gray Fox	-0.02	-0.11	0.92
	Raccoon	0.09	0.49	0.62
	Red Fox	0.12	0.79	0.44
Predators	Bobcat	-0.09	-0.60	0.55
	Dog	0.07	0.46	0.64
	Coyote	-0.21	-1.43	0.16

CHAPTER 4

DISCUSSION

My study employed camera traps and capture-recapture methodology to estimate cat abundance across a habitat gradient in rural southern Georgia. My results show that free-roaming cats are abundant across the habitat gradient used in this study, their distribution is somewhat predictable, and management options could be informed by this distribution in order to maximize the efficiency of any management efforts.

The first key result of my study is that free-roaming cats are abundant across the south Georgia landscape. I detected cats at 51% of locations and identified a mean of 2.1 cats per site (Appendix 2). Some sites had an estimated populations as high as 13.4 cats. A mean of 4.3 cats was detected at occupied sites. These numbers of free-roaming cats are broadly similar to those reported in other studies. For example, Hand and Regis (2019) found a similar distribution of cats with 62% of locations to have cats present, similar to this study (Hand and Regis, 2019).

A second key result is that, although cats are abundant, they are not found everywhere. I rarely detected cats at sites farther than 440 m from a building, higher than 50% forest cover, and at building densities less than 0.02 buildings/ha. Cats showed a relationship to density of structures. Habitat explained variation in cat numbers with building density being the key explanatory variable when other variables were held constant. Relatively few other studies have assessed cat abundance across a landscape gradient. Morin et al., 2018 indicated similar findings in that free-roaming cats were less influenced by land cover types but were directly tied to anthropogenic features and more localized to urban areas (Morin et al., 2018). Bennett et al. (2021) found that the highest abundance of free-roaming cats was in areas closest to human buildings with mean population estimates ranging from 2.9 – 6.7 cats per site, as shown in this study as well (Bennett et al., 2021).

My final key result is that the relationship between cats and habitat (building density) might help target cat management efficiently. Efforts such as trapping or TNR could be directed to areas that the landscape features predict to be associated with large cat populations. However, this possibility comes with the built-in problem that areas near buildings probably have a mixture of feral and owned cats. In fact, I photographed several cats with collars during the course of my study. There are likely to be strong and conflicting opinion among stakeholders about possible cat management in these areas. Legge et al. (2020) showed that owned cats had a predation rate that was up to 2 times higher than feral cats in urban areas (Legge et al., 2020), indicating that some options for management must fall upon cat owners.

My results show it is feasible to predict areas of cat abundance from habitat data, and these sites might be candidates for cat management. However, the key question that is beyond the scope of my study is what cat management option is best suited for situations like that in my study? These issues raised can be mitigated by cat owners becoming educated on free-roaming cat environmental impacts and keeping owned cats indoors. For unowned cats, management options include Trap-Neuter-Return and culling. With this, Trap-Neuter-Return does not significantly reduce population numbers as well as returning cats to the environment allows predation (and other negative impacts) to continue (Natoli et al., 2006). Alternatively, culling directly removes individuals from the environment and effectively decreases cat population sizes but faces criticism from the public regarding cat welfare.

The findings discovered in this study closely match other research in the field and encourage future research on free-roaming cats by offering new information for others to branch into different aspects of free-roaming cat distribution and mitigation such as options to improve public opinion on effective management techniques. Overall, free-roaming cats and their impacts must be mitigated rapidly in densely urbanized zones in order to encourage biodiversity and wildlife conservation as urbanization steadily spreads into new habitats worldwide.

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APPENDIX 1

LOCATION, CAMERA TRAP EFFORT, AND PHOTO RESULTS FOR EACH STUDY SITE

Site	Latitude	Longitude	Dates Sampled (2021)	# of Nights Deployed	Frequency Cats	Detection Rate Cats	Frequency Opossum	Detection Rate Opossum
1	32.429317	-81.783973	February 6 – March 6	29	9	18.62	14	10.6
2	32.412764	-81.788416	February 6 – March 6	29	0	0	15	23.50
3	32.518095	-81.855424	February 6 – March 6	29	3	2.40	13	73.97
4	32.279372	-81.845275	February 6 – March 6	29	0	0	0	0
5	32.440000	-81.700000	February 6 – March 6	29	0	0	7	4.90
6	32.328919	-81.809222	February 6 – March 6	29	4	3.50	12	18.62
7	32.391742	-81.81596	February 6 – March 6	29	14	12.24	0	0
8	32.39813	-81.763519	February 6 – March 6	29	14	27.48	10	23.59
9	32.460224	-81.784025	February 7 – March 6	28	17	23.61	8	10.43
10	32.453473	-81.736132	March 6 – April 6	29	5	11.14	10	20.90
11	32.385904	-81.661197	March 6 – April 6	29	6	5.48	0	0
12	32.192042	-81.769423	March 6 – April 6	29	3	1.97	0	0

APPENDIX 1 CONTINUED

Site	Latitude	Longitude	Dates Sampled (2021)	# of Nights Deployed	Frequency Cats	Detection Rate Cats	Frequency Opossum	Detection Rate Opossum
13	32.265543	-81.760373	March 6 – April 6	29	20	16.27	7	9.60
14	32.440981	-81.76156	March 6 – April 6	29	17	24.21	0	0
15	32.449058	-81.782253	March 6 – April 6	29	8	5.60	0	0
16	32.43531	-81.785762	March 6 – April 6	29	17	15.28	1	1.14
17	32.433393	-81.780344	March 6 – April 6	29	19	36.03	0	0
18	32.4853176	-81.571557	April 7 – May 6	28	0	0	4	14.04
19	32.4700553	-81.569220	April 7 – May 6	28	0	0	4	4.00
20	32.347572	-81.61106	April 7 – May 6	28	0	0	5	6.70
21	32.4007339	-81.652717	April 7 – May 6	28	14	15.40	2	3.54
22	32.5069877	-81.832437	April 7 – May 6	28	3	1.81	0	0
23	32.4069436	-81.783759	April 7 – May 6	28	4	3.82	0	0
24	32.4042900	-81.797105	April 7 – May 6	28	4	6.86	16	27.07

APPENDIX 1 CONTINUED

Site	Latitude	Longitude	Dates Sampled (2021)	# of Nights Deployed	Frequency Cats	Detection Rate Cats	Frequency Opossum	Detection Rate Opossum
25	32.475095	-81.736018	April 7- May 6	28	11	17.46	19	110.39
26	32.283443	-81.834902	May 6 – June 5	28	11	12.64	10	17.21
27	32.2899641	-81.839684	May 6 – June 5	28	0	0	14	37.14
28	32.2996431	-81.827299	May 6 – June 5	28	0	0	0	0
29	32.322393	-81.541472	May 6 – June 5	28	0	0	4	6.75
30	32.3814461	-81.606841	May 6 – June 5	28	0	0	5	5.64
31	32.408499	-81.557464	May 6 – June 5	28	10	14.92	16	42.57
32	32.4279864	-81.759861	May 6 – June 5	28	6	14.82	0	0
33	32.411111	-81.775617	May 7 – June 5	27	22	61.66	11	34.66
34	32.4624512	-81.577292	June 7 – July 7	29	0	0	7	14.28
35	32.4988896	-81.793691	June 7 – July 7	29	0	0	0	0
36	32.2975461	-81.755857	June 7 – July 7	29	0	0	14	56.24
37	32.4158684	-81.585282	June 7 – July 7	29	5	10.03	12	34.21

APPENDIX 1 CONTINUED

Site	Latitude	Longitude	Dates Sampled (2021)	# of Nights Deployed	Frequency Cats	Detection Rate Cats	Frequency Opossum	Detection Rate Opossum
38	32.3793077	-81.541067	June 7 – July 7	29	0	0	5	16.03
39	32.3610798	-81.562649	June 7 – July 6	28	0	0	0	0
40	32.3452573	-81.575957	June 7 – July 6	28	0	0	0	0
41	32.3216933	-81.737083	June 7 – July 6	28	3	3.18	17	53.21
42	32.4381655	-81.770602	July 7 – August 6	28	3	6.11	2	8.04
43	32.4173503	-81.772281	July 7 – August 6	28	21	51.5	13	45.5
44	32.4168488	-81.794745	July 7 – August 6	28	10	22.07	0	0
45	32.4103308	-81.733213	July 7 – August 6	28	6	20.40	13	42.75
46	32.38963778	-81.827599	July 7 – August 6	28	4	11.75	17	50.36
47	32.3940765	-81.750083	July 7 – August 6	28	3	4.36	3	4.67
48	32.4175739	-81.742371	July 7 – August 6	28	19	89.71	4	13.21
49	32.3903328	-81.727724	July 7 – August 6	28	0	0	17	46.61

APPENDIX 1 CONTINUED

Site	Frequency Gray Fox	Detection Rate Gray Fox	Frequency Raccoon	Detection Rate Raccoon	Frequency Dog	Detection Rate Dog	Frequency Red Fox	Detection Rate Red Fox
1	11	23.50	8	3.03	0	0	0	0
2	11	34.14	17	82.07	0	0	0	0
3	10	41.07	11	74.48	1	0.59	0	0
4	12	21.21	0	0	0	0	2	1.80
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	1	0.59
8	13	45	9	23.62	0	0	0	0
9	0	0	0	0	0	0	0	0
10	12	17.62	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	1	0.76	2	2.60	0	0	0	0
13	0	0	2	2.62	1	0.41	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	2	1.80	0	0	0	0
17	0	0	0	0	0	0	0	0
18	2	6.07	0	0	1	3.7	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	8	10.75	0	0	9	16	0	0
22	0	0	0	0	4	5.46	0	0
23	14	42.93	0	0	9	14.79	0	0
24	0	0	8	11.57	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	12	9.43

APPENDIX 1 CONTINUED

Site	Frequency Gray Fox	Detection Rate Gray Fox	Frequency Raccoon	Detection Rate Raccoon	Frequency Dog	Detection Rate Dog	Frequency Red Fox	Detection Rate Red Fox
27	0	0	7	20.46	0	0	0	0
28	0	0	0	0	0	0	0	0
29	3	4.32	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	9	17.93	8	22.82	11	15.14
32	0	0	14	41.61	0	0	0	0
33	0	0	9	28.37	0	0	0	0
34	0	0	0	0	2	3.89	0	0
35	0	0	0	0	3	9.14	0	0
36	0	0	0	0	0	0	0	0
37	0	0	2	6.40	0	0	0	0
38	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	3	9.29	0	0	0	0
42	0	0	0	0	0	0	0	0
43	0	0	0	0	2	3.93	0	0
44	0	0	0	0	0	0	0	0
45	4	23.29	0	0	0	0	0	0
46	0	0	14	36.82	0	0	0	0
47	0	0	5	10.96	0	0	0	0
48	6	17.96	10	24.54	0	0	0	0
49	0	0	8	16.18	0	0	0	0

APPENDIX 1 CONTINUED

Site	Frequency Coyote	Detection Rate Coyote	Frequency Bobcat	Detection Rate Bobcat	Species Richness
1	0	0	0	0	4
2	0	0	0	0	3
3	0	0	2	1.45	6
4	2	1.10	0	0	3
5	0	0	1	0.45	2
6	0	0	0	0	2
7	0	0	0	0	2
8	0	0	0	0	4
9	0	0	0	0	2
10	0	0	0	0	3
11	0	0	0	0	1
12	0	0	0	0	3
13	0	0	0	0	4
14	0	0	0	0	1
15	0	0	0	0	1
16	0	0	0	0	3
17	0	0	0	0	1
18	0	0	0	0	3
19	0	0	0	0	1
20	4	6.82	0	0	2
21	0	0	0	0	4
22	0	0	0	0	2
23	0	0	0	0	3
24	0	0	0	0	3
25	0	0	1	0.79	3
26	0	0	0	0	3

APPENDIX 1 CONTINUED

Site	Frequency Coyote	Detection Rate Coyote	Frequency Bobcat	Detection Rate Bobcat	Species Richness
27	0	0	0	0	2
28	0	0	0	0	0
29	0	0	0	0	2
30	0	0	0	0	1
31	0	0	0	0	5
32	0	0	0	0	2
33	0	0	0	0	3
34	0	0	0	0	2
35	1	2.38	0	0	2
36	0	0	0	0	1
37	0	0	0	0	3
38	0	0	0	0	1
39	0	0	0	0	0
40	0	0	0	0	0
41	4	9.89	0	0	4
42	0	0	0	0	2
43	0	0	0	0	3
44	0	0	0	0	1
45	0	0	0	0	3
46	0	0	0	0	3
47	0	0	0	0	3
48	0	0	0	0	4
49	0	0	0	0	2

APPENDIX 2

SUMMARY DATA FOR EACH SITE, INCLUDING ESTIMATED CAT POPULATION AND HABITAT VARIABLES

Site	Estimated Cat Population	Distance to Buildings (m)	Density of Buildings (buildings/hectare)	% Forest
1	6	176.74	1.42	32.16%
2	0	160.23	1.13	21.37%
3	2	163.82	0.27	43.66%
4	0	240.53	0.11	34.12%
5	0	92.23	0.13	48.30%
6	2	44.00	0.24	10.36%
7	4	80.09	0.53	4.23%
8	3	47.59	0.92	37.98%
9	7	3.00	2.33	5.76%
10	0	159.00	0.51	10.41%
11	0	82.43	0.79	3.42%
12	1	311.49	0.02	9.30%
13	8	1.02	0.67	3.88%
14	6	44.45	0.99	8.46%
15	6	0.23	2.46	0.86%
16	8	2.67	1.35	23.60%
17	7	5.32	1.19	7.21%
18	0	494.54	0.09	51.23%
19	0	1244.50	0	83.75%
20	0	726.43	0	56.34%
21	4	69.46	0.42	14.13%
22	0	40.67	0.23	26.69%
23	1	251.75	0.55	17.59%
24	0	347.65	0.10	33.57%
25	4	200.46	0.08	50.19%
26	3	52.64	0.15	14.58%
27	0	570.34	0	33.69%
28	0	992.08	0	52.55%
29	0	191.32	0.29	21.34%
30	0	1102.34	0	87.07%
31	2	103.56	0.24	3.85%
32	1	32.75	0.66	34.82%
33	5	20.86	2.43	5.88%
34	0	909.44	0	18.41%
35	0	401.12	0.22	27.09%

APPENDIX 2 CONTINUED

Site	Estimated Cat Population	Distance to Buildings (m)	Density of Buildings (buildings/hectare)	% Forest
36	0	1202.33	0	82.40%
37	0	947.85	0	64.07%
38	0	608.89	0	24.60%
39	0	789.61	0	83.07%
40	0	852.99	0	79.48%
41	0	439.34	0.04	8.76%
42	0	60.45	1.55	2.09%
43	13.4	11.61	1.67	1.16%
44	2	120.56	1.07	6.95%
45	0	152.61	0.56	6.91%
46	2	222.78	0.22	12.50%
47	1	143.56	0.27	38.94%
48	5	422.57	0.79	8.01%
49	0	473.86	0.51	10.11%
Mean:	2.11	322.77	0.56	27.90%
Range:	0 – 13.4	0.23 – 1244.50	0 – 2.46	0.86 – 87.07%
SD:	3.01	355.82	0.67	25
95% CI:	[1.2, 2.9]	[220, 424]	[0.4, 0.8]	[20.7, 35.1]