RESOURCE PARTITIONING OF SYMPATRIC CARNIVORES IN WESTERN NORTH CAROLINA

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By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

RESOURCE PARTITIONING OF SYMPATRIC CARNIVORES IN WESTERN NORTH CAROLINA

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Four species of sympatric mesocarnivores occur in western North Carolina, coyote (*Canis latrans*), bobcat (*Lynx rufus*), gray fox (*Urocyon cinereoargenteus*), and red fox (*Vulpes vulpes*). The coyote has been known to suppress the population of smaller carnivores in the area, which can lead to a shift in the overall ecosystem through interspecific competition. My goal was to perform a preliminary study examining the diet and geospatial use of these four species to better understand their interactions. To examine diet, scat samples were collected in and around Cullowhee, NC. The outside was swabbed for DNA identification of the carnivore and the rest of the sample was taken back to the lab. Each sample was weighed, and a subsample was washed through a set of sieves. The contents were visually examined and classified as mammal, vegetation, insect, bird, or anthropogenic item. To examine geospatial use, foot traps were set in the summer of 2019 and fall of 2020. Seven individuals were fitted with GPS collars to record their movements in and around Cullowhee. I assessed their movements in program R using the resource selection functions (package: lme4) with generalized linear models based on distances to habitat and landscape characteristics. Of 103 scat samples, 31 were identified with the DNA analysis. 24 were identified as bobcat, 4 coyote, 2 red fox, and 1 gray fox. All species contained at least trace amounts of mammal, though canids were more likely to include other food sources

as well. Vegetation was found in samples from both foxes and coyotes. One red fox sample was composed primarily of insects and the gray fox sample was the only one to contain bird feathers. Two bobcats, two coyotes, two red foxes, and one gray fox were GPS-collared during the study. For both bobcats, one red fox and the gray fox the Tuckasegee River acted as a barrier within their home range. The gray fox was the only individual to consistently use powerline corridors for travel. All carnivores selected for early successional land. Coyotes stayed in the less densely populated areas, while the other species were closer to areas with higher human densities. The overlapping home ranges of bobcats and foxes indicate competition with and an avoidance of coyotes.

CHAPTER ONE: INTRODUCTION

Carnivore species will often rely on similar resources when living in the same habitat (Breuer, 2005; Wang & Fuller, 2003) which can lead to an increase in competition (Prugh & Sivy, 2020; Ripple et al., 2014). Competition between carnivores can happen in different ways: through exploitative competition, interference competition, or both (R. Harrison, 1997; Litvaitis & Harrison, 1989). In exploitative competition, individuals compete indirectly for the same resource. One form of exploitative competition is when individuals utilize different habitats to reduce competition. The lesser white-toothed shrew (*Crocidura suaveolens*) and greater white-toothed shrew (*Crocidura russula*) are reported to coexist by utilizing different habitats in Iberia (Biedma et al., 2020). In other areas different species may consume different prey species. The African lion (*Panthera leo*) and leopard (*Panthera pardus*) live in very similar habitats but the leopard is known to consume prey of a smaller body size than the lion (du Preez et al., 2017). Carnivores may also utilize different times of the day depending on the other carnivores present. In Mexico the gray fox (*Urocyon cinereoargenteus*) and the white-nosed coati (*Nasua narica*) had similar habitat use and different temporal activity (Gomez-Ortiz et al., 2019). Interference competition can be aggressive with individuals fighting each other for territory or survival. Evidence for this has been seen in Australia where red fox (*Vulpes vulpes*) remains were found in dingo (*Canis lupus dingo*) scat (Cupples et al., 2011).

Human disturbance can have many different effects on niche partitioning among carnivores, but those effects are largely dependent on the landscape itself (Seveque et al., 2020). Many carnivores need large stretches of intact natural landscape without much human interference (Gilroy et al., 2015), while some, such as the red fox and coyote (*Canis latrans*) are able to live in both urban and rural areas (Morey et al., 2007; Stark et al., 2019). Bobcats (*Lynx* *rufus*) tend to show a preference for a more rural habitat and a much greater avoidance of human activity (Stark et al., 2019) though they can tolerate intermediate levels of urbanization (Riley et al., 2003).

Coyotes are a relatively new arrival to much of the eastern U.S. They are native to the western portion of the country, but with the extirpation of gray wolves (*Canis lupus*) they have expanded their range to cover most of the continent. With the influx of coyotes into new areas, some of the habitat preferences and niche partitioning among subordinate carnivores can change to accommodate the new competition (Major & Sherburne, 1987). By invading the territory of already established mesocarnivores, coyotes can increase the competition between carnivore species with similar habitat and dietary needs (D. J. Harrison et al., 1989; Levi et al., 2012). This is documented throughout North America for the red and gray fox both in the west (Fedriani et al., 2000) and in the east (Rich et al., 2018). Other canid species, such as the kit fox (*Vulpes macrotis*) in Arizona did not avoid coyote territory possibly due to prey specialization and multiple tunnels for escape routes (White et al. 1994). Canids do not seem to show as much direct aggression towards felids (Prugh & Sivy, 2020) but may indirectly affect their population through exploitative competition (Litvaitis & Harrison, 1989).

In western North Carolina (hereafter, NC) there are four species of mesocarnivores, bobcat, coyote, gray fox, and red fox. For many carnivores their diet is known to change seasonally depending on the available prey and vegetation (Andelt et al., 1987; Diaz-Ruiz et al., 2013; Fritts & Sealander, 1978; Swingen et al., 2015; Witmer & DeCalesta, 1986). Diet may also change spatially depending on the amount of human interference (Dumond et al., 2001). All felids (i.e. bobcat) are considered specialized carnivores whose main food source in many areas is lagomorphs with ungulates becoming more common during the winter (Fritts & Sealander, 1978; Litvaitis et al., 1984). Most canids (i.e. coyote and fox) are omnivores, consuming meat along with other food types such as insects or berries (Etheredge et al., 2015; Soe et al., 2017; Swingen et al., 2015). Coyotes are known to consume meat or vegetation depending on what is available (Andelt et al., 1987; Witmer & DeCalesta, 1986), and have also been known to consume garbage in urban areas during the winter (Morey et al., 2007). Foxes tend to avoid coyote territories (Fedriani et al., 2000) but also partition food resources between themselves. Red fox were found to have consumed more mammals and gray fox consumed more vegetation during the fall and winter months in Maryland (Hockman & Chapman, 1983).

In general, felids are known to be more solitary than canids except for mating season (Kleiman & Eisenberg, 1973). Bobcats are the largest wild felid in western NC. Male bobcats tend to have a larger home range than females (Fuller et al., 1985; Kitchings & Story, 1984) and both sexes have a larger home range size in the summer as opposed to winter (Koehler & Hornocker, 1989). Coyotes are the only canids known to form packs in western NC while both species of fox are usually solitary or live in pairs (Kleiman & Eisenberg, 1973). Some coyotes will change their home range size or status seasonally (Sasmal et al., 2019). They are also known to change their temporal movements in relation to human activity and disturbance (Kitchen et al., 2000). Much of this information and the dynamics between these species is unknown for parts of the east coast, including western NC.

Analyzing scat samples is a common method of assessing species diet in carnivores (Ciucci et al., 1996). as it is noninvasive and large samples can be collected quickly. (Harvey, 1989). To gain a better understanding of carnivore ecology and interactions in western NC we assessed the diet and space use of the four species of mesocarnivores (bobcat, coyote, gray fox, and red fox). For this study we hypothesized that (I) All species will have a similar diet containing mostly mammals, though both species of fox will have more vegetation than bobcats and coyotes. (II) Both species of fox will not be found near coyotes, but bobcats and coyotes may share closer home ranges.

CHAPTER TWO: METHODS

Study Area

The study area for this research was western NC with research efforts centered within Jackson County in and around Cullowhee. The average annual rainfall is 1,432.81mm (56.41in) with steady precipitation throughout the year. Annual minimum and maximum temperatures can range from -12.78ºC (9ºF) to 32.78ºC (91ºF). The average annual minimum temperature is 1.83ºC (35.3ºF) and the average annual maximum temperature is 21.94ºC (71.5ºF) (National Weather Service, 2022). Scat collection and capture efforts were made at three locations within Jackson County (Figure 1). The first location, Balsam Mountain Preserve (BMP) is a 4,400-acre low-density residential area off Hwy 74. The southern edge of the property borders the Nantahala National Forest, and the preserve includes a golf course as well as many hiking and horseback riding trails, riding stables, and fields. The road corridors and golf course borders provided early successional forests along the borders. The land is dominated by hardwood forests, including trees such as tulip poplar (*Liriodendron tulipifera*), oaks (*Quercus spp.)*, maples (*Acer spp.*) and pines (*Pinus spp.*). The elevation of the site ranges from 998.22 – 1,427 m (3,275 - 4,681ft).

The other two trapping locations were in a more densely populated urban area in Cullowhee, Jackson County, NC. Cullowhee has a population density of 1,777 people per mi^2 (U.S. Census Bureau, 2021) and includes a range of habitats. including the urban campus of Western Carolina University (WCU), urban residential homes and forested hiking trails. One trapping location was in the valley to target fox populations and the other on the adjacent ridge. A four-lane highway (Hwy 107) runs through the eastern portion of the study area and the Tuckasegee river borders the northern edge. Human residences dominate most of the land use within the study area, with the university campus being the most densely populated. The forested portions include trees such as tulip poplar, oaks, and maples with elevation ranges from 630 – 849 m (2,066 to 2,785ft). Along the higher elevations many shrubs such as Rhododendron (*Rhododendron spp.*) and mountain laurel (*Kalmia latifolia*) are also present.

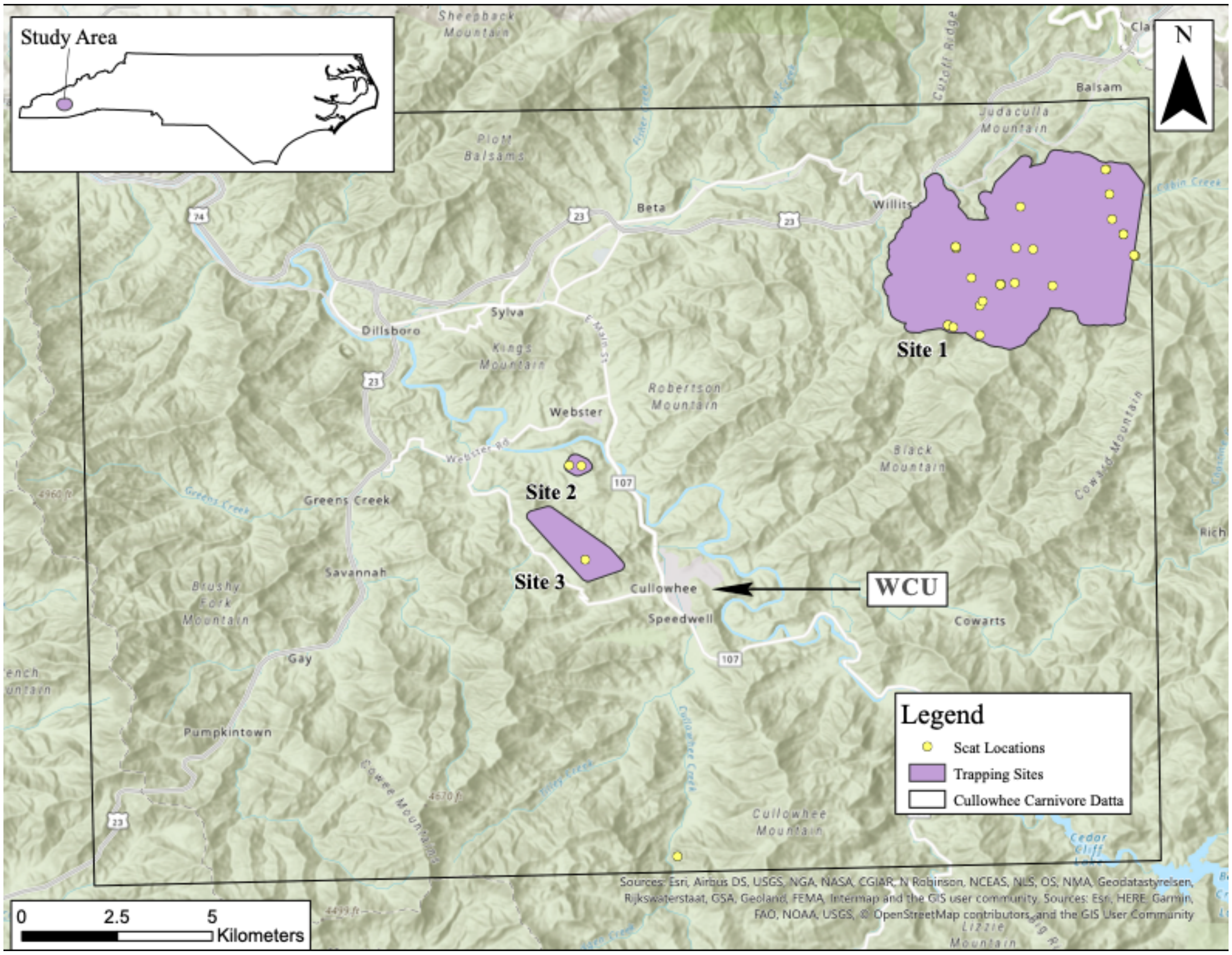

Figure 1. Locations of study area, trapping sites, and scat locations in western North Carolina in relation to Western Carolina University (WCU)

Diet Analysis

Scat was collected weekly within the study area from 2019-2021. Most of the samples were collected from September to January as dense vegetation and time constraints decreased the number of samples found during the spring and summer. Samples were collected at BMP by walking game and hiking trails. Few signs of red and gray fox were found at BMP so additional trails were walked in more urban areas around Cullowhee during 2020 and 2021 (Figure 1).

Samples were identified in the field based on the morphological characteristics of length, scent, and the general shape of the sample, such as twisted cords and tapered versus blunt ends (Elbroch, 2003; Halfpenny, 1986; Prugh & Ritland, 2005; Reed et al., 2004). The outside of each sample was also swabbed for epithelial cells that could later be used for DNA confirmation of the carnivore species as recommended by Morin et al. (2016). A 2.5cm portion was preserved in 70% ethanol for disease analysis and the GPS location of each sample was recorded. The rest of the sample was placed in a Ziplock bag and placed in a small cooler for transport. Within 24 hours each sample was taken back to the lab and stored in a freezer for later processing.

To prepare for processing each sample was removed from the freezer and a wet weight was taken. The bag was opened, and samples were dried in a Fisher Scientific drying oven overnight at 40ºC. Once ready to process, a dry weight was recorded and if the sample was longer than 5cm a portion of the end and middle was used as a subsample equal to 5cm. This method allows for less processing time and does not significantly decrease the accuracy of the analysis (Di Domenico et al., 2012). The weight of the subsample was recorded and it was then washed through a set of four sieves (Rühe et al., 2008). The sample was then placed in an oven at 40ºC overnight to dry. The next day the contents of each sample were examined under a microscope to be visually identified and sorted as one of five categories: mammal, vegetation, insect, bird, or anthropogenic item. Once sorted the contents were weighed by category to determine the percentage of each sample they represented.

DNA analysis was performed by a collaborator to confirm the carnivore species of each sample (Priest et al, 2023). The Qiagen-EZQ DNA Investigator kit was used to extract DNA from the swabs collected in the field. Mitochondrial DNA was amplified using PCR with carnivore-specific primers and verified using electrophoresis on an Agilent Bioanalyzer. Samples that were successfully amplified were cleaned and the sequences were run on ABISeqStudio and searched against GenBank database using BLAST. Any samples from the DNA analysis that could not be matched to a physical sample due to mislabeling or could not be confidently identified were removed from the final analysis.

For each prey item identified, the frequency of occurrence (FO) (Breuer, 2005) and the fecal volume (FV) were calculated for each carnivore species. FO measures the percentage of scat samples that contain a given prey item and was calculated as

$$FO_i\ (\%) = (n_i/N) * 100,$$

where n_i is the number of samples containing prey item *i* and *N* is the total number of scat samples for that species. Trace amounts of food items were not included in the FO but were mentioned in the results to document rare occurrences found in samples (Breuer, 2005; Klare et al., 2011). The raw frequencies of the FO data were also used to test for differences in diet composition between species using a Fisher's exact test (Andres & Tejedor, 1997). FV measures percent volume of each prey item found in the scat samples for each species and was calculated as

$$FV_i\ (\%) = (m_i/M) * 100,$$

Where m_i represents the weight of a food item *i* for a particular species and *M* is the total weight of all scat sample from that species. If a prey item represented ≤ 1% of a scat sample, it was considered a trace item and was excluded from further FV analyses (Ciucci et al., 1996; Klare et al., 2011; Ward et al., 2018).

Space Use

We captured individuals with #1.5 Oneida Victor soft catch and #1.75 Oneida Victor laminated offset modified traps. Traps were set at three locations in Jackson County during 2019 and 2020. During each trapping session 21 - 53 foothold traps were set per location. Traps were checked twice daily in 2019 and every morning in 2020 due to a lack of daytime captures. Captured individuals were fitted with a Lotek LiteTrack 120 (gray fox, red fox) or 330 (bobcat, coyote) Iridium collar with proximity and VHF capabilities. The collars recorded locations every hour for five days surrounding each moon phase (new, first quarter, full, last quarter) from the time of capture to the time of mortality or battery death of the collar. If a mortality signal was received or if new locations were not being uploaded, VHF tracking was used to determine the location of the collar and check if the individual was still active.

Collars were field tested prior to deployment to ensure locations were accurate to within 10 meters. Based on testing data all GPS locations with a position dilution of precision (PDOP) > 3.5 (Visscher, 2006) were removed from the analysis. Location data were analyzed using the resource selection function (RSF) under a use versus available design (Hillard et al., 2021; Manly et al., 2002). Generalized linear models (package: lme4) were created based on location and distances to landscape features. This allowed for the comparison of the used and available locations using a logistic regression framework with a binary response (1 = use, 0 = available) to represent carnivore locations. Seasonal GPS locations from each carnivore were defined as used locations for analysis. Random locations were generated in a 15 km buffer surrounding all carnivore locations using package terra in R (R Core Team, 2020) and defined as available locations throughout the study site.

Pairwise correlations between landscape cover variables were calculated at the second-order selection of home range selection within study site (Johnson, 1980). To test for high correlation between landscape variables Pearson Correlation Coefficients (PCC) were tested in R (packages: corrplot and Hmisc) for . For pairs of highly correlated ($|r| \geq 0.7$, $P<0.01$) variables, the variable that provided the simplest biological explanation was retained for further analysis (Dormann et al., 2013). Fourteen landscape features were examined including nine land cover types (water, HDL (Human Density Low, combined open space and low intensity development), HDH (Human Density High, combined medium intensity and high intensity development), deciduous forest, mixed forest (combined mixed and pine forest), shrubland, grassland/herbaceous, agriculture, and wetland) from National Land Cover Data (NLCD, Homer et al., 2015). In addition to the land cover classes the variables slope, aspect, elevation, secondary roads, and primary roads were also examined. All distances (km) and further GIS operations were conducted in R (R Core Team, 2020). The mean distance (km) from used and available locations to the nearest patch of each cover type was calculated using program R (package: amt) (Benson, 2012). Under the null hypotheses of no selection the distances to available locations were deemed expected and the mean distances from animal locations to each cover type were considered the estimate of habitat selection (Connor et al., 2003).

The home range for each individual was calculated using kernel density estimators (KDE) in program R (R Core Team, 2020) (package: amt, adeHabitat). To explain variation in carnivore habitat selection, models were developed using all combinations of covariates at the second-order and third-order scales. The difference in Akaike's Information Criterion (ΔAIC) values was used to rank candidate models (Burnham & Anderson, 2002). Studies have demonstrated differences in seasonal habitat use among mesocarnivore species (Andelt et al., 1987; Dumond et al., 2001; Koehler & Hornocker, 1989; Sasmal et al., 2019), which along with the small sample size, led to modelling each collared individuals separately in the analysis.

CHAPTER THREE: RESULTS

Diet

A total of 103 scat samples were collected, of which nine were collected outside of the study area in a neighboring county and removed from the analysis. Out of the 94 samples within the study area, 38 were identified in the field as bobcat, 40 as coyote, and 16 as fox. The DNA analysis confirmed the identity of 38 samples (Priest et al 2023) of which 31 were matched with processed scat samples and were retained for further analysis. The remaining seven samples were unable to be matched due to missing labels and were removed from the study. 24 of those samples were identified as bobcat, four as coyote, two as red fox, and one as gray fox.

All but one of the 31 samples confirmed with DNA were collected in the fall or winter months with one bobcat sample collected in the summer. Other food items of note were found in samples whose species could not be confirmed with DNA and so were not included in the analysis. Those items included hooves or bones from larger mammals and seeds from pokeweed (*Phytolacca decandra*). A significant difference was found between the diets of the carnivore species ($P = 0.02$, Fisher's exact test).

Bobcat

All 24 bobcat samples contained mammal hair or bones, five contained vegetation higher than a trace amount, and two contained trace anthropogenic items. Trace amounts of insect exoskeleton, such as beetles and ticks were seen in nine samples (Table 1). Of all the contents mammal bones and hair were the most prominent (Figure 2). Rodents were the most common mammal, but shrew teeth were also observed. One sample contained many seeds but the only bit of vegetation in the others were small bits of debris. In both samples with anthropogenic items the object was a small bit of string. In the field 15 bobcat samples were identified correctly, two samples were misidentified as coyote, and seven samples were misidentified as fox. All bobcat samples were collected at site 1 (Figure 1).

Coyote

Two of the coyote samples were composed mostly of mammal items and two were primarily vegetation (Table 1, Figure 2). Insect exoskeletons and one anthropogenic item were also present in trace amounts. Rodents were the most common mammal in both samples. The samples containing vegetation were primarily composed of grass along with one sunflower seed, which was classified as an anthropogenic item. Three of the samples were correctly identified in the field and one sample was misidentified as bobcat but was shown to be coyote after the DNA analysis. Three coyote samples were collected at site 1 and one sample was collected at site 3 (Figure 1).

Red Fox

One red fox sample contained mammal hair and bones along with vegetation. The vegetation was grass along with some seeds. The sample also contained trace amounts of black feathers and insect exoskeletons. The other sample contained some mammal items but was primarily composed of grasshopper exoskeletons (*Melanoplus spp,*). Rodents were the most common mammal in both samples (Table 1, Figure 2). Both red fox samples were collected at site 2 when the red foxes were fitted with GPS collars (Figure 1).

Gray Fox

The gray fox sample was composed mainly of small bird feathers and some vegetation (Table 1, Figure 2). The feathers ranged in color from black, white, and reddish brown. The vegetation was composed of seeds from the Virginia Creeper (*Parthenocissus quinquefolia*).

There were bones from both mammals and birds, and some mammal teeth. The gray fox sample was collected from Site 1 and was misidentified as coyote in the field (Figure 1).

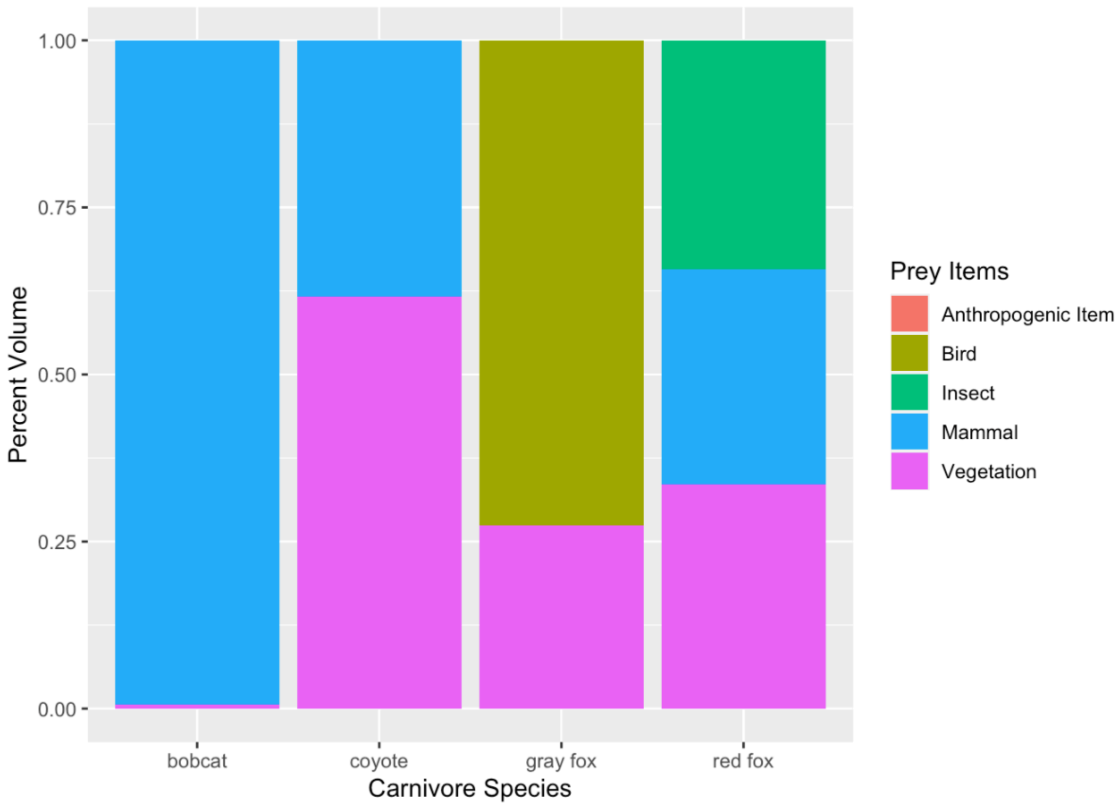

Figure 2. Percent volume of prey items found in scat by species scaled to 100%. Bobcat (N = 24), coyote (N = 4), gray fox (N = 1), and red fox (N = 2).

Table 1. Percent frequency of occurrence (FO) of scat samples for bobcat, coyote, red fox, and gray fox found in and around Cullowhee, NC.

Prey Item	Bobcat N = 24	Coyote N = 4	Red Fox N = 2	Gray Fox N = 1
Mammal	100%	50%	100%	0%
Vegetation	20.83%	50%	50%	100%
Insect	0%	0%	50%	0%
Bird	0%	0%	0%	100%
Anthropogenic	0%	0%	0%	0%

Space Use

Trapping

Out of 1486 trap nights eight individuals from the target species were captured and fitted with GPS collars. Three bobcats (two females, one male), two coyotes (two females), two red fox (one male, one female), and one gray fox (male) were collared during the summer of 2019 (448 trap nights, Site 1) and the summer and fall of 2020 (1038 trap nights, Sites 2 and 3) (Table 2). The collar of bobcat 1 (male) was only active for 18 days, yielding too few GPS locations (< 100) and was not included in the analysis. All other collars were active for two to ten months (Table 2) and yielded a total of 7,073 locations. Out of the total locations 3,693 were usable (PDOP <3.5), and there was an average of 483 locations for each individual (Table 3). The locations of bobcat 3, coyote 1, gray fox 1, and red fox 2 were primarily in the fall. Bobcat 2 and red fox 1 primarily had locations in the summer and the locations of coyote 2 were during the winter months (Table 2).

Table 2. Overview of data from carnivore collared in Cullowhee, NC.

Carnivore	Sex	Age	Start Date	End Date	Ultimate Fate	No. Days	Capture Locations
Bobcat 1	M	Adult	6/25/19	7/13/19	Deceased	18	Site 1
Bobcat 2	F	Adult	6/29/20	9/30/20	Unknown	93	Site 2
Bobcat 3	F	Juvenile	10/15/20	3/3/22	Alive	504	Site 3
Coyote 1	F	Adult	6/23/19	10/28/19	Hunter Harvested	127	Site 1
Coyote 2	F	Adult	10/20/20	5/6/21	Car Fatality	198	Site 3
Gray Fox 1	M	Adult	9/23/20	7/21/21	Deceased	301	Site 3
Red Fox 1	M	Adult	6/11/20	8/5/21	Car Fatality	420	Site 2
Red Fox 2	F	Juvenile	10/1/20	2/7/21	Deceased	129	Site 2

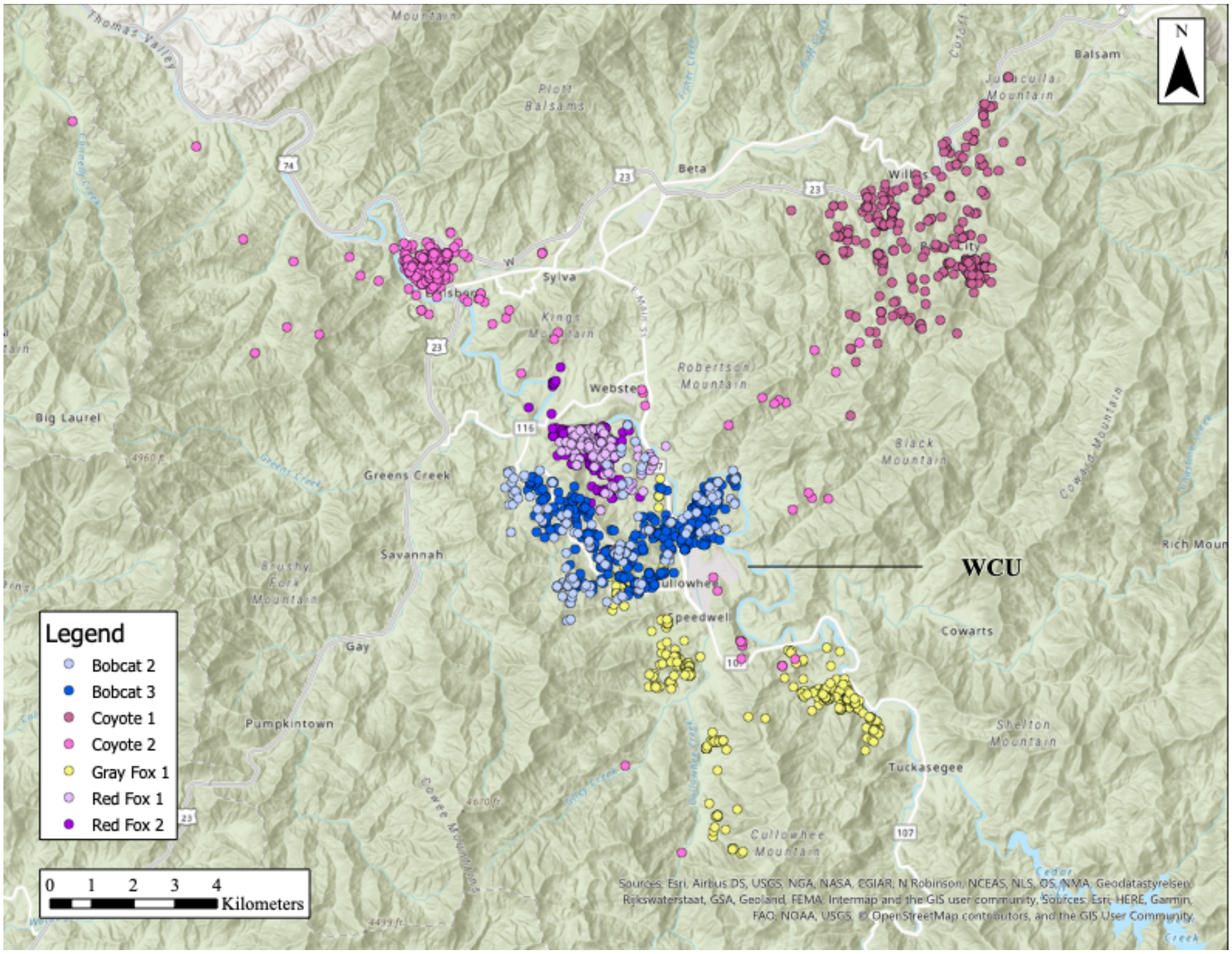

Figure 3. All carnivore GPS locations (PDOP<3.5) in and around Cullowhee, NC from all seasons.

Home Range

Red fox 1 and bobcat 3 had GPS locations primarily during the summer. The KDE home range of red fox 1 was 370.90 m^2 and bobcat 2 was 2,919.60 m^2 (Table 3, Figure 4). Bobcat 3, coyote 1, gray fox 1, and red fox 2 all had GPS locations primarily in the fall. The KDE for each carnivore was 1,515.96 m^2 (bobcat 3), 2,595.53 m^2 (coyote 1), 3,330.40 m^2 (gray fox 1), and 290.10 m^2 (red fox 2) (Table 3, Figure 5). Coyote 2 was the only carnivore with GPS locations primarily during the winter. The KDE for coyote 2 was 427.36 m^2 (Table 3, Figure 6).

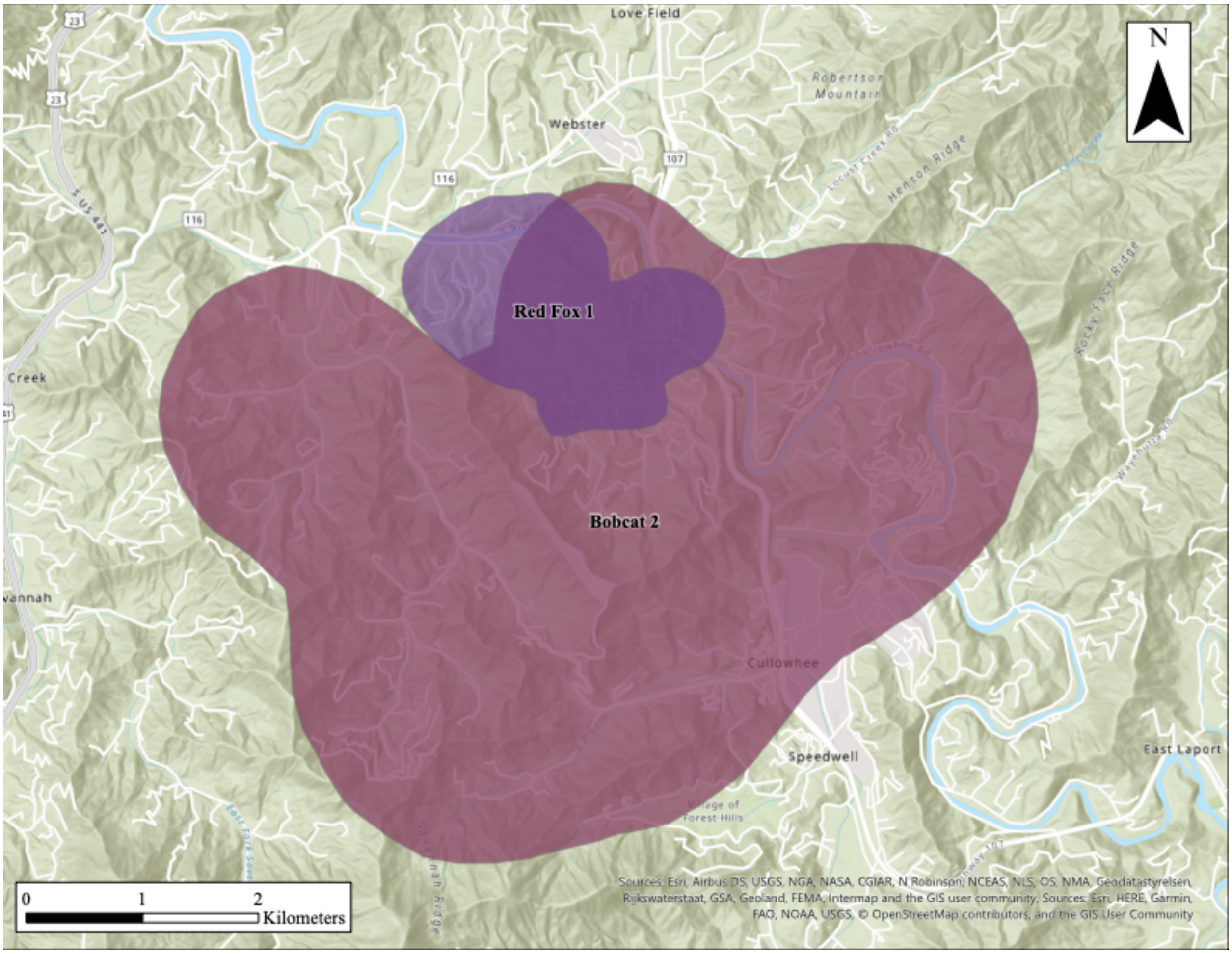

Figure 4. 95% KDE home range map for bobcat 2 (F) and red fox 1 (M) both collared in 2020.

Table 3. Home range size (m^2) and number of GPS locations for carnivores collared in 2019 and 2020 in Cullowhee, NC.

Carnivore	No. Data Points	Home Range (m^2)
Bobcat 2	294	2920
Bobcat 3	598	1516
Coyote 1	433	2596
Coyote 2	619	427.4
Gray Fox 1	643	3330
Red Fox 1	293	370.9
Red Fox 2	500	290.1

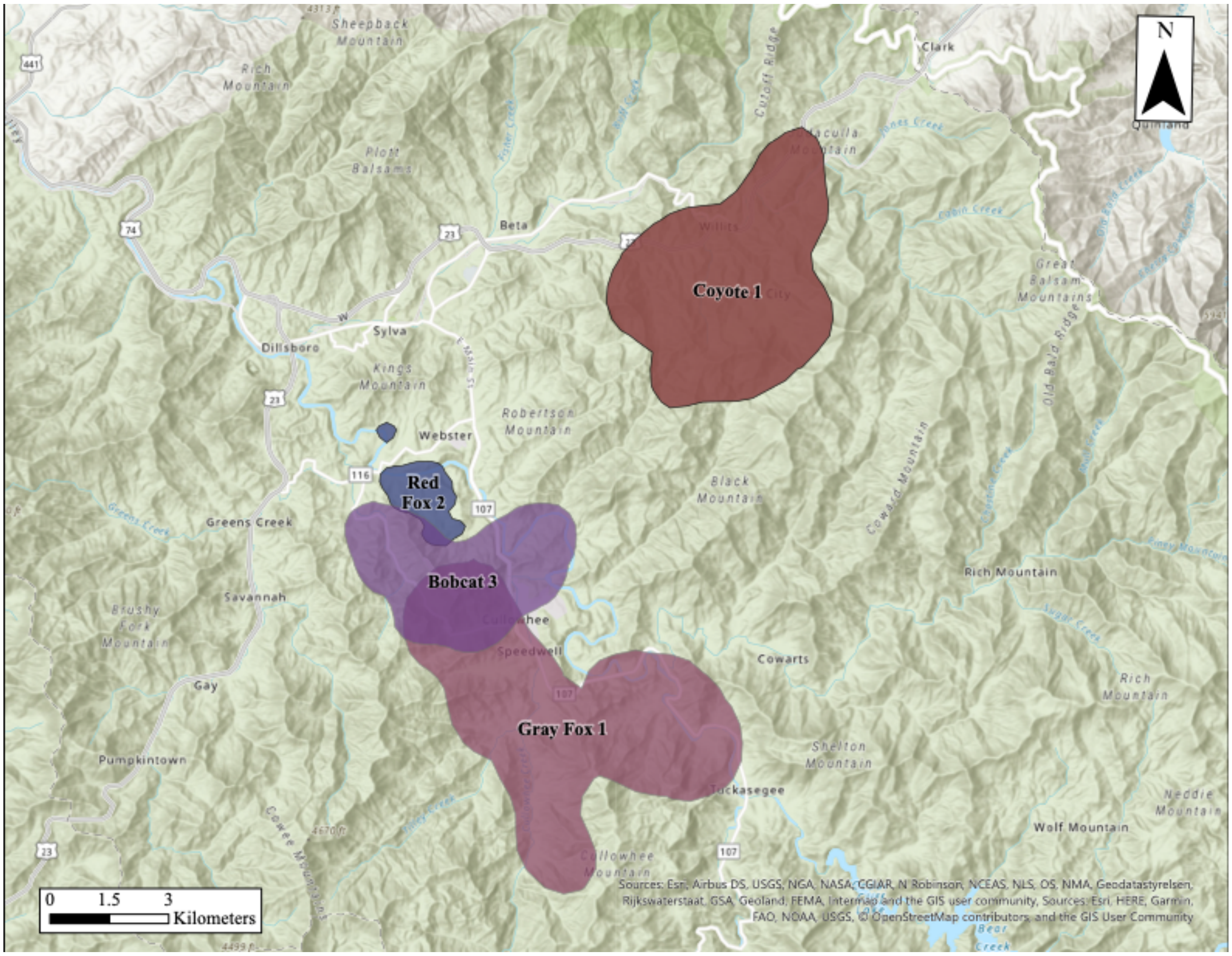

Figure 5. 95 % KDE home range map for during the fall season for bobcat 3 (F), coyote 1 (F), gray fox 1 (M), and red fox 2 (F). Coyote 1 was captured during the 2019 trapping season and all other fall carnivores were captured during 2020.

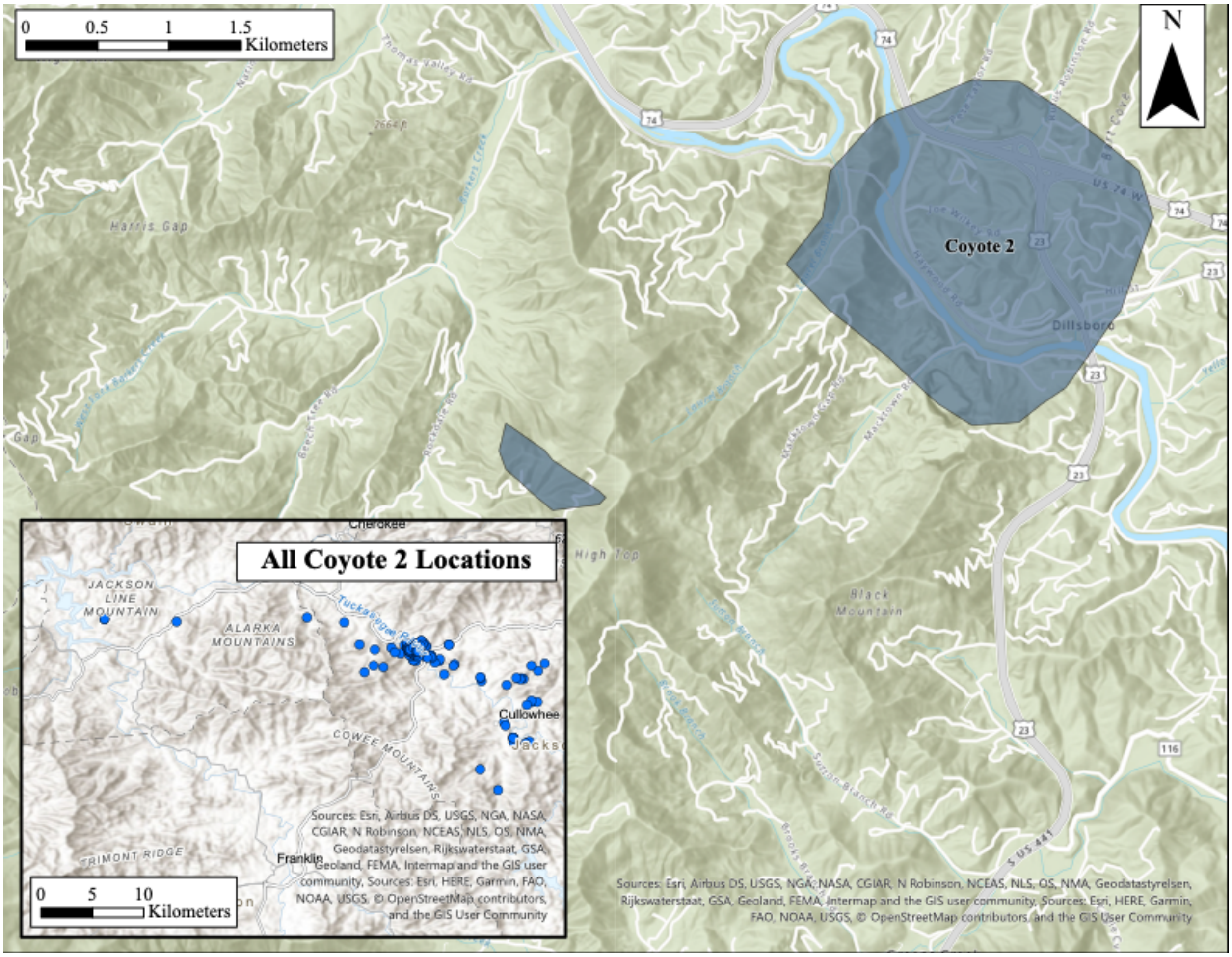

Figure 6. 95% KDE home range map for Coyote 2 (F) the only carnivore with predominately winter locations. Coyote 2 was captured in the 2020 trapping season. Insert shows all locations when Coyote 2 traveled from Cullowhee out to Fontana Lake and back to Dillsboro.

Habitat Selection

Four pairs of variables had a high correlation (|r|≥0.7, P<0.01); water and elevation, water and wetlands, HDH and agriculture, and agriculture and elevation. To keep the simplest biological explanation the coefficients of elevation, wetlands, and HDH were excluded from the analysis (Dormann et al. 2013).

The top models for bobcat 2 (summer) and bobcat 3 (fall) included the same variables that all significantly influenced their habitat selection. Both bobcats selected for habitats closer to water, HDL, deciduous forests, grassland/herbaceous, and agriculture. They selected for areas further away from shrubland and primary roads (Table 4, Table 5, Figure 7). The variables with the most influence on bobcat habitat selection were the distance to open water, HDL, and agriculture.

Table 4. Top model for Bobcat 2, an adult female, during the summer 2020.

	Estimate	SE	z	P
(Intercept)	-2.198	0.1816	-12.11	9.676e-34
Water	-1.285	0.1562	-8.226	1.93e-16
HDL	-1.579	0.3188	-4.952	7.354e-07
Deciduous	-0.3867	0.1124	-3.441	0.0005805
Shrubland	0.3394	0.1202	2.823	0.004764
Grassland/Herbaceous	-0.5718	0.1647	-3.471	0.0005182
Agriculture	-0.9651	0.2354	-4.1	4.128e-05
Primary roads	0.5309	0.1435	3.701	0.000215

Table 5. Top model for Bobcat 3, a juvenile female, during the fall of 2020.

	Estimate	SE	z	P
(Intercept)	-1.301	0.1396	-9.317	1.196e-20
Water	-1.574	0.1518	-10.37	3.359e-25
HDL	-0.8206	0.2498	-3.284	0.001022
Deciduous	-0.4535	0.09416	-4.817	1.46e-06
Shrubland	0.8689	0.1157	7.507	6.07e-14
Grassland/Herbaceous	-0.7533	0.1502	-5.016	5.278e-07
Agriculture	-1.904	0.2483	-7.67	1.721e-14
Primary roads	0.4691 5	0.1198	3.915	9.036e-05

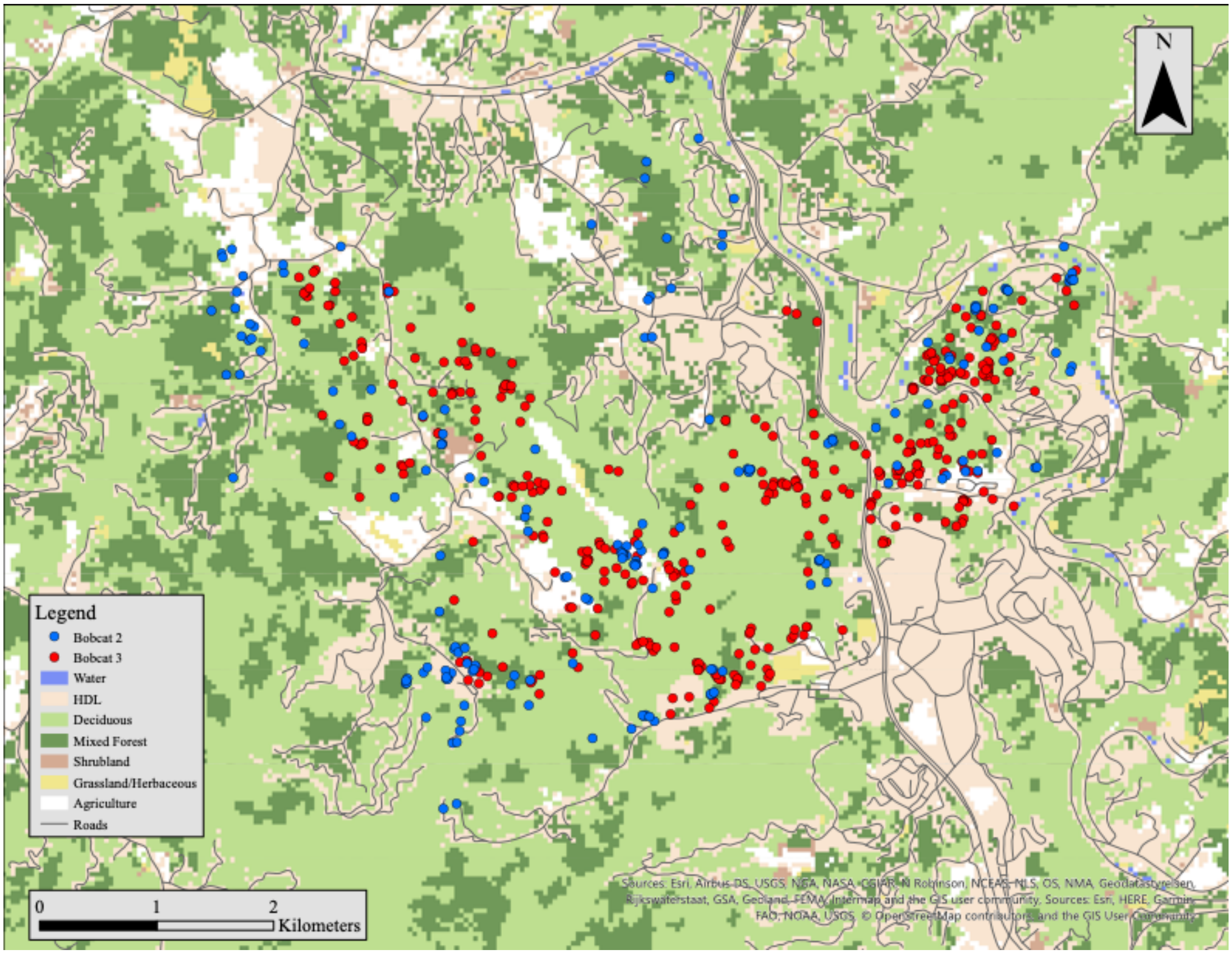

Figure 7. GPS locations for bobcat 2 (F) and bobcat 3 (F) with NLCD landcover data. Bobcat 2 was collared in the summer of 2020 at Site 2 and Bobcat 3 in the fall of 2020 at Site 3.

All variables in the top model for coyote 1 (fall) were significant. Coyote 1 selected for distances closer to deciduous forest, shrubland, grassland/herbaceous, agriculture, and secondary roads, while selecting for distances further away from water and mixed forests. The distances to water, grassland/herbaceous land, agriculture, and secondary roads had the most influence on habitat selection (Table 6, Figure 8).

The Top model for coyote 2 (winter) selected for distances closer to many variables, including water, mixed forests, grassland/herbaceous land, agriculture, and secondary roads, while using distances further away from shrubland. The only variable not significant was the distance to agriculture. Distance to water, shrubland, grassland/herbaceous, and secondary roads had the most influence on the model (Table 7, Figure 9).

Table 6. Top model for Coyote 1, an adult female, for the fall of 2019.

	Estimate	SE	z	P
(Intercept)	-1.692	0.1553	-10.89	1.227e-27
Water	1.773	0.1287	13.77	3.739e-43
Deciduous	-0.3333	0.1109	-3.006	0.002649
Mixed	0.2737	0.1098	2.493	0.01268
Shrubland	-0.3075	0.1422	-2.163	0.03057
Grassland/Herbaceous	-1.283	0.2177	-5.891	3.838e-09
Agriculture	-1.054	0.2126	-4.959	7.074e-07
Secondary roads	-1.46	0.2037	-7.17	7.508e-13

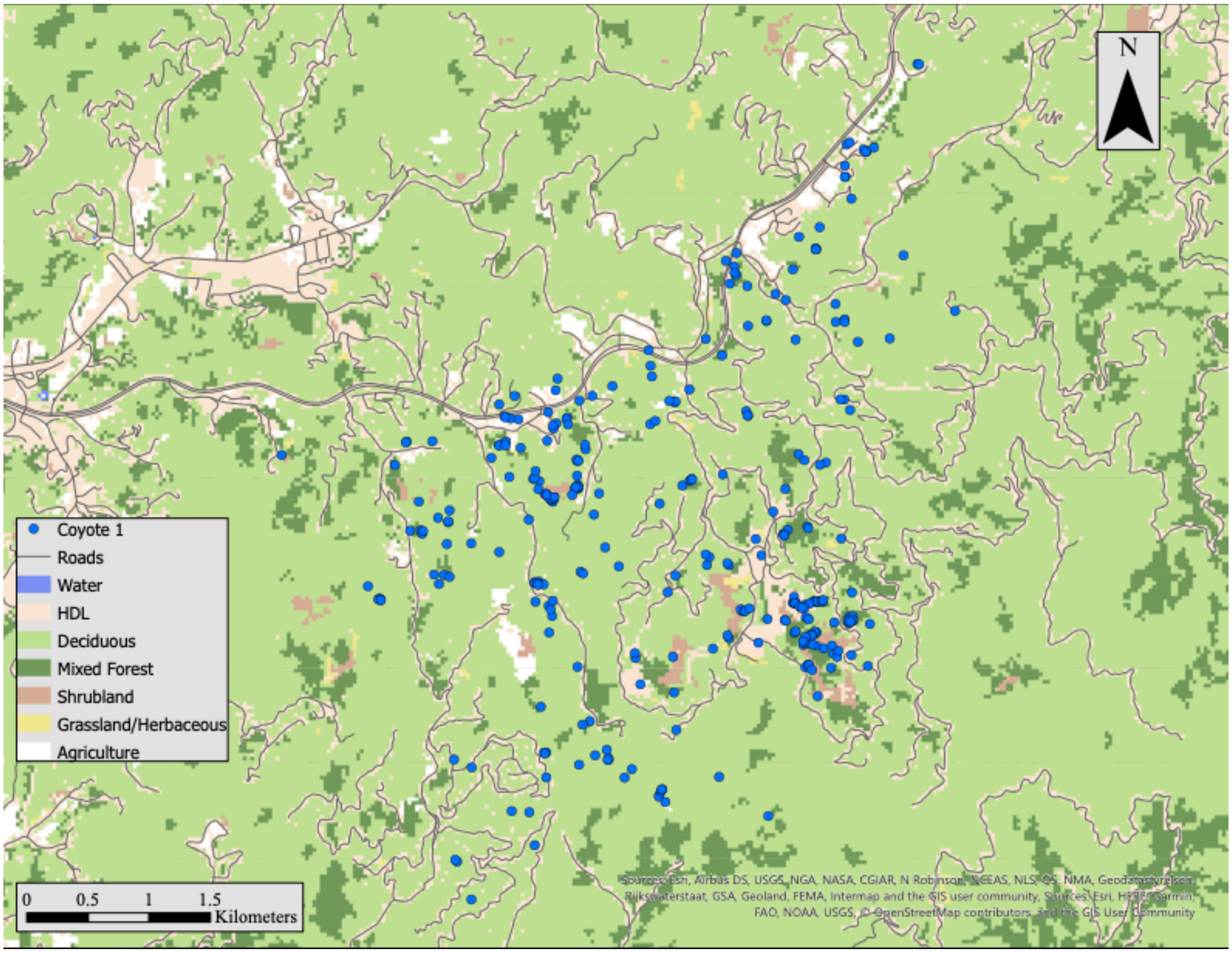

Figure 8. GPS locations for coyote 1 with NLCD land cover data. Coyote 1 was captured in the fall of 2019 at BMP.

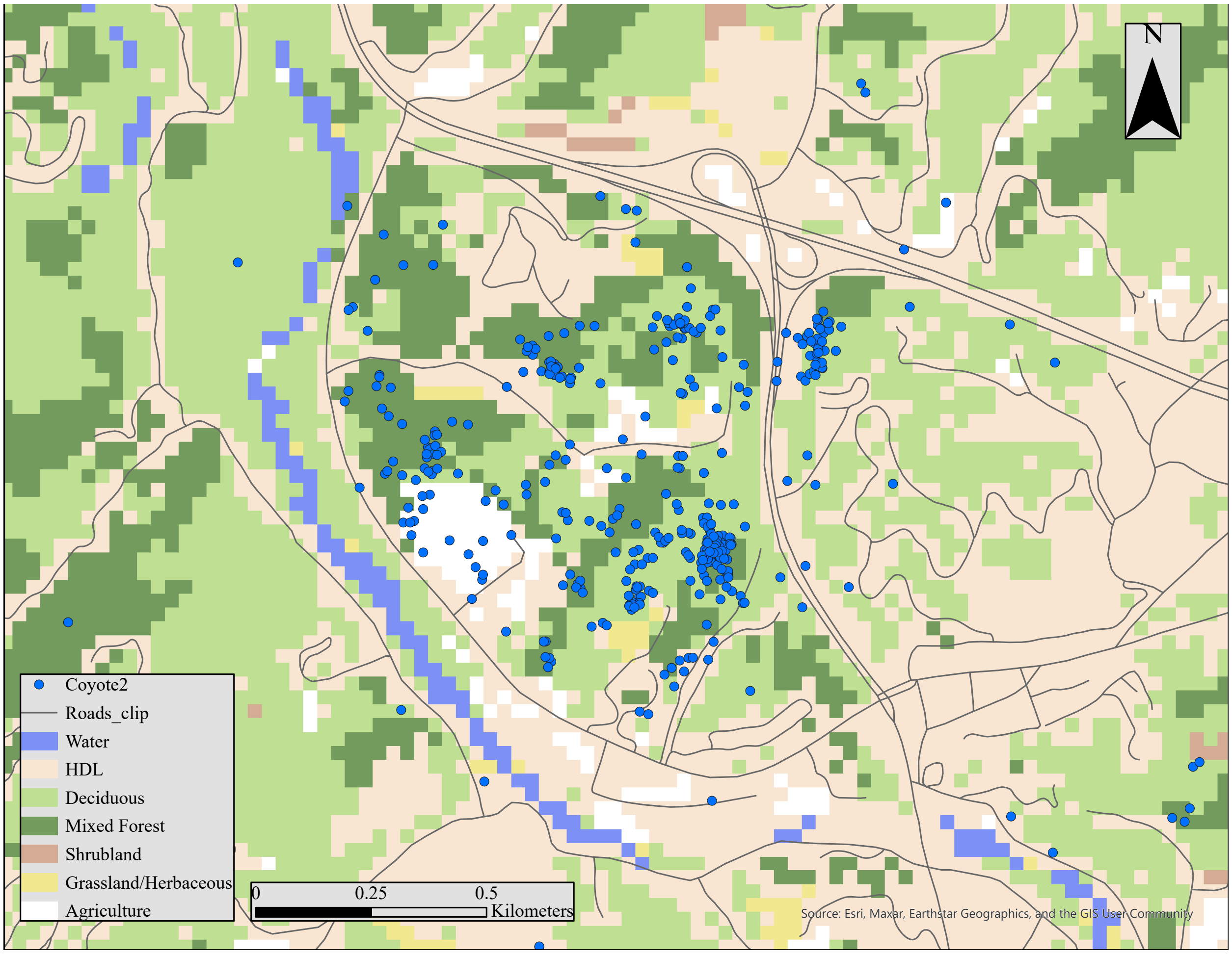

Figure 9. GPS locations for coyote 2 in and around Dillsboro NC with NLCD land cover data. Coyote 2 was captured in 2020 at Site 3.

Table 7. Top model for Coyote 2, an adult female, for the winter of 2020-2021.

	Estimate	SE	z	P
(Intercept)	-1.347	0.1532	-8.791	1.479e-18
Water	-1.857	0.2085	-8.906	5.305e-19
Mixed	-0.3167	0.1307	-2.424	0.01536
Shrubland	0.8605	0.1327	6.483	9.003e-11
Grassland/Herbaceous	-2.038	0.2887	-7.061	1.653e-12
Agriculture	-0.5213	0.2825	-1.845	0.06502
Secondary roads	-1.033	0.1329	-7.772	7.755e-15

The top model for both red foxes included water, mixed forest, grassland/herbaceous land, and agriculture (Tables 8 and 9). They differed in that red fox 1 (summer) included primary roads in its top model (Table 8, Figure 10) and red fox 2 (fall) included HDL and secondary roads (Table 9, Figure 10). Both foxes selected for areas closer to all the variables in their models and every variable was significant. For red fox 1 the distance to water was the most influential variable and for red fox 2 the distances to water and agriculture were the most influential (Tables 8 and 9).

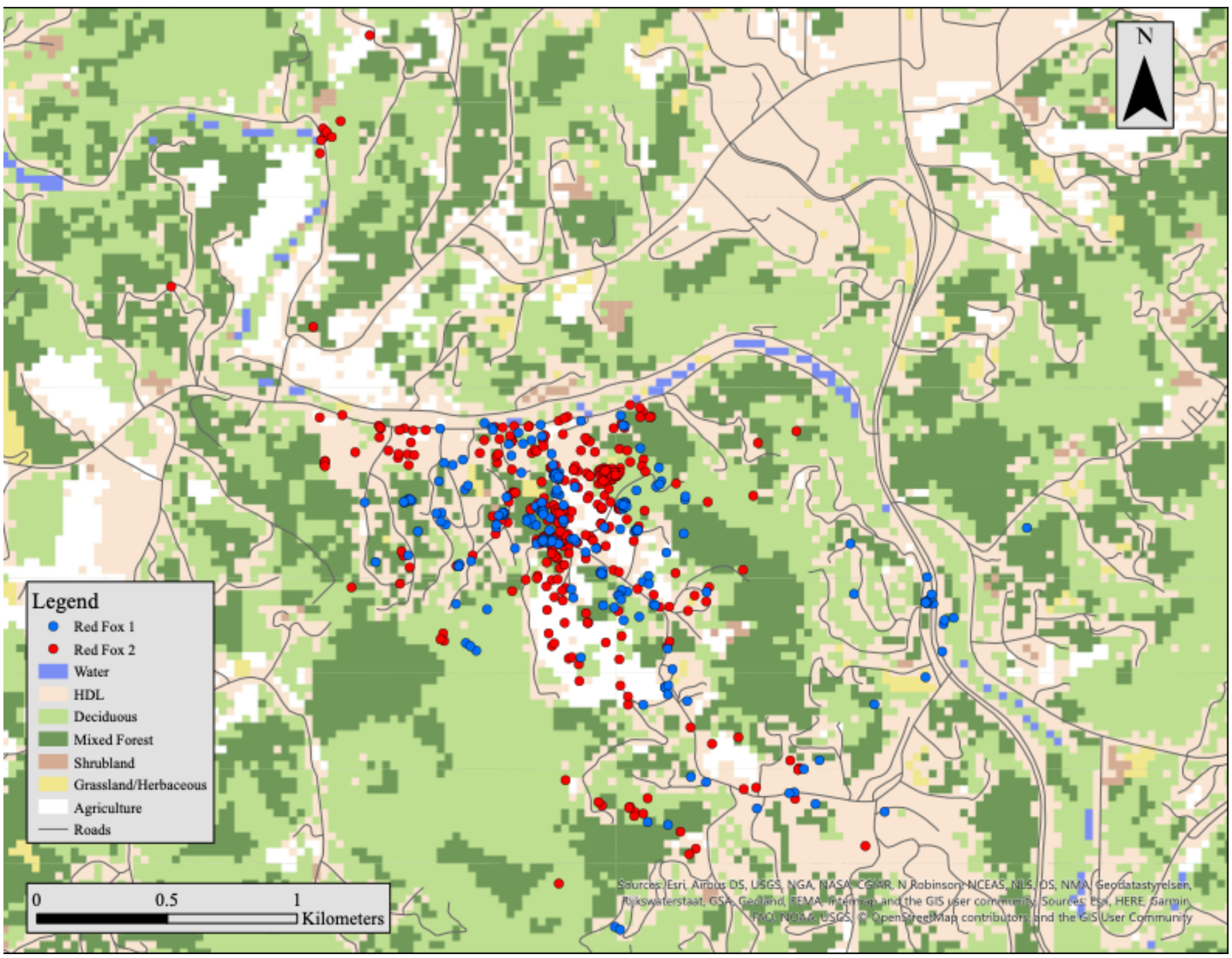

Figure 10. GPS locations for red fox 1 (M) and red fox 2 (F) with NLCD land cover data. Red fox 1 was collared in the summer of 2020 and red fox 2 was collared in the fall of 2020. Both red foxes were collared at Site 2.

Table 8. Top model for red fox 1, an adult male in the summer of 2020.

	Estimate	SE	z	P
(Intercept)	-7.256	0.7078	-10.25	1.165e-24
Water	-3.249	0.4767	-6.817	9.276e-12
Mixed	-1.2	0.2871	-4.179	2.925e-05
Grassland/Herbaceous	-3.058	0.6078	-5.031	4.87e-07
Agriculture	-3.006	0.6727	-4.469	7.877e-06
Primary roads	-2.046	0.3976	-5.147	2.65e-07

Table 9. Top model for red fox 2, a juvenile female in the fall of 2020.

	Estimate	SE	z	P
(Intercept)	-7.378	0.7077	-10.42	1.909e-25
Water	-3.519	0.4344	-8.1	5.508e-16
HDL	-2.819	0.7972	-3.536	0.0004065
Mixed	-1.146	0.2394	-4.788	1.688e-06
Grassland/Herbaceous	-2.628	0.5234	-5.02	5.162e-07
Agriculture	-5.379	0.7176	-7.495	6.613e-14
Secondary roads	-0.3145	0.1484	-2.119	0.03409

The top model for gray fox 1 (fall) selected for distances closer to water, HDL, grassland/herbaceous land, agriculture, primary roads, and aspect. Distances further away from mixed forest, shrubland, secondary roads, and slope were selected for. All variables except HDL, primary roads and slope had a significant influence on the model. The distance to secondary roads had the most impact followed by agriculture and grassland/herbaceous (Table 10, Figure 11).

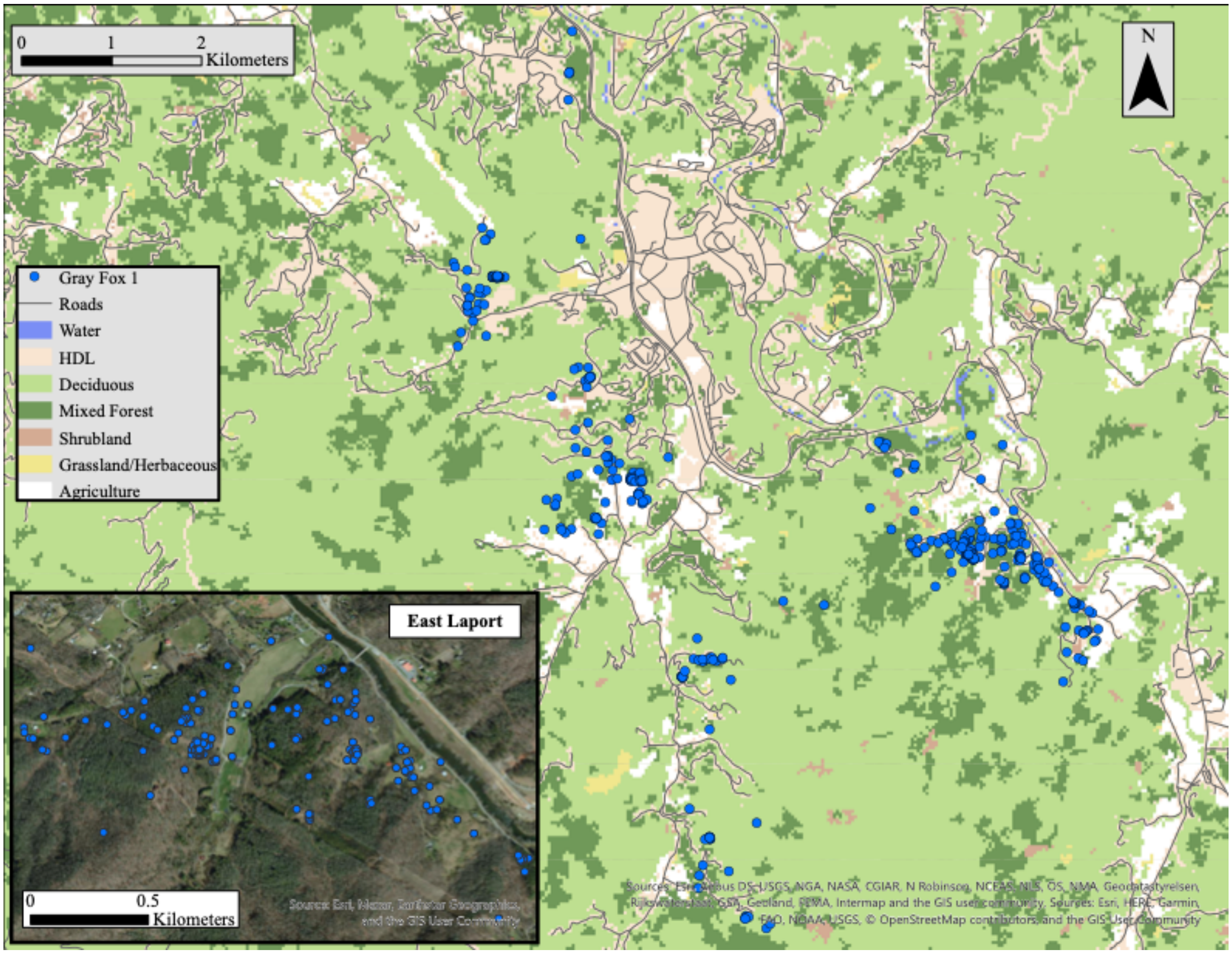

Figure 11. GPS locations for gray fox 1 with NLCD land cover data. Gray Fox 1 was collared in the fall of 2020 at Site 3.

Table 10. Top model for gray fox 1, an adult male in the fall of 2020.

	Estimate	SE	z	P
(Intercept)	-1.141	0.1412	-8.08	6.485e-16
Water	-0.4475	0.1225	-3.652	0.0002602
HDL	-0.3006	0.2376	-1.265	0.2058
Mixed	0.3255	0.09303	3.499	0.0004679
Shrubland	0.4508	0.1355	3.326	0.0008795
Grassland/Herbaceous	-1.502	0.2312	-6.496	8.221e-11
Agriculture	-2.06	0.2574	-8.003	1.211e-15
Secondary roads	1.261	0.1029	12.25	1.627e-34
Primary Roads	-0.2052	0.136	-1.509	0.1313
Slope	0.1812	0.09716	1.865	0.06223
Aspect	-0.1996	0.0896	-2.227	0.02593

CHAPTER FOUR: DISCUSSION

Mesocarnivores that live in close proximity may compete for similar resources. Coyotes have been known to compete with other mesocarnivores throughout North America, especially other canids (Prugh & Sivy, 2020). They have the ability to live in both urban and rural habitats (Morey et al., 2007; Poessel et al., 2016; Stark et al., 2019) and are known to affect the temporal and hunting patterns of other mesocarnivores (Fedriani et al., 2000; Gomez-Ortiz et al., 2019; Major & Sherburne, 1987; Rich et al., 2018). Studies also show that diet and habitat use change seasonally for mesocarnivores (Andelt et al., 1987; Dumond et al., 2001; Koehler & Hornocker, 1989; Sasmal et al., 2019).

In this study all the carnivores in every season had distance to water as the top predictor in their model except the gray fox. The carnivores may be selecting for closer distances to the water in order to take advantage of higher prey densities and denser cover associated with riparian habitats, similar to mountain lions (Smereka et al. 2020). Coyote 1 was the only individual to show an avoidance of open water, but it was also the only individual whose home range was not close to the Tuckasegee River.

There can be individual variation in coyote space use (Gosselink et al., 2003) but both coyotes in our study selected for more grassland and agricultural habitat. In this study coyote 1 (fall) stayed in a habitat further away from the other target species and in an area with less human density. Habitats close to secondary roads were also a top predictor for both coyotes and both would cross a four-lane highway multiple times. Coyote 2 was the only carnivore with primarily winter locations. It also utilized grassland habitat but did avoid shrubland. Open water was a top predictor in its model and its home range did border the Tuckasegee River.

Coyotes are known to utilize edge habitat and natural spaces when close to urbanization (Riley et al., 2003) similar to the coyotes in our study. Both species of fox stayed in areas with a higher human density than coyotes which is one way foxes and coyotes have been known to partition habitats (Fedriani et al., 2000; Gosselink et al., 2003). The best predictor for gray fox 1 (fall) was the avoidance of secondary roads. This gray fox was the individual who utilized powerline corridors most often. The GPS locations show its home range formed a distinct Y pattern and many of the points are within or near a powerline corridor. These corridors can help to increase biodiversity and provide a habitat with greater prey density for carnivores (Garfinkel et al., 2022). These results are also consistent with those of Harrison (1997), who found that gray foxes stayed close to human development but avoided high density subdivisions.

Both red foxes selected for areas closer to water and utilized grassy habitat much closer to human habitation. They differed in that red fox 1 (summer) selected for areas closer to primary roads, possibly to utilize the edge habitat and be closer to the human development (Gosselink et al., 2003). Red fox 2 (fall) and bobcat 3 (fall) utilized similar areas of grassland and agriculture but differed in their use of forests. Red fox 2 selected for mixed forests, while bobcat 3 was selecting for deciduous forests. A better predictor for bobcat 3 was its avoidance of shrubland, and the early successional forest found there. Bobcat 2 (summer) did select for areas with low human development but still stayed in areas with more forest cover. It selected against primary roads and utilized the more forested habitat similar to Riley et al. (2003). Although both bobcats contain many points on both sides of Hwy 107 the area where they crossed contains a drain and a tunnel under the road that they may have utilized.

The scat samples used to assess diet in this study were collected primarily in the winter months and are consistent with other studies (Fedriani et al., 2000; Hockman & Chapman, 1983;

Litvaitis et al., 1986; Swingen et al., 2015). The diet analysis shows that the canids seem to have a more similar diet and might compete among each other more often. This research also demonstrates the importance of confirming carnivore species through DNA analysis. Even with experienced trackers there was a 40% discrepancy between field and DNA ID (Priest et al 2023), in some cases samples with a field ID as bobcat or coyote were mistaken for fox similar to Laguardia et al. (2015).

As coyotes are still relatively new to NC it is important to understand the effects their presence has on the local ecosystem. The other species of mesocarnivores in this study are staying in areas with more human density possibly to avoid coyote interactions (D. J. Harrison et al., 1989). A topic for future research that could help examine this question would be temporal movement of the carnivores. Many carnivores have been known to change their temporal habits based on the competitors around them (Gomez-Ortiz et al., 2019). This was not examined during this project due to time constraints, but the collars were set to record a location every hour so that the data could be explored in the future. The competition between these four species is not fully understood in western North Carolina but this study can be used as a reference for future research and management.

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