Assessing Wild Canid Distribution Using Camera Traps in the Pioneer Valley of Western Massachusetts

ASSESSING WILD CANID DISTRIBUTION USING CAMERA TRAPS IN THE PIONEER VALLEY OF WESTERN MASSACUSETTS

A Thesis Presented

by

ERIC G. LEFLORE

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DEDICATION

For my mother

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ABSTRACT

ASSESSING WILD CANID DISTRIBUTION USING CAMERA TRAPS IN THE PIONEER VALLEY OF WESTERN MASSACUSETTS

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With the ever-increasing human population, more people reside in urban areas than ever before; this is having marked effects on the landscape and in turn, wildlife. This study uses automatically triggered wildlife cameras to assess the distribution of three carnivore species (coyotes, *Canis latrans*; red foxes, *Vulpes vulpes*; and gray foxes, *Urocyon cinereoargenteus*) around the Pioneer Valley of Massachusetts in relation to a gradient of human development. Cameras were placed at 141 locations within the 320-km^2 study area over the course of three field seasons (3,052 trap nights). Relative abundances for fourteen other species and site characteristics (e.g., elevation, forest cover type, distance to urban edge) for each camera location were determined to develop a generalized linear model for the distribution of each species across the study area. Coyote distribution was most affected by the relative abundances of their prey species and not by landscape characteristics or sympatric carnivore species. Coyotes are the top predator in the area and therefore their distribution is correlated with the relative abundances of their prey species, unlike other parts of their range where they are controlled by larger carnivores. Red and gray foxes both had negative relationships with the relative abundance of coyotes as coyotes have been shown to adversely impact fox distributions

and access to resources. Both red and gray foxes were also negatively or uncorrelated with increased levels of urbanization, which is both supported and refuted by published literature and is likely system specific.

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CHAPTER 1

ASSESSING WILD CANID DISTRIBUTION USING CAMERA TRAPS IN THE PIONEER VALLEY OF WESTERN MASSACHUSETTS

1.1 Introduction

Urbanization has extreme effects on the landscape; natural landscapes are fragmented, degraded and turned into isolated patches of habitat (Marzluff 2001), light and noise pollution increases, ambient temperature is usually higher in cities due to the "heat island effect", and altered hydrology results in diverted streams and increased surface runoff (Gehrt 2010). All of these factors have major impacts on wildlife in urban and adjacent areas, causing changes in animal movements, behaviors, density, and distribution (Gehrt 2010). Exotic wild species, in particular, are able to thrive in urban areas though their distributions are likely to be highly variable, and urban ecosystems also tend to have increased numbers of domestic cats and dogs (Gehrt 2010). Even though exotics are common within urbanized areas, animal diversity is typically homogenized there (Gehrt 2010, McKinney 2006); in contrast, biodiversity may be highest at the urban edge due to the mix of species that are sensitive to urbanization and other development and those that benefit from being close to humans (Gehrt 2010, Pickett et al. 2008). Urban edges may abut natural, less disturbed ecosystems, but often are adjacent to agricultural land that itself is highly modified with its own set of limitations and opportunities for wildlife (e.g., Wilson et al. 2009).

Different taxa respond in various ways to anthropogenically disturbed landscapes. In general, carnivore species are extremely variable in their behaviors and can be found across the globe in vastly different environments, from the arid deserts of Africa to the frozen tundra of Siberia (Fuller et al. 2010). Carnivores are thought to be especially vulnerable to habitat loss and fragmentation because of their need for large amounts of space, low densities, and conflicts with humans (Crooks 2002; Noss et al. 1996), but in the face of development, some carnivores have greatly expended their ranges (e.g., coyotes *Canis latrans*; Parker 1995), increased their numbers (e.g., bobcats *Lynx rufus*; Roberts and Crimmons 2010), and have higher densities in urban vs. rural areas (e.g., raccoons *Procyon lotor*; Prange et al. 2003).

Carnivore species will react differently to pressures of urban environments, but a few generalizations can be made about carnivores that thrive in such regions (Fuller et al. 2010). Successful urban carnivores tend to be relatively small to medium in size and usually have higher reproductive capabilities. One of the most essential characteristics of an urban carnivore is that they are diet generalists that can survive on vegetation, live animals, carrion, and human refuse, depending on what is available. Successful urban carnivores tolerate being in close proximity to humans, and this is sometimes encouraged by humans that, purposefully or not, provide food and shelter resources (e.g., Kanda et al. 2009).

Carnivores can be difficult to study with typical observational and capture-based methods due to their relative rarity, elusiveness, and wide-ranging movements (MacKay et al. 2008). Still, carnivores leave identifiable signs of their presence via tracks or droppings, and many species protect territories, travel on routes, and practice marking behaviors, all of which aid in detection. For these reasons, noninvasive survey methods, which are techniques that do not involve the direct observation, capture or handling of individuals, are suitable for the study of carnivores (Zielinski and Kucera 1995, Long et al. 2008). Self-triggering, remote cameras have long been used to obtain evidence of rare and/or elusive wildlife (Cutler and Swann 1999), and more particularly to show that a species is not extinct (Brink et al. 2002), to describe animal distribution (Zielinski et al. 2005), to derive indices of relative abundance (MacKenzie et al. 2006), and to measure density (Nichols and Dickman 1996).

Frequent observations of carnivore carcasses on roadways, and of the animals themselves, in the relatively highly populated and developed Pioneer Valley in western Massachusetts led to curiosity concerning their distribution and abundance in the area, a mix of agriculture, suburban neighborhoods, and an urbanized university campus, all adjacent to isolated or contiguous naturally forested areas. This study employs automatically triggered wildlife cameras to investigate the distribution of three canid species: coyotes, red foxes (*Vulpes vulpes*), and gray foxes (*Urocyon cinereoargenteus*). It is an attempt to understand the landscape features that influence the ways in which a variety of carnivore species utilize, and seem to thrive in, a very human-influenced ecosystem. My specific objective was to assess carnivore distribution across the study area by relating species-specific photo locations to landscape characteristics via statistical models.

Coyotes can be found throughout North and Central America in a wide variety of habitats ranging from fallow agricultural land and urbanized areas to brushy fields and edges of secondary growth forests (DeGraaf and Yamasaki 2001). They are opportunistic hunters but typically prey on snowshoe hare (Lepus americanus), deer (Odocoileus spp.), beavers (Castor canadensis), muskrats (Ondatra zibethicus), and small mammals. They eat vegetation, mostly fruit and berries when present, and invertebrates. Coyotes are the top predator in most cities throughout its range and are one of the most successful urban carnivores (Gehrt and Riley 2010). In the East, coyotes have interbred with gray wolves (Canis lupus/lycaon) and are larger than coyotes of the west (Parker 1995). Males have larger home ranges than females and in Maine, home ranges averaged 52 km^2 for males and 48 km^2 for females. Coyotes typically den in secluded areas with rocky caves, hollowed logs, or excavated burrows.

Red foxes can be found on five continents in habitats ranging from the Sahara Desert to the taiga forests of Canada (Henry 1986). They have a varied diet that typically changes from season to season, and consume mainly small rodents, rabbits (family Leporidae), insects, wild fruits and berries, but birds and other plants. Red foxes are also effective scavengers. They are typically crepuscular hunters that utilize edge habitats to find prey. Red fox usually utilize and defend family home ranges between 5 and 7.5 km^2.

Gray foxes are found throughout the United States and their range continues north into southern Ontario and Quebec (DeGraaf and Yamasaki 2001). They frequent dense northern hardwood forests and mixed forest habitats as well as areas that are a network of old fields hardwood forests. Gray fox are crepuscular and nocturnal and can be seasonally omnivorous. They feed on cottontail rabbits (Sylvilagus sp.) and small rodents in winter, but in summer, change diets to mostly include birds, reptiles, and amphibians and their eggs, as well as insects. Vegetation is consumed during the fall, including foods like acorns, apples, grapes, and corn. Home range sizes will vary with food availability, season, and various disturbances. Both males and females will range farther during the fall and winter months. During denning, home ranges can be 1.6 km wide while during the fall they can grow to 8 km wide. Gray fox typically den in tree crevices and hollow logs as well as rock cavities and underneath abandoned buildings.

I hypothesized that in addition to landscape characteristics, the distribution of each focal species will be impacted by the relative abundances of prey species and sympatric carnivores. Each species' distribution (photo locations) will correspond to features like land use type; distance to next nearest "other" land use type; distance to water, roads or urbanization; elevation; and land use category, as well as the relative abundances of other species, whether prey or competitor. The statistical model for each species should capture the characteristics that are most important to the distribution of that species and thus be useful for future carnivore management. I proposed that, analogous with the intermediate disturbance hypothesis (Connell 1978) which states that the highest levels of biodiversity are maintained at intermediate levels of disturbance, the focal species would generally utilize "altered" landscapes (see below) more frequently than natural or urban land ones, because of the increased amount of resources that come from creating edge habitat as a result of human development. More specifically, I hypothesized that coyotes would be detected more in smaller forest patches (Cove et al. 2012), which would be in areas with increased levels of development. With previous detection levels showing a positive correlation with urbanization (Cove et al. 2012), I expected that red foxes would be captured most often in "urban" areas, and gray foxes would utilize areas that are close to human development and would be photographed more frequently in "altered" and "urban" land uses (Kapfer and Kirk 2012).

1.2 Study area

This study was conducted in the Pioneer Valley of western Massachusetts, a section of the Connecticut River Valley near the town of Amherst. The 320-km^2 study area is bounded on the south by the Mt. Holyoke Range State Park, the north by Mount Toby State Forest, the west by the Connecticut River, and the east by the Quabbin Reservoir (Figure 1). Within the study area, more urban, suburban, and agricultural areas (i.e., urban and altered; see below) occur in the southwest "developed" half, versus the predominantly naturally "forested" area (i.e., natural) in the northeast half (Table 1, Appendix 1).

Amherst is a growing New England town with a population that is approaching 40,000 people and a population growth rate of 8.4% since the year 2000 (Office of the Secretary of the Commonwealth of Massachusetts, 2010). The landscape is fragmented with many roads, farms, and residential and commercial developments. The greater Amherst area is also home to five colleges and universities which add to the population for a considerable portion of the year and must support and maintain the level of infrastructure that accompanies such institutions.

1.3 Methods

1.3.1 Data Collection

During September 2011-November 2012, automatic cameras were placed at 141 sites within the study area during three field seasons (Table 2). The cameras were set at sites in three different land use classes (natural [N], altered [A], and urban [U]), similar to classifications for an urban carnivore meta-analysis conducted in southern California (Ordeñana et al. 2010). The distribution of these consolidated land use classes was derived from the Land Use 2005 data layer from the Massachusetts GIS website (Appendix 1).

In Fall 2011, students, as part of a course field exercise, placed cameras at locations of their choice in the study area, given assigned land use classes that were equally distributed among the three categories. Each camera site had to be at least 50 m from the edge of a land use class and in what looked like a spot where animals would travel. This resulted in a wide but haphazard distribution of cameras in the area. In Summer 2012, the 320-km^2 study area was gridded into 80 4-km^2 cells. I placed cameras across the study area by randomly selecting grid cells. Once a grid cell was selected, cameras were placed within that cell in a forest patch where access was permitted by the landowner. Within the forest patch, an in situ evaluation of wildlife paths was used for specific camera placements. In Fall 2012, students again placed cameras as part of their class field exercise, but the assigned locations followed the grid cell selection process analogous to summer 2012. Students were instructed specifically where to place their camera in the grid cell, and the specific site of the camera followed methods from the previous summer.

Once a camera site location was chosen, an infrared and motion-activated Bushnell Trophy Cam (Bushnell Outdoor Products, model numbers: 119436, 119446, 119456) was affixed to a tree at about 0.5m above the ground pointing to a focal area where an animal was likely to pass. Vegetation that was in the field of view and would trigger the camera was cleared. A scent lure (either Badlands Bob - BB; John Graham's Fur Country Lures, Jordan, Montana; or Powder River – PR, O'Gorman Enterprises, Freemont, Nebraska) was rubbed in the focal area, approximately 2-3 m from the face of the camera. Cameras were left in the field for at least 10, and no longer than 25, days (X = 21.3 days).

1.3.2 Data Organization

For each field season, we recorded the camera station number, lure used, initial habitat class (N, A, U), location (UTM coordinates/GPS coordinates), date set, and date closed. Independent photo events were recorded noting the camera station number, species, date, time. Photos of individuals of the same species were said to be independent after a 30-min interval (Yasuda 2004). The photo data were organized to indicate total counts of the number of observations for each species by camera station. The camera station data were then merged to the photo data. For each species, photo capture rates were calculated by taking the number of observations divided by the number of trap nights for that station. For comparison across stations, as well as the published literature, these rates were standardized as number of captures per 100 trap nights. The data were organized into a site-by-species data matrix and a site-by-habitat variables data matrix.

1.3.3 GIS and statistical analysis

The consolidated land use layer (Appendix 1), as well as the Digital Elevation Model layer, Mass DOT Roads layer, and Community Boundaries (cities and towns), were obtained from Mass GIS (http://maps.massgis.state.ma.us/map_ol/oliver.php. Accessed Sep 2011). Land cover, vegetative structure, and traffic rate GIS data were downloaded from the University of Massachusetts Conservation Assessment and Prioritization System (UMass CAPS 2011; http://umasscaps.org/data_maps/data.html. Accessed 15 Jul 2013). These GIS data layers were used in subsequent GIS analyses.

For each camera location, I identified site-specific characteristics including: elevation; forest cover type; station-specific photo rates of prey, sympatric carnivore species (including dogs and cats), and humans; distances to urban edge, natural edge, altered edge, agricultural edge, water, and roads; and percentage of natural, altered, and urban land use within a 500-m radius of the camera location calculated using Arc GIS 10 (Table 3). All of the aforementioned site characteristics were added to the site-by-habitat data matrix for statistical analyses.

Using the most complete data set (Fall 2012: 79 cameras – 4 cameras were eliminated due to camera malfunction and errors in GPS coordinates, Figure 2), I used R statistical software (version 2.15.1, R Core Team 2012) to run four types of generalized linear models (GLMs) for each species: Poisson, negative binomial, zero-inflated Poisson, and zero-inflated negative binomial (Zuur et al. 2009). Each of these distributions is typically used for species count data because each produces integers bounded by zero (inclusive). Zero-inflated models are typically used for species count data where there is a high frequency of observations with a count of zero; they account for true zeroes as well as false zeroes (Zuur et al. 2009). Starting with a full Poisson model for each species, I used a stepwise selection process, drop1 (R Core Team 2012) to eliminate parameters that were not having a major effect on the response variable (relative abundance of each focal species). Confounding and correlation between the independent parameters were compared by Variance Inflation Factors (VIF) (Zuur et al. 2013). If the VIF is below 10 for all parameters in the model, the information derived from the model is statistically sound (Montgomery and Peck 1992). If the Poisson model was overdispersed (variance > mean), I fit a negative binomial regression which better fits overdispersed data. Due to the high number of zeroes recorded at many sites for the focal species, I also fit zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB) GLMs. Best models for each focal species were selected by a comparison of Akaike information criterion (AIC) values, a measure used to address overall model quality by accounting for the goodness of fit in relation to the model's complexity (Zuur et al. 2009). The lower the AIC value, the better the model fit.

1.4 Results

Across the three field seasons 35 species were detected, including domesticated species and humans: 10 herbivores, 11 carnivores, 2 omnivores, 9 birds, as well as 3 categories of unknown small mammals, carnivores, and birds (Appendix 2). During Fall 2012, the number of independent observations of species used in statistical analyses ranged from 19-781 and those observations occurred across a range of 8-57 sites (Table 4, Appendix 3).

During Fall 2012, coyotes were detected at 36 camera sites (74 independent observations during the 1,670 trap nights) with the number of detections at each site ranging from 0-10. The distribution of coyotes was most accurately portrayed with a negative binomial generalized linear model. Coyote distribution and relative abundance was positively correlated with the relative abundances of Eastern gray squirrels (*Sciurus carolinensis*), wild turkeys (*Meleagris gallopavo*), Eastern cottontail rabbits (*Sylvilagus floridanus*), and unknown small mammals, and negatively correlated with Eastern chipmunks (*Tamias striatus*) and by the amount of altered habitat within a 500-m buffer of the camera site (Table 5). There was also a significant interaction effect between portion of study area (Northeast vs. Southwest) and distance to water; coyote distribution was affected by distance to water differently in the two sections of the study area (Table 5). Overall, coyote photo rates were not affected by the relative abundances of sympatric carnivores (red fox *Vulpes vulpes*, gray fox *Urocyon cinereoargenteus*, common raccoon *Procyon lotor*, and Virginia opossum *Didelphis virginiana*). In sum, the distribution of coyotes in the Pioneer Valley is affected by the relative abundance of their prey species and structural habitat variables, but not by the relative abundances of sympatric carnivore species.

Gray foxes were detected at 16 of the 79 camera sites with the number of detections at each site ranging from 0-15. Gray fox distribution was most accurately portrayed with a zero-inflated negative binomial model. A "best" model was identified, but it should be noted that there were two other comparable models that have similar weight to the best model in an AIC framework (Table 6). The three models are similar to the top model but they are less parsimonious, with added parameters. The less parsimonious models did not overcome the AIC penalty for the added parameters, and thus are lower ranked models in the AIC table (Table 6). In the negative binomial portion of the top model, gray fox relative abundance was positively correlated with distance to water ($p= 0.02$; Table 7). While not statistically significant ($p = 0.06$), the distribution of gray foxes was negatively correlated with distance to altered land use (Table 7). Additionally there was a significant relationship with study area in the negative binomial portion of the model (Table 7). In the binomial portion of the model, none of the covariates showed a significant relationship with the presence of gray foxes (Table 7), however, there were negative relationships with raccoons and gray squirrels and positive relationships with Eastern chipmunks and white-tailed deer. The information from the 2^{nd}

and 3rd ranked gray fox models is important to note (Tables 8 and 9). While the relationships were not statistically significant, there are negative relationships between gray foxes and both coyotes and common raccoons (Tables 8 and 9). In sum, gray fox distribution and relative abundance are most significantly affected by structural habitat variables like increasing distance to water and decreasing distance to altered land use, while being unaffected by relative abundances of prey species and sympatric carnivore species, except perhaps for coyotes.

Red Foxes were detected at 16 of the 79 camera sites with the number of detections at each site ranging from 0-6. Red fox distribution was most accurately portrayed with a zero-inflated Poisson model. In the Poisson portion of the model, the distribution and relative abundance of red fox were positively correlated with the relative abundance of domestic dogs (*Canis lupis familiaris*), distance to urban land use, the amount of water within a 500-m buffer of the camera site, and negatively correlated with the relative abundance of coyotes, white-tailed deer, and the distance to water (Table 10). There was also a significant interaction effect between portion of study area (Northeast vs. Southwest) and distance to water; red fox distribution was affected by distance to water differently in the two sections of our study area (Table 10). In the binomial portion of the model, none of the parameters were statistically significant. There was a negative relationship with the amount of traffic within a 500-m buffer of the camera site and a positive relationship with distance to roads. In sum, the distribution of red foxes is negatively affected by the relative abundance of coyotes and proximity to urban land use, positively impacted by the presence and amount of water across the landscape, and is not affected by the relative abundances of prey species or sympatric carnivore species other than coyotes.

1.5 Discussion

In support of my first hypothesis, which stated that each of the focal species' distributions would be based on landscape characteristics as well as prey and sympatric carnivore relative abundances, all three species distribution models included landscape variables, like percent "altered" or distance to water, as well as site variables, like relative abundances of Eastern gray squirrels or raccoons. My findings reinforce the notion that structural and vegetative habitat can be important influences on the distribution of carnivore species, but also confirms that carnivore habitat includes prey and sympatric species. Data regarding prey and sympatric species relative abundances are typically left out of distribution assessments for medium-large carnivores (e.g., Ordeñana et al. 2010, Gese et al. 2012, Dodge and Kashian 2013), often because obtaining this information can be difficult. In camera analyses of wildlife distributions, researchers should include data about all species that could be affecting the focal species distributions, prey species as well as competitors (Ngoprasert et al. 2012, Mondal et al. 2013, Bashir et al. 2014).

My second hypothesis, asserting that the focal species would generally use "altered" areas more frequently than "urban" or "natural" areas in conjunction with the intermediate disturbance hypothesis (Connell 1978), was not fully supported by the above modelling efforts. Coyotes had a significant negative relationship with the percent of altered land use within a 500-m radius of each camera site. Neither gray fox nor red fox had percent of altered land use left in the best models, meaning that the amount of altered land use around each camera site was not influential in the distribution of either species.

However, it should be noted that coyotes and gray foxes did have a negative relationship with distance to altered – as the distance to the nearest altered patch increased, the relative abundance of both species decreased. These relationships were not statistically significant at the α=0.05 level, with a p-value of 0.103 for coyotes and 0.063 for gray fox, but could be ecologically significant. These species have some affinity to the altered land use where they can utilize the available food resources but apparently the amount of altered land use is not influential to their distributions.

The results also refute my final hypothesis that the three canid species would show positive correlations to areas of increased human development. Overall, none of the species showed a positive correlation to the percent of altered or urban land use within 500-m of each camera site. In addition, red foxes showed a significant positive correlation with distance to urban land use types; as distance to the nearest urban patch increased the relative abundance of red fox also increased. My results are in contrast with information presented in Cove et al. (2012) and Kapfer and Kirk (2012), who concluded that all three species had positive relationships with increasing development, but are supported by conclusions of Gese et al. (2012), Randa and Yunger (2006), and Riley (2006). Gese et al. (2012) stated that coyotes preferred nonurban habitats which provide more area for resting, denning, and cover to avoid humans. Randa et al. (2006) indicated that both coyotes and red foxes were detected more often in areas with lower human abundances. Riley (2006) concluded that gray foxes in Golden Gate National Recreation Area and the surrounding urbanized area had core areas of their range within the park.

Coyotes are a highly adaptable predator in the Pioneer Valley, where they are the top predator. Their distribution seems affected mostly by prey distributions, unlike other parts of their range where they co-occur and are limited by larger competitors such as wolves (*Canis lupis*) and mountain lions (*Puma concolor*) (Berger et al 2008, Ripple et al. 2013, Boyd and O'Gara 1985, Koehler and Hornocker 1991). It seems that in the Pioneer Valley, prey availability drives their relative abundances and distributions more than vegetative or structural habitat. The smaller foxes occur within the same spatial extent as coyotes but their distributions and relative abundances seem negatively correlated with coyote abundance, consistent with previous studies (Voigt and Earle 1983, Harrison et al. 1989, Fedriani et al. 2000, Henke and Bryant 1999, Levi and Wilmers 2012). In the Pioneer Valley, gray and red fox distributions are limited by the level of development in the area as well as the relative abundance of coyotes, while not being influenced by the relative abundances of prey species.

Table 1. Percent of land use classification types (see Appendix 1) in northeast and southwest portions of the study area.

	Northeast	Southwest
Natural	92.8	53.2
Altered	3.2	25.8
Urban	3.3	19.4
Water	0.8	1.6

Table 2: Season and dates during which automatic cameras were deployed in the Pioneer Valley of Massachusetts.

Season	Dates
Fall 2011	9/22/11 - 11/29/11
Summer 2012	5/14/12 - 8/21/12
Fall 2012	9/18/12 - 11/8/12

Table 3: Description of independent variables.

Variable	**Description**
Station ID	Individual station identification number
Land Use	Natural, Altered, or Urban land use classification
Trap Night	Number of trap nights each camera was set
Study Area	Southwest or Northeast half of study area
Coyote	Count of independent observations of Coyotes
Domestic Dog	Count of independent observations of Domestic Dogs
Virginia Opossum	Count of independent observations of Virginia Opossums
Domestic Dog	Count of independent observations of Domestic Cats
Humans	Count of independent observations of Humans
Wild Turkey	Count of independent observations of Wild Turkeys
White-tailed Deer	Count of independent observations of White-tailed Deer
Common Raccoon	Count of independent observations of Common Raccoons
Gray Squirrel	Count of independent observations of Eastern Gray Squirrels
Cottontail Rabbit	Count of independent observations of Eastern Cottontails
Red Squirrel	Count of independent observations of Red Squirrels
Eastern Chipmunk	Count of independent observations of Eastern Chipmunks
Unknown Small Mammal	Count of independent observations of Unknown Small Mammal
Gray Fox	Count of independent observations of Gray Foxes
Red Fox	Count of independent observations of Red Foxes
CAPS Land Value	Classification of land use value
CAPS Veg Structure	Classification of vegetation from 0 (grassland) to 10 (closed canopy)
Distance.Natural	Distance in meters from each camera site to the nearest patch of Natural land use
Distance.Altered	Distance in meters from each camera site to the nearest patch of Altered land use
Distance.Urban	Distance in meters from each camera site to the nearest patch of Urban land use
Distance.Water	Distance in meters from each camera site to the nearest Water source
Distance.Road	Distance in meters from each camera site to the nearest Road
Natural.Avg	Average percentage of Natural land use within 500-m buffer of each camera site
Altered.Avg	Average percentage of Altered land use within 500-m buffer of each camera site
Urban.Avg	Average percentage of Urban land use within 500-m buffer of each camera site
Water.Avg	Average percentage of Water within 500-m buffer of each camera site

Traffic.Avg	Average percentage of Traffic within 500-m buffer of each camera site
Elevation	Average elevation in meters within 500-m buffer of each camera site
P/A Eastern Chipmunk	Presence /Absence of Eastern Chipmunks
P/A Domestic Dog	Presence /Absence of Domestic Dogs

Table 4: Species used in statistical analyses with number of independent observations in Fall 2012 across the specified number of camera sites.

Species	**Number of Observations**	**Number of Sites**
Carnivores		
Coyote	74	36
Gray Fox	74	16
Red Fox	33	16
Virginia Opossum	265	54
Common Raccoon	102	38
Domestic Dog	70	20
Domestic Cat	33	16
Herbivores		
Eastern Gray Squirrel	781	57
White-tailed Deer	107	44
Eastern Cottontail	65	20
Unknown Small Mammal	26	9
Northern Flying Squirrel	22	10
Eastern Chipmunk	19	8
Birds		
Wild Turkey	27	14
Omnivores		
Human	32	16

Table 5. Summary of best model (negative binomial generalized linear model) for coyote distribution.

Covariate	**Estimate**	**Standard Error**	**P-value**	**Significance level**
Intercept	-21.26	0.413	< 0.001	***
Altered.Avg	-3.872	1.392	0.005	**
Distance.Natural	-0.029	0.018	0.112	
Distance.Altered	$-4.469e^{-4}$	$2.744e^{-4}$	0.103	
Study Area	-0.076	0.474	0.872	
Distance.Water	$5.136e^{-4}$	$2.259e^{-4}$	0.023	*
Distance.Water^2	$-1.389e^{-7}$	$3.775e^{-8}$	<0.001	***
Gray Squirrel	0.030	0.013	0.019	*
Cottontail Rabbit	0.224	0.092	0.015	*
Wild Turkey	0.362	0.156	0.020	*
Eastern Chipmunk	-1.138	0.370	0.002	**
Unknown Small Mammal	0.448	0.142	0.002	**
Study Area:Distance.Water	$-7.756e^{-4}$	$3.870e^{-4}$	0.045	*

Table 6. AIC table for top 3 gray fox (GF) models (zero-inflated negative binomial).

Model ID	AIC Value	Degrees of Freedom	Difference in AIC Value	Weight
GF1	150.2	10	0.0	0.14966
GF2	150.4	13	0.2	0.13491
GF3	150.5	12	0.3	0.12920

Table 7. Summary of best gray fox model (zero-inflated negative binomial).

	Estimate	**Standard Error**	**P-Value**	**Significance**
Negative Binomial Covariate				
(Intercept)	-22.1	1.16	< 0.001	***
Study Area	2.26	1.08	0.037	*
Distance.Water	$3.38e^{-4}$	$1.47e^{-4}$	0.021	*
Distance.Altered	-0.003	0.001	0.063	.
Log(theta)	-1.41	0.34	$3.52e^{-5}$	***
Zero-Inflation Covariate				
(Intercept)	-9.145	36.745	0.803	
White-tailed Deer	21.451	55.584	0.7	
Common Raccoon	-13.709	37.956	0.718	
Gray Squirrel	-5.99	15.085	0.691	
P/A Eastern Chipmunk	148.674	358.313	0.678	

Table 8. Summary of 2nd ranked gray fox model (zero-inflated negative binomial).

	Estimate	**Standard Error**	**P-Value**	**Significance**
Negative Binomial Covariate				
(Intercept)	-21.4	1.23	<0.001	***
Study Area	2.35	1.08	0.029	*
Distance.Water	$3.50e^{-4}$	$1.45e^{-4}$	0.015	*
Distance.Altered	-0.003	0.001	0.061	.
Common Raccoon	-0.182	0.124	0.141	
Coyote	-0.388	0.249	0.119	
Log(theta)	-1.19	0.346	<0.001	***
Zero-Inflation Covariate				
(Intercept)	17.24	59.63	0.773	
White-tailed Deer	60.24	76.84	0.433	
Common Raccoon	-41.45	62.1	0.505	
Gray Squirrel	-16.55	20.95	0.43	
P/A Eastern Chipmunk	398.7	494.62	0.42	
P/A Domestic Dog	35.82	77.52	0.644	

Table 9. Summary of 3rd ranked gray fox model (zero-inflated negative binomial).

	Estimate	**Standard Error**	**P-Value**	**Significance**
Negative Binomial Covariate				
(Intercept)	-21.4	1.32	< 0.001	***
Study Area	2.47	1.16	0.034	*
Distance.Water	$3.91e^{-4}$	$1.47e^{-4}$	0.008	**
Distance.Altered	-0.003	0.002	0.029	*
Common Raccoon	-0.172	0.134	0.198	
Coyote	-0.432	0.259	0.094	.
Log(theta)	-1.24	0.348	<0.001	***
Zero-Inflation Covariate				
(Intercept)	-13.196	16.777	0.432	
White-tailed Deer	14.205	31.5	0.652	
Common Raccoon	-9.217	18.508	0.619	
Gray Squirrel	-4.023	8.397	0.632	
P/A Eastern Chipmunk	101.564	203.508	0.618	

Table 10. Summary of best red fox distribution model (zero-inflated Poisson).

	Estimate	**Standard Error**	**P-Value**	**Significance**
Poisson Covariates				
Intercept	-24	1.21	<0.001	***
Study Area	2.443	1.10	0.027	*
Distance.Water	$-7.69e^{-4}$	$7.09e^{-5}$	<0.001	***
Distance.Urban	0.002	$5.07e^{-4}$	0.001	***
Coyote	-0.372	0.197	0.059	.
Domestic Dog	0.032	0.119	0.007	**
Water.Avg	14.64	3.45	<0.001	***
White-tailed Deer	-1.899	0.642	0.003	**
Study Area:Distance.Water	0.002	$2.02e^{-4}$	<0.001	***
Zero-Inflation Covariate				
Intercept	-24.225	1.438	<0.0001	***
Distance.Road	0.005	0.004	0.148	
$Traffic.Avg^2$	-24.323	16.980	0.152	
$Traffic.Avg^2$	-31.503	19.360	0.104	

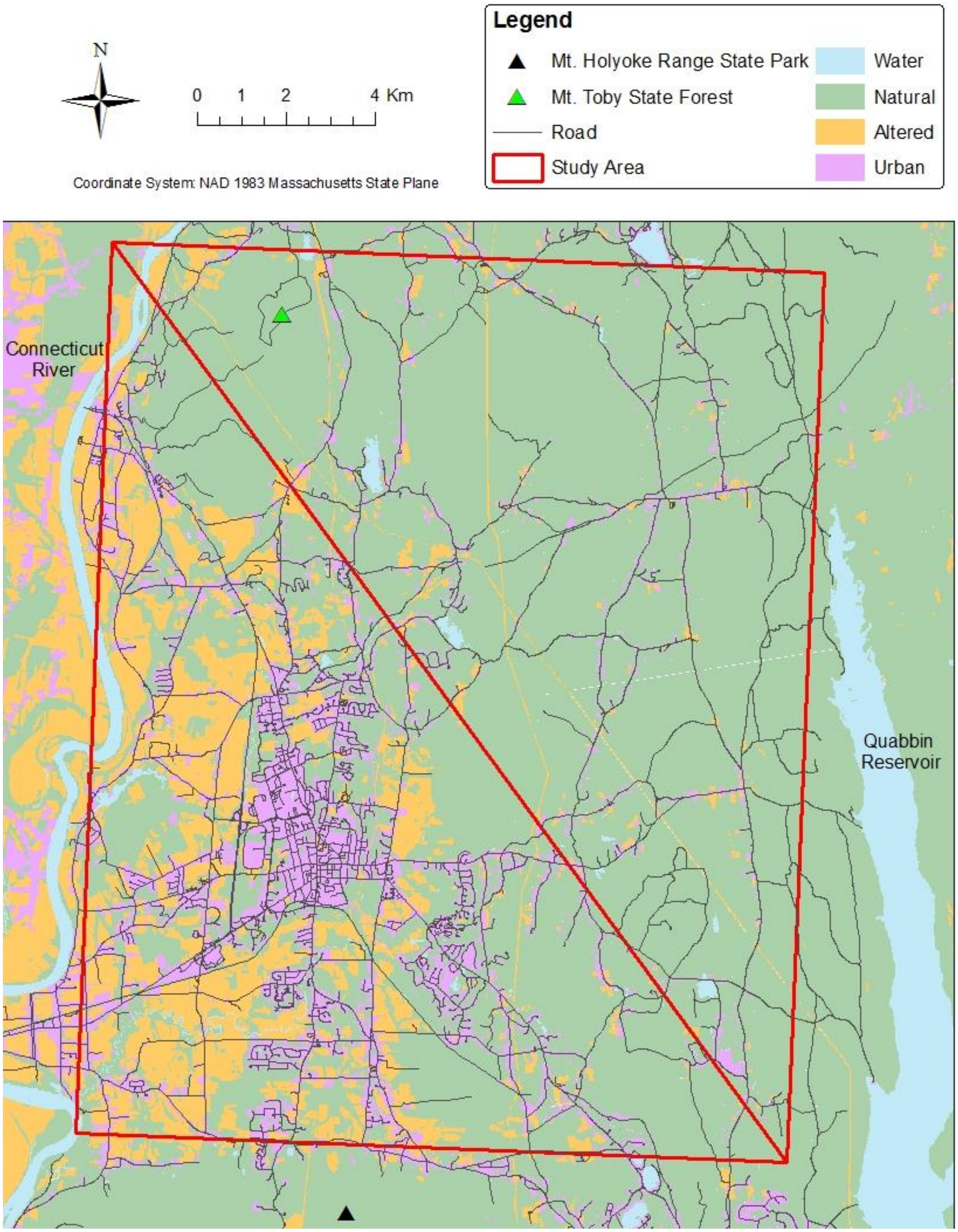

Figure 1. Map of the study area used to investigate the distribution of wild canids in the Pioneer Valley of western Massachusetts during 2011-2012.

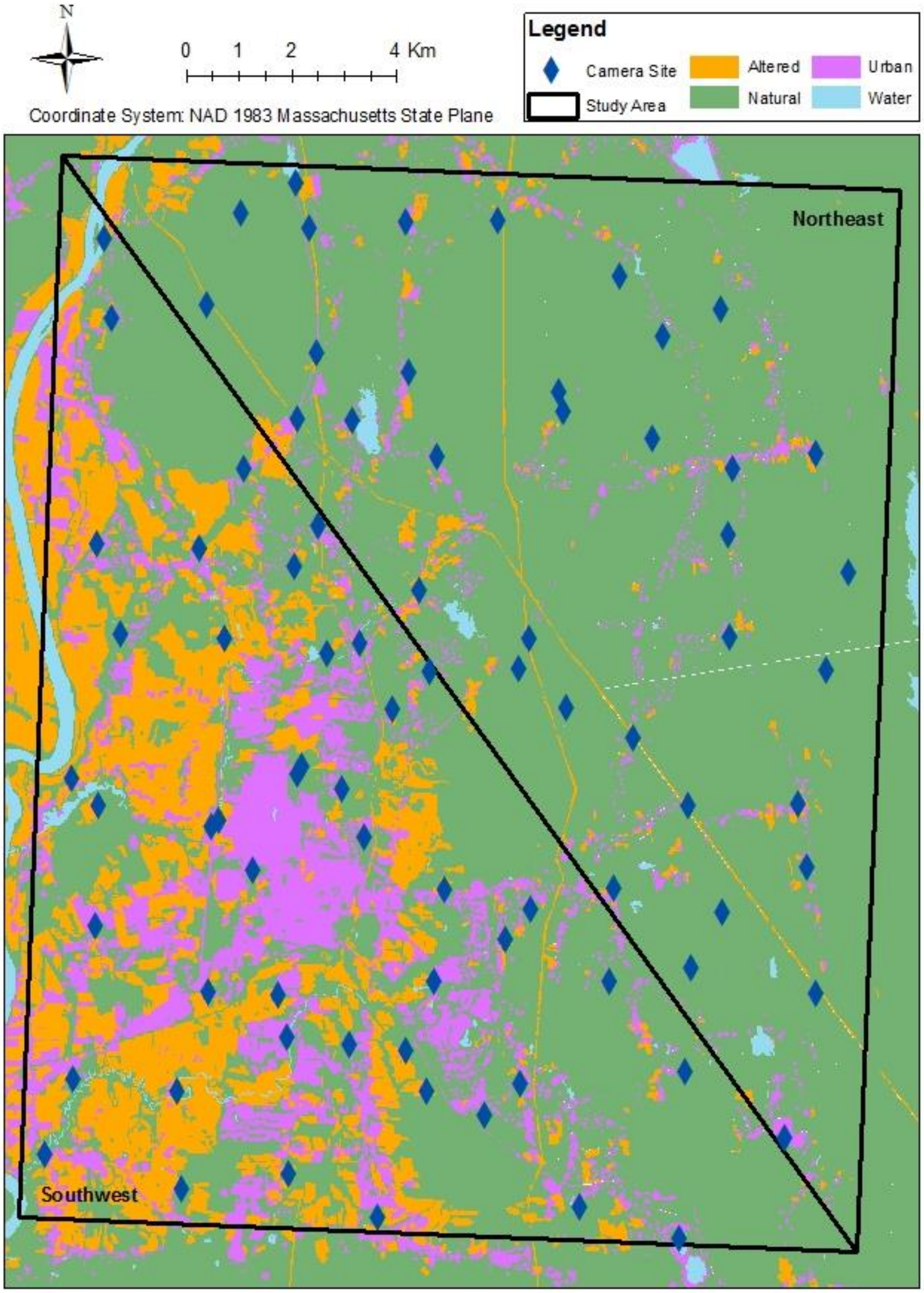

Figure 2. Camera locations during Fall 2012 used to assess the distribution of wild canids in the Pioneer Valley of western Massachusetts.

APPENDIX 1

LAND USE CATEGORIES (CF. ORDEÑANA ET AL. 2010) SYNTESIZED FROM MASS GIS OLIVER WEBSITE LAND USE 2005 DATA LAYER CATEGORIES

Natural

Brushland/Successional: Predominantly (> 25%) shrub cover, and some immature trees not large or dense enough to be classified as forest. It also includes areas that are more permanently shrubby, such as heath areas, wild blueberries or mountain laurel.

Forest: Areas where tree canopy covers at least 50% of the land. Both coniferous and deciduous forests belong to this class.

Forested wetland: Wooded swamp with deciduous, coniferous, or mixed forest.

Non-forested wetland: permanently wet area without forest cover, e.g., bog, deep marsh, shallow marsh, wet meadow, fen, and shrub swamp.

Altered

Cemetery: includes the gravestones, monuments, parking lots, road networks and associated buildings.

Cropland: Generally tilled land used to grow row crops. Boundaries follow the shape of the fields and include associated buildings (e.g., barns). This category also includes turf farms that grow sod.

Golf course: Includes the greenways, sand traps, water bodies within the course, associated buildings and parking lots. Large forest patches within the course greater than 1 acre are classified as Forest (Natural). Does not include driving ranges or miniature golf courses.

Mining: Includes sand and gravel pits, mines and quarries. The boundaries extend to the edges of the site's activities, including on-site machinery, parking lots, roads and buildings.

Open land: Vacant land, idle agriculture, rock outcrops, and barren areas. Vacant land is not maintained for any evident purpose and it does not support large plant growth.

Participation recreation: Facilities used by the public for active recreation. Includes ball fields, tennis courts, basketball courts, athletic tracks, ski areas, playgrounds, and bike paths plus associated parking lots. Primary and secondary school recreational facilities are in this category, but university stadiums and arenas are considered Spectator Recreation. Recreation facilities not open to the public such as those belonging to private residences are mostly labeled with the associated residential land use class not participation recreation. However, some private facilities may also be mapped.

Pasture: Fields and associated facilities (barns and other outbuildings) used for animal grazing and for the growing of grasses for hay.

Powerline/Utility: Powerline and other maintained public utility corridors and associated facilities, including power plants and their parking areas.

Transitional: Open areas in the process of being developed from one land use to another (if the future land use is at all uncertain).

Urban

Multi-family residential: Duplexes (usually with two front doors, two entrance pathways, and sometimes two driveways), apartment buildings, condominium complexes, including buildings and maintained lawns.

High density residential: Housing on smaller than 1/4 acre lots. See notes below for details on Residential interpretation.

Medium density residential: Housing on 1/4 - 1/2 acre lots. See notes below for details on Residential interpretation.

Low density residential: Housing on 1/2 - 1 acre lots. See notes below for details on Residential interpretation.

Very low density residential: Housing on > 1 acre lots and very remote, rural housing.

Commercial: Malls, shopping centers and larger strip commercial areas, plus neighborhood stores and medical offices (not hospitals). Lawn and garden centers that do not produce or grow the product are also considered commercial.

Industrial: Light and heavy industry, including buildings, equipment and parking areas.

Urban public/institutional: Lands comprising schools, churches, colleges, hospitals, museums, prisons, town halls or court houses, police and fire stations, including parking lots, dormitories, and university housing. Also may include public open green spaces like town commons.

Transportation: Airports (including landing strips, hangars, parking areas and related facilities), railroads and rail stations, and divided highways (related facilities would include rest areas, highway maintenance areas, storage areas, and on/off ramps). Also includes docks, warehouses, and related land-based storage facilities, and terminal freight and storage facilities. Roads and bridges less than

200 feet in width that are the center of two differing land use classes will have the land use classes meet at the center line of the road (i.e., these roads/bridges themselves will not be separated into this class).

Marina: Including parking lots and associated facilities

Nursery: Greenhouses and associated buildings as well as any surrounding maintained lawn. Christmas tree (small conifer) farms are also classified as Nurseries.

Waste disposal: Landfills, dumps, and water and sewage treatment facilities such as pump houses, and associated parking lots. Capped landfills that have been converted to other uses are coded with their present land use.

Junkyard: Includes the storage of car, metal, machinery and other debris as well as associated buildings as a business.

Spectator recreation: University and professional stadiums designed for spectators as well as zoos, amusement parks, drive-in theaters, fairgrounds, race tracks and associated facilities and parking lots.

Water-based recreation: Swimming pools, water parks, developed freshwater and saltwater sandy beach areas and associated parking lots. Also included are scenic areas overlooking lakes or other water bodies, which may or may not include access to the water (such as a boat launch). Water-based recreation facilities related to universities are in this class. Private pools owned by individual residences are usually included in the Residential category. Marinas are separated into code 29.

APPENDIX 2

SPECIES DETECTED OVER THE THREE FIELD SEASONS

Common Name	Scientific Name	Species Code
Herbivores		
Moose	*Alces alces*	ALAL
White-tailed deer	*Odocoileus virginianus*	ODVI
Northern Flying Squirrel	*Glaucomys sabrinus*	GLSA
Eastern Gray Squirrel	*Sciurus carolinensis*	SCCA
Eastern Cottontail Rabbit	*Sylvilagus floridanus*	SYFL
American Red Squirrel	*Tamiasciurus hudsonicus*	TAHU
Eastern Chipmunk	*Tamias striatus*	TAST
Groundhog	*Marmota monax*	MAMO
Unknown Small Mammal	-	UNSM
Porcupine	*Erethizon dorsatum*	ERDO
Domestic Horse	*Equus ferus caballus*	EQFECA
Carnivores		
Coyote	*Canis latrans*	CALA
Domestic Dog	*Canis lupus familiaris*	CALUFA
Gray Fox	*Urocyon cinereoargenteus*	URCI
Red Fox	*Vulpes vulpes*	VUVU
Bobcat	*Lynx rufus*	LYRU
Common Raccoon	*Procyon lotor*	PRLO
Virginia Opossum	*Didelphis virginiana*	DIVI
Domestic Cat	*Felis catus*	FECA
Striped Skunk	*Mephitis mephitis*	MEME
Short-tailed Weasel	*Mustela ermine*	MUER
Fisher	*Martes pennanti*	MAPE
Unknown Carnivore	-	UNCA
Omnivores		
Black Bear	*Ursus americanus*	URAM
Human	*Homo sapiens*	HOSA
Birds		
Blue Jay	*Cyanocitta cristata*	CYCR
American Robin	*Turdus migratorius*	TUMI
Great Blue Heron	*Ardea herodias*	ARHE
Ruffed Grouse	Bonasa umbellus	BOUM
Northern Cardinal	*Cardinalis cardinalis*	CACA
Mourning Dove	*Zenaida macroura*	ZEMA
Wild Turkey	*Meleagris gallopavo*	MEGA

American Woodcock	*Scolopax minor*	SCMI
American Crow	*Corvus brachyrhynchos*	COBR
Unknown Bird	-	UNBI

APPENDIX 3

NUMBER OF INDEPENDENT OBSERVATIONS FOR ALL SPECIES ACROSS SEASONS

		Season		
		Fall 2011	Summer 2012	Fall 2012
	No. of Cameras	34	28	79
Species	No. of Trap Nights	780	1,650	1,670
Herbivores				
Moose		3	8	2
White-tailed deer		50	155	107
Northern flying squirrel		14	2	1
Eastern gray squirrel		457	932	781
Eastern cottontail rabbit		41	26	65
American red squirrel		31	41	22
Eastern chipmunk		137	304	19
Groundhog		2	2	3
Unknown small mammal		39	52	26
Porcupine		3	12	4
Domestic horse		0	7	0
Carnivores				
Coyote		36	37	74
Gray fox		47	32	74
Red Fox		47	11	33
Domestic dog		49	35	70
Bobcat		11	8	6
Domestic cat		21	71	33
Common raccoon		87	159	102

Virginia opossum	155	201	265
Striped skunk	7	18	16
Short-tailed weasel	1	4	3
Fisher	6	7	14
Unknown carnivore	2	3	3
Omnivores			
Black bear	0	5	5
Humans	27	55	32
Birds			
Blue jay	7	1	4
American robin	18	15	7
Great blue heron	0	0	4
Ruffed grouse	0	2	3
Northern cardinal	2	0	3
Mourning dove	2	9	0
Wild turkey	15	17	27
American woodcock	2	1	0
American crow	0	10	0
Unknown bird	3	32	7

APPENDIX 4

PHOTO CAPTURE RATES (PER 100 TRAP NIGHTS, ROUNDED TO NEAREST WHOLE PHOTO) FOR ALL SPECIES OBSERVED ACROSS ALL SEASONS

		Season		
		Fall 2011	Summer 2012	Fall 2012
Herbivores				
	Moose	0	0	0
	White-tailed deer	6	9	6
	Northern flying squirrel	2	0	0
	Eastern gray squirrel	59	56	47
	Eastern cottontail rabbit	5	2	4
	American red squirrel	4	2	1
	Eastern chipmunk	18	18	1
	Groundhog	0	0	0
	Unknown small mammal	5	3	2
	Porcupine	0	1	0
	Domestic horse	0	0	0
Carnivores				
	Coyote	5	2	4
	Gray fox	6	2	4
	Red Fox	6	1	2
	Domestic dog	6	2	4
	Bobcat	1	0	0
	Domestic cat	3	4	2
	Common raccoon	11	10	6
	Virginia opossum	20	12	16
	Striped skunk	1	1	1
	Short-tailed weasel	0	0	0

	Fisher	1	0	1
	Unknown carnivore	0	0	0
Omnivores				
	Black bear	0	0	0
	Humans	3	3	2
Birds				
	Blue jay	1	0	0
	American robin	2	1	0
	Great blue heron	0	0	0
	Ruffed grouse	0	0	0
	Northern cardinal	0	0	0
	Mourning dove	0	1	0
	Wild turkey	2	1	2
	American woodcock	0	0	0
	American crow	0	1	0
	Unknown bird	0	2	0

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