Dietary Analysis of the Coyote (*Canis latrans*) Population at Black Rock Forest, New York



Photograph courtesy of camera traps at Black Rock Forest

Ellery Vaughan
Department of Environmental Science, Barnard College
emv2137@barnard.edu

Research Mentor: **Bill Schuster,** Ph.D.
Black Rock Forest
wschuster@blackrockforest.org

Senior Seminar Advisor: **Suzanne Macey,** Ph.D.
American Museum of Natural History
smacey@amnh.org

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ABSTRACT

Coyotes (*Canis latrans*) historically occupied the grasslands of central North America; however, in the early 1900s they began a rapid colonization of much of North America. This rapid expansion was, in part, facilitated by human extirpation of larger, apex predators and conversion of forests to agricultural landscapes; ecosystem modifications that enabled the coyote to become a top terrestrial predator in the northeastern U.S. Genetic, morphological, and ecological differences between western and northeastern coyotes suggest that northeastern coyotes hybridized with wolf populations prior to their colonization into the northeastern U.S. This hybridization introduced genetic variation into the expanding front of northeastern coyotes, potentially enabling them to occupy the niche previously filled by wolves and to become a more efficient deer predator. One way to study how these predators are potentially affecting prey populations is to study their diet. Determining the key prey species and the breadth of prey species consumed by a carnivore provides important insight into their role in an ecosystem. In this study, I analyze the diet of the coyotes in Black Rock Forest (Cornwall, New York) to further our understanding of how this relatively recently established carnivore of the BRF ecosystem is interacting with its environment.

Coyote scats were collected at Black Rock Forest opportunistically from December 2017 to July 2018. Diet items were identified using bone and hair analysis. I identified white-tailed deer (*Odocoileus virginianus*) remains in 68.1% of the 69 scat samples analyzed. There is a significant difference in the amount of deer remains observed in the scats between the three seasons, winter, spring and summer, with the highest proportion of deer remains observed in winter. Other species included were squirrel (*Sciurus caroliniensis*), muskrat (*Ondatra zibethicus*), groundhog (*Marmota monax*), raccoon (*Procyon lotor*), vole (*Microtus* spp.), skunk (*Mephitis mephitis*), rabbit (*Sylvilagus floridanus*), shrew (*Sorex*

cinereus cinereus), beaver (*Castor canadensis*), opossum (*Didelphis virginiana*) and Eastern chipmunk (*Tamias striatus*).

This study, the first formal analysis of the coyote's diet in Black Rock Forest, determined that white-tailed deer do constitute a large portion of the Black Rock Forest coyote population's diet as seen by the high proportion of deer remains found in the coyote scat throughout the year. It is unknown to what extent this is the result of coyotes killing the deer themselves or scavenging deer remains. The conclusion that white-tailed deer, an ecologically and economically important species, constitutes a large part of this carnivore's diet, is important information for forest managers. Knowing that coyotes consume a lot of deer is important when determining annual hunting quotas, for both deer and coyotes, and also for more informed decision making as a result of overall better understanding of the system.

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I. INTRODUCTION

a. Geographic Expansion of the Coyote Across North America

As humans continue to dominate and change natural landscapes, species worldwide are at a continually increasing risk of extinction, in fact recent species extinction rates are 100 to 1000 times greater than the rates before the Anthropocene, the current time period where human activity is the prevailing force of change on the climate and global environment (Pimm, Russell, Gittleman & Brooks, 1995; Vitousek, Mooney, Lubchenco & Melillo, 1997; Ehrlich, 1998). It is difficult to provide a single statistic to summarize the state of endangered species in the U.S. because so many species remain unclassified and new threats are constantly evolving, but of the described plant, animal and fungi species, 7 to 18% are currently imperiled (Wilcove and Master, 2005). As part of this trend, the range and population sizes of many North American species appear to be declining at an accelerating rate due to overexploitation, introduction of invasive species, pollution, and most importantly loss of suitable habitat (Wilcove, Rothstein, Dubow, Phillips & Losos, 1998).

Laliberte and Ripple (2004) used geographic information system (GIS) to better understand how human expansion has influenced species' ranges in North America. To determine this, they selected 43 species and compared their historical (pre-European colonization) ranges to current ranges. By this comparison, they were able to determine areas of habitat expansion, reduction and persistence for each species (Laliberte and Ripple, 2004). They discovered a trend of range contraction for most large carnivores, with grizzly bears (*Ursus arctos*) experiencing a 53% decrease in habitat range, gray wolves (*Canis lupus*) experiencing a 42% decrease, and cougars (*Puma concolor*) experiencing a 36% decrease (Laliberte and Ripple, 2004). In contrast, species better adapted to living in close proximity to humans experienced habitat expansions: White-tailed deer (*Odocoileus virginiana*) habitat range increased 6%,

red foxes (*Vulpes vulpes*) by 13%, raccoons (*Procyon lotor*) by 18% and coyotes (*Canis latrans*) by a stunning 40% (Laliberte and Ripple, 2004).

Considering that the geographic range of the coyote, *Canis latrans*, is expanding during a time when most other North American mammal's ranges are shrinking, the expansion of the coyote presents a case study of a species adapting to the Anthropocene and an opportunity to explore the potential management and conservation consequences for ecosystems invaded by these coyote populations (Laliberte and Ripple, 2004; Hody and Kays, 2018). To better understand the geographic distribution of the North American coyote population before European settlement and to discern its subsequent expansion across the continent in the 20th century, Hody and Kays (2018) reviewed museum collections of coyotes and biological surveys, studied fossil and zooarchaeological records, researched the peer-reviewed literature, and read management agency reports. Their results revealed that the historical (pre-European colonization) range of coyotes was larger than often cited in the literature, occupying the space between the Mississippi River and California (Hody and Kays, 2018). The gradual expansion of the coyote from this range began in the early 1800s; however, it was in the early 1900s, that the coyote population began explosively expanding to the point that it now extends from the Pacific Coast to the Atlantic Coast and reaches from Alaska down to Panama (Figure 1; Hody and Kays, 2018).

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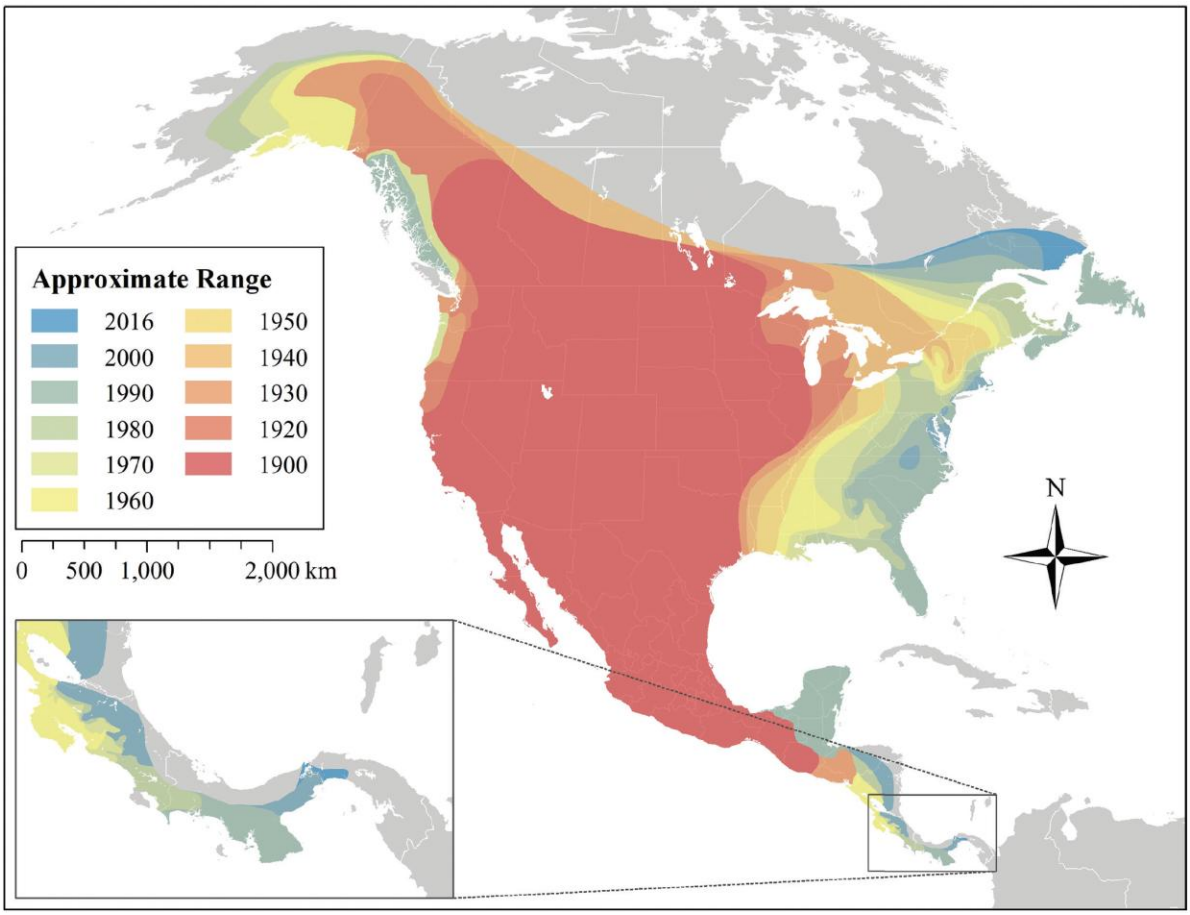


Figure 1: Expansion of Coyotes Across North and Central America. Map showing the range expansion of coyotes (*Canis latrans*) from their historical range in decade increments beginning in 1900 and ending in 2016 (Hody & Kays, 2018).

There are three widely studied and accepted factors that contributed to this rapid expansion. The first is the extirpation of apex predators such as wolves, cougars, and jaguars (*Panthera onca*): with large predators absent, coyotes exploited the available niche in the ecosystem (Hody and Kays, 2018). By doing so, coyote abundance and their geographic range grew as they were simultaneously freed from interference competition (physical competition over resources that can lead to the displacement of one species) and predation from these predators and could now utilize new food resources, such as larger prey, previously consumed by apex predators (Bekoff and Gese, 2003; Berger and Gese 2007; Cove, Pardo, Spínola, Jackson & Sáenz, 2012; Hody and Kays, 2018). The second factor contributing to the geographic expansion of the coyote was the direct result of human modification of the landscape: as

humans converted forested lands into agricultural, logging, or livestock grazing landscapes across the U.S., they created more suitable habitat for coyotes (Vaughan, 1983; Fener, Ginsberg, Sanderson, & Gompper, 2005; Hody and Kays, 2018). Coyotes prefer open, rural landscapes to forested habitat, which Huff (2015) proposes is because more open terrains enable coyotes to take advantage of their impressive speed as predators (Samson and Crête, 1997; Tremblay, Crête & Huot, 1998; Crête et al., 2001; Berger and Gese, 2007). This preference was additionally demonstrated by Fener (2005) who observed that coyotes colonizing New York first occupied the agricultural areas surrounding the Adirondacks before inhabiting this densely forested region. The last potential factor that expedited the coyote's migration across eastern North America is the hybridization of coyotes with wolves and dogs (Hody and Kays, 2018). This interspecies breeding added new genotypes into the coyote population that aided in colonization and increased the likelihood of survival for these new coyote populations in the habitats of the northeastern U.S. (Kays, Curtis & Kirchman, 2010; VonHoldt et al., 2011; Thornton and Murray, 2014). For example, a morphological change in the northeastern coyote population that likely resulted from hybridization with wolves is an increase in body size, which is advantageous for hunting larger prey (Kays et al., 2010). The colonization advantage gained by coyotes from hybridization with wolves can be visualized by examining two different colonizing fronts of coyotes (Figure 2). The coyote population that traveled north through Ontario, and was therefore exposed to potential hybridization with wolves, colonized the northeastern U.S five times faster than the coyote front that traveled south of the Great Lakes through habitat where wolves had already been extirpated (Kays et al., 2010).

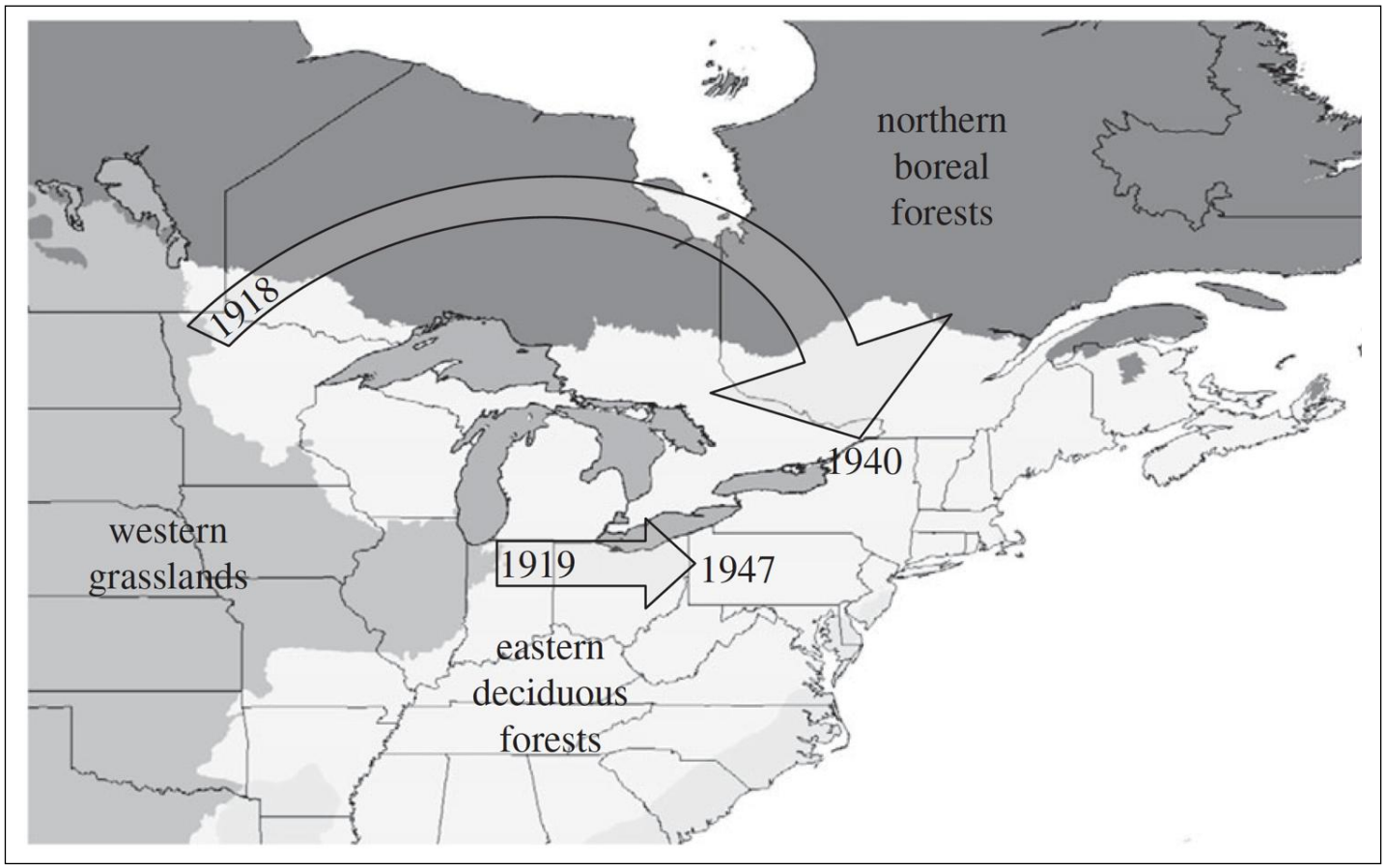


Figure 2. The Eastward Expansion of Coyotes (*Canis latrans*). This map shows the two colonization routes taken by coyotes as they left their historic range in the grasslands of the mid-western U.S and headed to the deciduous forests in the east. One path went north into Canada introducing those coyotes to hybridization with wolves, whereas the other group stayed south of the Great Lakes and did not interbreed with wolves (Kays et al., 2010).

b. Coyote-Wolf Hybridization (The "Northeastern Coyote")

Whereas this is a very plausible hypothesis, it is difficult to tease out with certainty the role hybridization with wolves might have had in the migration of these coyotes, especially when other complicating factors are occurring simultaneously such as competition and suitable habitat availability. Whether or not this hybridization did indeed speed up the eastward migration of the northeastern coyote, this hybridization with another species has important implications for the way these coyotes interact with their environment, particularly which prey they are consuming. Several genetic studies have examined and confirmed the hypothesized hybridization between coyotes expanding eastward and the resident wolf populations (*C. lupus lycaon*; Koblmüller, Nord, Wayne & Leonard, 2009; Wheeldon and

White, 2009). Thornton and Murray (2014) propose that as a result of coyotes' hybridization with wolves, northeastern coyotes have experienced morphological, behavioral, and ecological changes that suggest they are adapting to fill a more wolf-like niche. Morphologically, northeastern coyotes are larger than their western relatives and have skull formations better adapted for increased bite strength, both qualities that enable a carnivore to prey on larger animals, such as deer (Kays et al., 2010).

Behaviorally, northeastern coyotes appear to be exhibiting temperature tolerances and a degree of tree cover preference more similar to wolves than to their western conspecifics (Thornton and Murray, 2014). For example, Thornton and Murray (2014) found that northeastern coyotes were less tolerant to warmer temperatures and more tolerant of colder temperatures and exhibited a less positive response to human disturbance than western coyotes. Both Kays et al. (2010) and Thornton and Murray (2014) determined that northeastern coyotes have a higher tolerance for more heavily forested ecosystems. Additionally, northeastern coyotes are ecologically different from their conspecifics in that they typically eat more deer, but fewer small mammals (Kays et al., 2010). All of these variations, which are assumed to be the result of the hybridization between coyotes and wolves, better equipped the northeastern coyotes to adapt to the forests of the northeastern U.S.

c. Presence of Northeastern Coyotes in New York State

Because of this hybridization, as well as other behavioral characteristics that make the coyote a very successful colonizer such as large dispersal ranges and an opportunistic, flexible diet, it follows that the coyote is now abundant throughout New York State (Chambers, 2006). To better understand the mechanisms of how coyotes came to cover almost all of New York, Fener et al. (2005) created a map of the species occurrence overtime throughout the state by gathering information from a variety of sources, such as county newspapers, regional scientific journals, personal observation from parks personnel, museum archives, professional trappers and more. Their exhaustive efforts produced a fine scale map

detailing the species' impressive 60-year journey from when it first entered the state until when it reached the southern extent of its range (Figure 3).

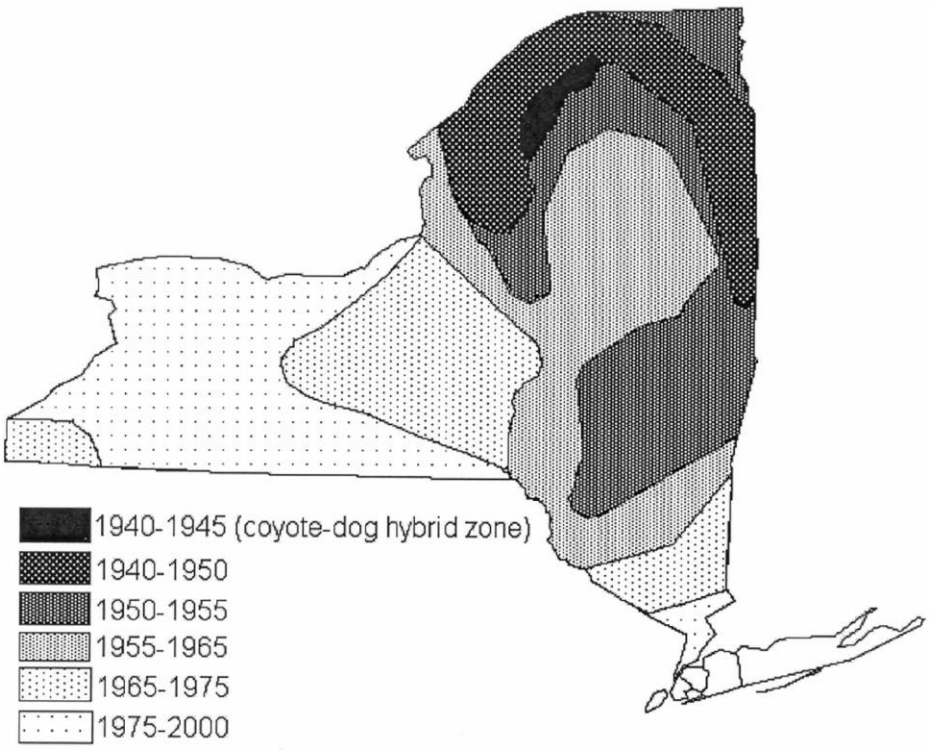


Figure 3: Colonization of New York State by Coyotes (*Canis latrans*). Coyote expansion began in the northern part of the state and gradually worked its way southward and westward at a pace of approximately 78km/decade (Fener et al., 2005).

Fener et al. (2005) proposed two theories for how coyotes came to enter the state: by passing through Québec or by crossing the St. Lawrence River and entering from Ontario. Given that Ontario was colonized by coyotes as early as the 1920s and 1930s and it wasn't until the early 1940s that Québec was colonized, Fener et al. argues coyote entry through Ontario was the most probable avenue (citing the theory of Parker 1995). By the early 1940s, coyotes were established in northern New York and during the 1950s, coyotes migrated south along the New York-Vermont border before turning back in towards the center of the state and then heading north again to establish a population in the Adirondacks in the late 1950s (Fener et al., 2005). Beginning in the 1960s coyote sightings were frequently reported in the Catskills region: a short twenty years later, coyotes were reportedly found

throughout the entire state, with the exception of New York City and Long Island (Fener et al., 2005). However, in the 1990s, Bronx County experienced coyote sightings and then in 1999 a coyote made its way to Central Park in Manhattan (Fener et al., 2005). Fener et al. (2005) determined that it only took this colonizing front of coyotes 60 years to make it the entire 470 km from the most northern part of New York state, at the Canadian border, to the most southern, New York City. Since then, coyotes have been observed in the Bronx, Central Park, Battery Park City, Staten Island and the area surrounding the LaGuardia Airport (Trezza, 2016; Colangelo, 2018). According to the Gotham Coyote Project, as of now, coyotes have yet to form a breeding population on Long Island; however, it seems only a matter of time before these stealthy predators establish themselves there as well (http://www.gothamcoyote.com/projects.html).

d. Ecosystem Effects of the Establishment of Northeastern Coyote Populations

The recent expansion of the coyote into southern New York provides a unique opportunity to study how this dynamic and hybridized species is adapting to its new environment and how it might potentially be affecting the ecosystem and the populations of native mammals who inhabit them. The potential of coyotes to have an effect on existing prey and mesocarnivore populations has been extensively studied (Harrison, Bissonette & Sherburne, 1989; Litvaitis & Harrison, 1989; Dibello, Arthur & Krohn, 1990; Patterson and Messier, 2000; Palomares and Caro, 1999; Ballard, Whitlaw, Young, Jenkins & Forbes, 1999; Ray, 2000; Crête et al., 2001; Kilgo, Ray, Vukovich, Goode & Ruth, 2012; Huff, 2015).

Huff (2015) discusses two examples where expanding coyote populations affected mesocarnivore populations (Harrison et al., 1989; Geese et al., 1996). In the first example, a study conducted on the home ranges of coyotes and foxes in Maine concluded that red foxes were not utilizing

suitable habitat that intersected coyote territory, likely to avoid aggression from this larger species (Harrison et al., 1989). A similar study in Wyoming observed coyote and red fox interactions and found less red fox spatial avoidance due to coyote presence than expected, but did determine that if a prey carcass was present during a coyote and red fox interaction, the coyote was more likely to be aggressive towards the fox (Geese et al., 1996).

As the new alpha predator and as a territorial species, when coyotes expand and establish new territories, they may deter, displace, or kill red foxes (*Vulpes vulpes*), pushing red fox populations closer to human populations (Huff, 2015). Often resident fox populations decrease when coyotes enter their territory because they exist in similar habitats and consume similar foods and coyotes have the size advantage (Huff, 2015). Additionally, coyotes can and do kill other medium to large sized mammals such as bobcat (*Lynx rufus*), racoon (*Procyon lotor*), and opossum (*Didelphis virginiana*) (Huff, 2015). They kill both with the intention of consuming these animals, and out of territoriality, eliminating competition when food resources are scarce, such as during the winter (Kamler and Gipson, 2004; Huff, 2015).

Another species that is likely to be heavily affected by the presence of coyotes is the white-tailed deer (*Odocoileus virginianus*). Coyotes kill and consume deer, both fawn and adult deer (Cepak, 2004; Huff, 2015). Whether or not this predation has an effect on the recruitment of white-tailed deer populations is under debate. Deer populations with low abundances are more likely to be limited by coyote predation than high density deer populations (Huff, 2015).

Determining an accurate understanding of a carnivore's diet provides essential information about how it is interacting with its environment (Klare, Kamler & Macdonald, 2011). By studying which prey species a carnivore is consuming one can determine the role they play in the ecosystem, such as a specialist or generalist predator, predict which species they might engage in competition with, anticipate

how they might impact prey populations, and hypothesize future population demographics depending on current resource availability (Klare et al., 2011). Because observing a carnivore eating in the wild is very difficult to do, scat (animal feces) analysis has historically been the most common method used for the study of carnivore diets and was therefore chosen as the method of dietary analysis for this study (Cepak, 2004; Gompper, Kays, Ray, Lapoint, Bogan & Cryan, 2006; Klare et al., 2011).

e. Coyotes in Black Rock Forest

To identify key prey species of the northeastern coyote, I conducted the first rigorous dietary analysis of the coyote population at Black Rock Forest (BRF), a forest preserve in southeastern New York. White-tailed deer are an important economic and cultural species in New York State and to the surrounding BRF and Cornwall community as they are hunted every year for food and sport. According to the New York Department of Environmental Conservation, the white-tailed deer is the most popular game animal in the state (https://www.dec.ny.gov/animals/6965.html). State-wide hunting of white-tailed deer generates revenue for the state and governmental agencies. Five-hundred thousand deer hunters participate in hunting annually, generating $690 million for the state and $35 million to support NYSDEC. Additionally, every year around two hundred and twenty thousand white-tailed deer are hunted, which translates to around 10.8 million pounds of locally sourced venison (https://www.dec.ny.gov/animals/6965.html).

As a new top predator in the forest, it is important to study the diet of the coyote for several reasons: 1) to develop a basic understanding of what this top predator in this forest is consuming to improve our understanding of this highly adaptive species and to be able to predict how they might be shaping ecosystem dynamics, and 2) to determine what proportion of their diet consists of deer so that forest managers may be able to better understand in future years how the coyote population and white-tailed deer population of this forest are connected.

I conducted a seasonal dietary analysis via scat examination of the coyote population at BRF to establish a basic understanding of which prey species this population of northeastern coyotes consumes throughout different times of the year. Because white-tailed deer are particularly susceptible to coyote predation when they are fawns, I predicted I would see the highest proportion of white-tailed deer remains in the coyote scat during peak fawning season, which is May 20th to June 20th (pers. comm., John Brady BRF Forest Manager, January 2018). In this study, I aim to contribute to the growing ecological literature concerning how coyotes interact with the BRF forest ecosystem.

II. METHODS

a. Site Description

BRF is a 3,914-acre research forest preserve located in Cornwall, NY, in the Hudson Highlands region (Figures 4 & 5; https://blackrockforest.org/about/about-forest-0). A one-hour drive from Manhattan, this forest is located about 50 miles north of New York City (Giles & Ascher, 2006). BRF is primarily a mixed hardwood forest dominated by oak species, but it also contains a variety of habitat types such as hemlock stands, chestnut-oak woods, red maple swamps, ponds, reservoirs and marshes (Giles & Ascher, 2006; Naeem, Prager, Weeks, Varga, Flynn, Griffin, Muscarella, Palmer, Wood & Schuster, 2016). Elevations in the forest extend from 110 to 450 meters above sea level (Schuster, Griffin, Roth, Turnbull, Whitehead & Tissue, 2008).

The forest has a long history of human disturbance. According to the Hudson Valley Magazine, archeological evidence found in present-day Westchester County on Croton Point, indicates the presence of humans in this geographical region 7,000 years ago and the Indigenous Peoples who occupied the Hudson Valley area at the time of European settlement were the Mohican and Lenape (Munsee) Tribes (http://www.hvmag.com/Hudson-Valley-Magazine/July-2016/The-Native-People-of-the-Hudson-

Valley/). As reported by Maher (1999), European settlers arrived and established themselves in this area from the late 1600s through the 1800s, altering this land extensively for agriculture, mining, and logging. In 1929, these lands were consolidated by the Stillman family and established as a research forest, to be known as Black Rock Forest. BRF is now operated by the Black Rock Forest Consortium, and functions as a place to conduct research, facilitate outdoor education and provide the community with beautiful outdoor recreation.

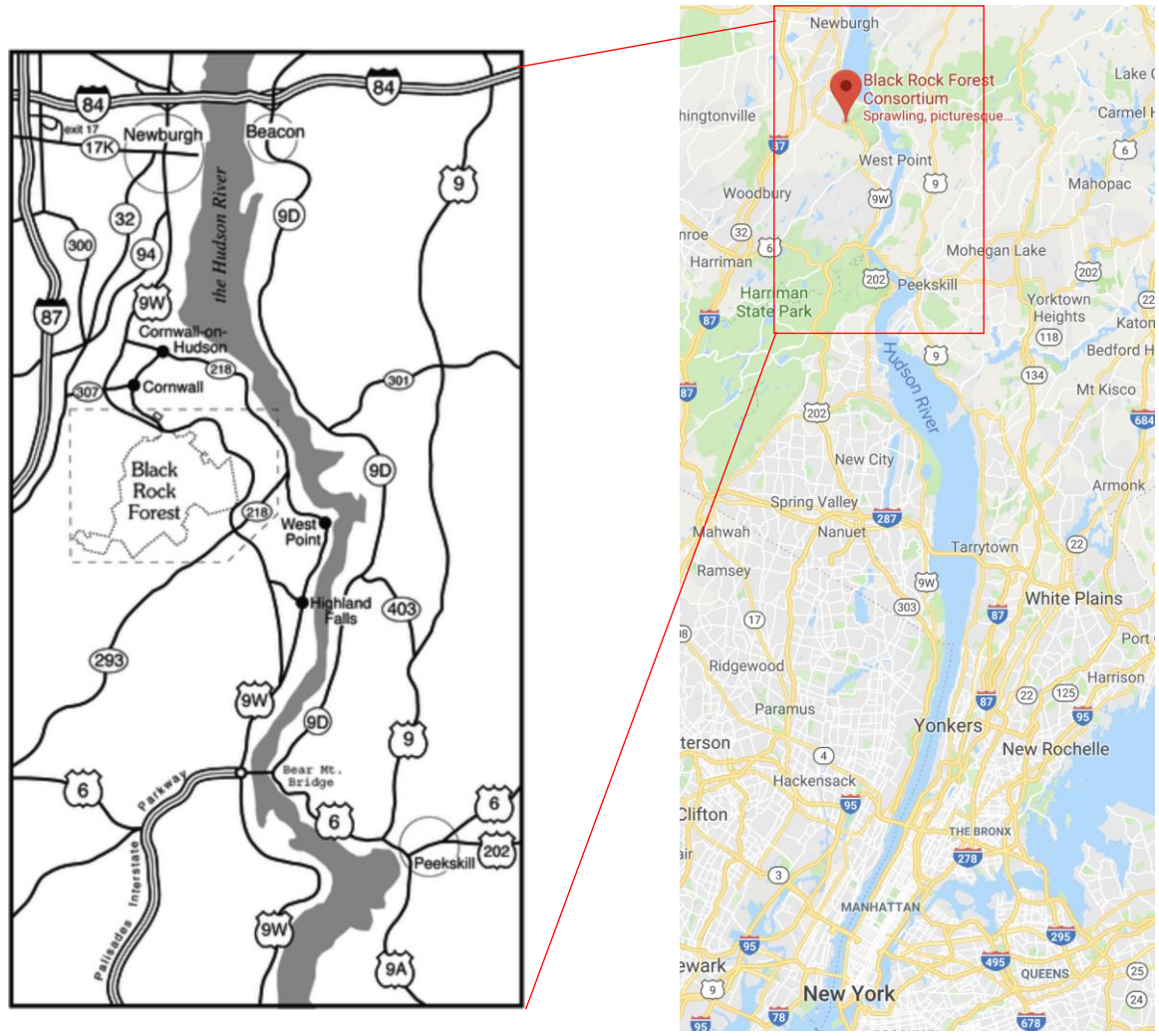


Figure 4: Study Site Location (left). Maps showing BRF in relation to its neighbor, West Point, and the nearby cities Newburgh and Peekskill. **(Right)** Black Rock Forest in relation to New York City. (https://blackrockforest.org/about/about-forest/maps & Google Maps).

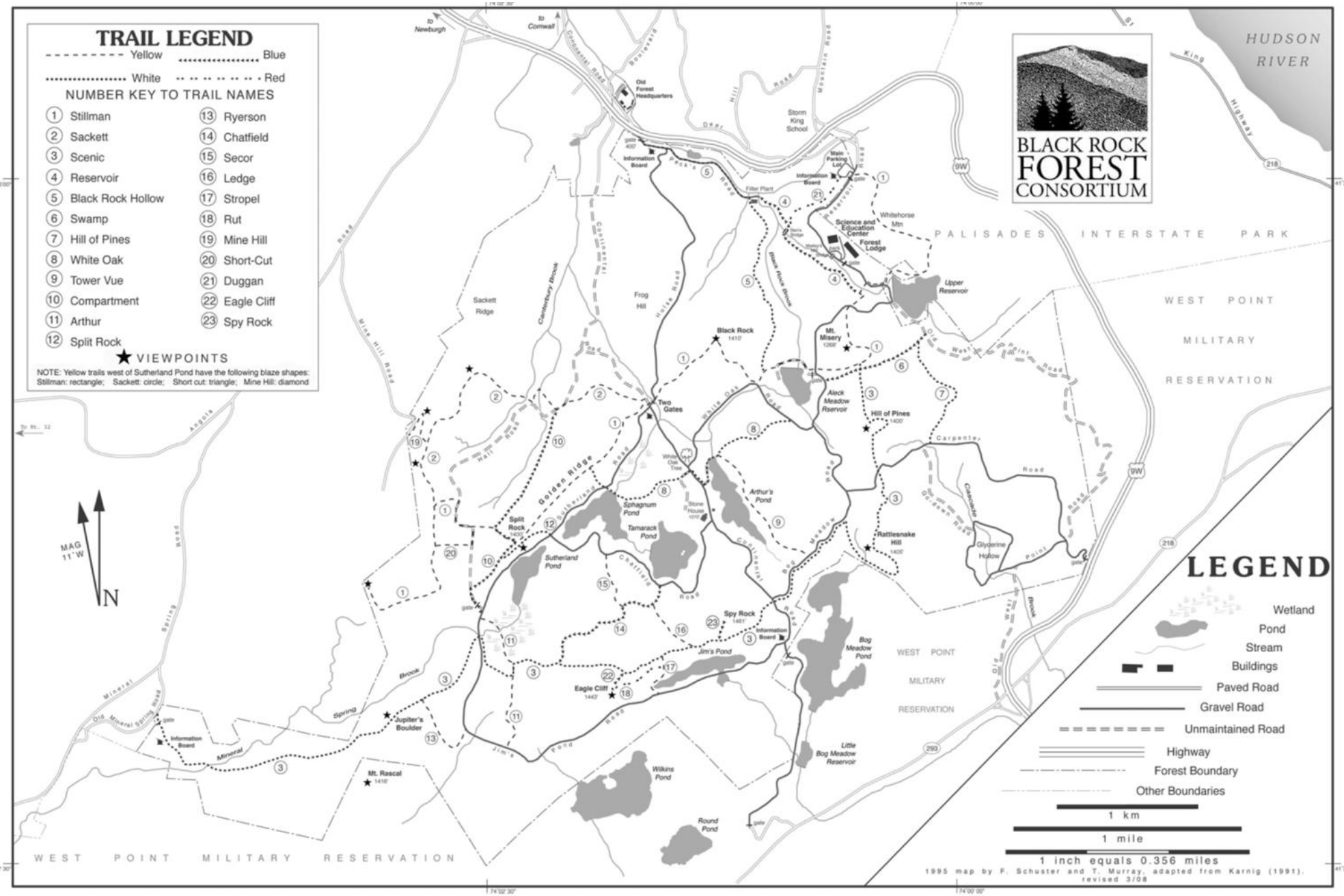


Figure 5: Study Site Location. Map of BRF showing key forest features such as important trails and roads and natural features such as ponds (https://blackrockforest.org/about/about-forest/maps).

b. Data collection/field work

Scats were collected opportunistically by Black Rock Forest staff, primarily the forest manager, John Brady, starting in December 2017 and continuing through May 2018 (though no samples were collected during the month of March 2018). I collected scat samples systematically from May through July 2018. I, and occasionally other BRF staff, would walk specific trails known for coyote activity every other day and collect coyote scat when observed. The most frequently hiked trails were Jim's Pond Road, Eagle Cliff, Hall Road, Old West Point Road, and smaller trails branching off from these.

Although it is hard to ensure that scat collected on a given day was deposited at that spot with certainty during the month it was collected, I attempted to minimize this uncertainty by repeatedly walking the same trails, making it more likely that scats spotted and collected were fresh. In the winter months, because of the stark color contrast between the scat and snow, it was easier to identify and collect recent scats. If scats were particularly hard/brittle and showed other indications of being old, such as formation of a white crust, they were not collected.

Coyote scat was identified by its physical characteristics such as size, shape, and composition (Cepak, 2004). A minimum size threshold of a roughly 20 mm diameter was applied to scats collected to ensure the highest likelihood of collecting coyote instead of fox or bobcat scats. Northeastern coyote scats are usually about 25 mm in diameter, whereas bobcat are slightly smaller at around 18.5 mm, and fox are usually around 12.5 mm (Gompper et al., 2006). Coyote scat tends to have a very characteristic appearance, being long and ropelike with tapered ends (Cepak, 2004). Another clear indication that the scat was coyote was the presence of fur, bones, claws, or teeth (Cepak, 2004). Because domestic dogs typically do not eat wild animals, the assumption was made that if the scats contained these materials, bones and fur, they were not from domestic dogs (Cepak, 2004). Additionally, while the forest is open to the public and used recreationally by many dog owners, most of the roads where scat was collected were

in more remote parts of the forest and less well traveled by humans and their dogs. There were two main ways to distinguish coyote and bobcat scat, besides the size threshold. The first is the physical appearances of the scats. According to a website about animal tracking, Bobcat Track and Sign, whereas coyote scat is usually long and ropelike, bobcat scat is typically rounder and sharply segmented (https://emammal.si.edu/okaloosa-science-home-page/blog/bobcat-track-and-sign). The second indicator that scat might be bobcat is the presence of scratch marks in the dirt surrounding the scat because bobcats often try to "bury" or cover up their scat with dirt. Therefore, if scrape marks or similar physical indentations were observed in the ground near the scat, it was likely to be bobcat and was not collected.

I collected scats using a sealable plastic bag and then labeled the bags with the location, a descriptive location and GPS coordinates, and date. I collected GPS coordinates, using the Avenza Maps (Avenza Systems Inc.) app on an iPhone, for scats collected in the summer months. Scats were then stored in a standard freezer until further analysis. For preparation, scats were placed in nylon stockings and then left to soak in a large bucket of water overnight (typically for at least 12 hours; Cepak, 2004). The next day, scats were removed from the stockings and spread over a large, flat, 1 m, mesh screen and washed with hot water until all the fecal matrix had been washed away leaving only hair and bones. Samples were then left inside the lab room to air dry on a screen near the window with direct sunlight access at room temperature for 7 days.

c. Prey Species Identification

When scat samples were completely dry, the contents were individually examined and separated into vials for each sample as either "Hair", "Bones", or "Miscellaneous." Any leftover hair or bones from the sample that did not fit in the vial were placed in sealable plastic bags and labeled with the ID of the corresponding scat sample.

i. Bone Identification

Mammalian diet items were identified using bones, primarily mandibles, teeth, incisors, and claws, and identified to the closest class (such as Mammalia or Aves), order (such as Rodentia), family, genus or species level possible (Figure 6; Roest, 1986; Knox Jones and Manning, 1992; Elbroch, 2006).



Figure 6: An example of bones identified within a sample. This is sample 20B which was collected in January. This sample is primarily squirrel with a few incisors from a smaller unidentifiable rodent.

ii. Hair Identification

The hair samples were extremely large for each sample; therefore, analyzing each hair was not feasible. To determine which hairs to select I first selected a sub-sample of the entire sample (the sample that was put in a bottle) that looked as representative of the entire sample as possible (pulling out representative hairs for every clump that appeared to be possibly different from other hairs in the sample.). From the sub-sample I then went through and picked hairs that looked representative of different hair types within this sample. I then mounted these hairs on microscope slides for further examination. Depending on the heterogeneity of the samples, sometimes this meant having one slide with two to three hairs on it, and other times a sample might be represented by two slides with 5 hairs on

each. The hairs were then viewed using several standard compound microscopes and one trinocular polarizing microscope and identified according to Moore et al. (1974) and Adorjan (1969) and by comparing them to a reference collection of hairs I made from animal pelts at Black Rock Forest and the American Museum of Natural History mammalian reference collection compiled by Neil Duncan for his New York City coyote dietary analysis project (see Figure 7). The polarizing function of the trinocular microscope was not necessary; however, this microscope was connected to a computer software program with which I could photograph the hairs.

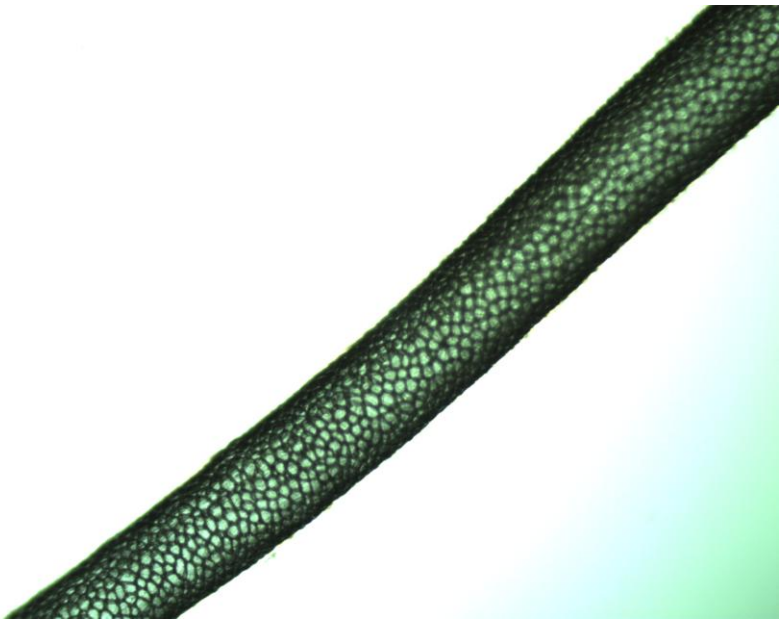


Figure 7a.

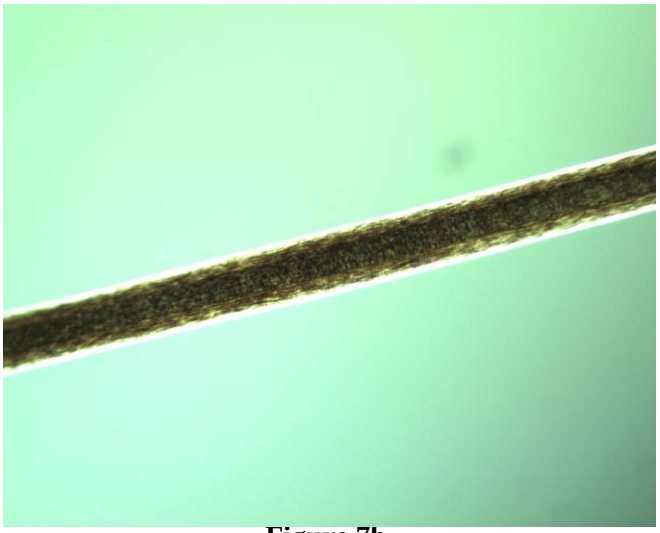


Figure 7b.

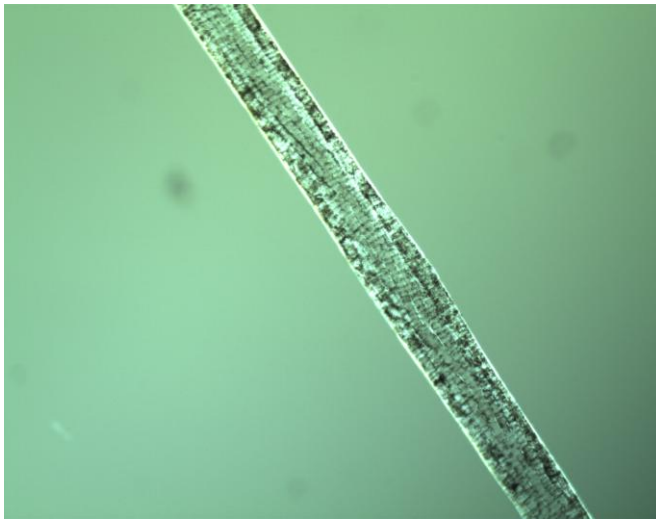


Figure 7c.

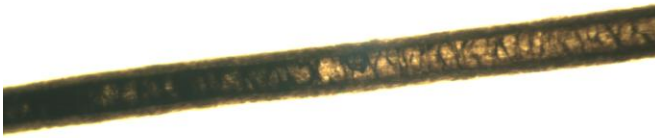


Figure 7d.

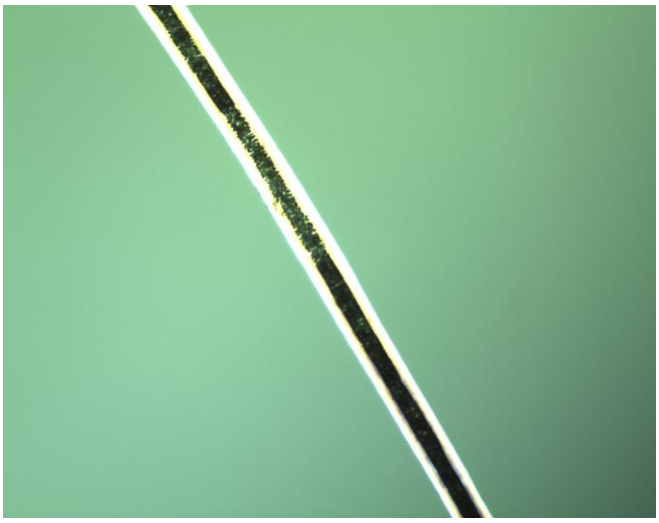


Figure 7e.

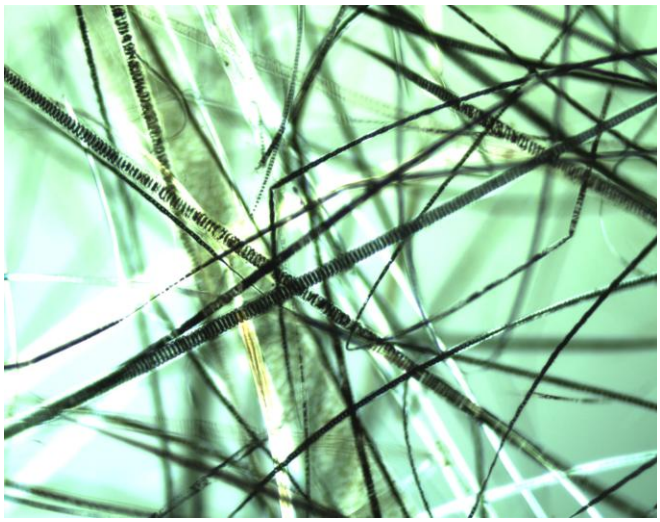


Figure 7f.



Figure 7g.

Figure 7: Microscopic view of several example species hairs. These images show the view of a few exemplary species, and families (*Microtus*), under the microscope. 7a. - white-tailed deer hair (*Odocoileus virginianus*), 7b. - muskrat (*Ondatra zibethicus*), 7c. - rabbit (*Sylvilagus floridanus*), 7d. - striped skunk (*Mephitis mephitis*), 7e. – northern raccoon (*Procyon lotor*), 7f. - shrew hair (*Sorex cinereus cinereus*), and 7g. - vole hair (*Microtus* spp.).

d. Statistical Analyses

I analyzed the contents of my scat using the frequency of occurrence method, which is the most widely used method in carnivore diet analyses (Klare et al., 2011). This can be done one of two ways. By noting the frequency of occurrence of prey items and then relating it to the total number of scats

examined or to the total number of prey items found (Klare et al., 2011). I chose to calculate my frequency of occurrence in relation to the total number of scats examined because this is one of the most widely used methods (Klare et al., 2011) and would therefore make my results comparable to other dietary studies and because it is easy to conceptualize frequency of prey items as a percentage of the scats that contain that prey item, though there are shortcomings to this method (see Discussion). To determine if there was a difference in the proportion of deer hair found in the scats between the three seasons, winter (December, January and February), spring (April and May) and summer (June and July) I conducted a Bayesian statistical analysis, that consisted of performing a binomial regression and creating a binomial generalized linear model, using the programming language R.

III. RESULTS

a. Results of Hair Examination

I collected and processed 71 scats beginning in December 2017 and ending in June 2018. After I began to examine more closely the 71 selected scat samples, I determined that two scats collected in May were dog and excluded them from my analysis. I included only the contents of sixty-nine of the scat samples in my hair and bone analysis. Of the sixty-nine samples, deer remains were found in 68.1% of samples via hair examination. During the winter (December, January, and February), deer remains were found in 87.1% of all samples, during the spring (April and May) deer remains were found in 55.6% of the samples via hair examination, and during the summer (June and July), deer remains were found in 50% of the samples (Figure 8).

I was unable to identify the species of all of the hair samples I chose to analyze. I made a total of 149 microscope hair slides. Because the hair composition of each scat was so heterogeneous, the number of hair microscope slides per scat and the number of hairs per microscope slide differed. Of the 149 microscope slides, there were 27 slides where I was unable to identify the species of any of the hairs on

the slide.

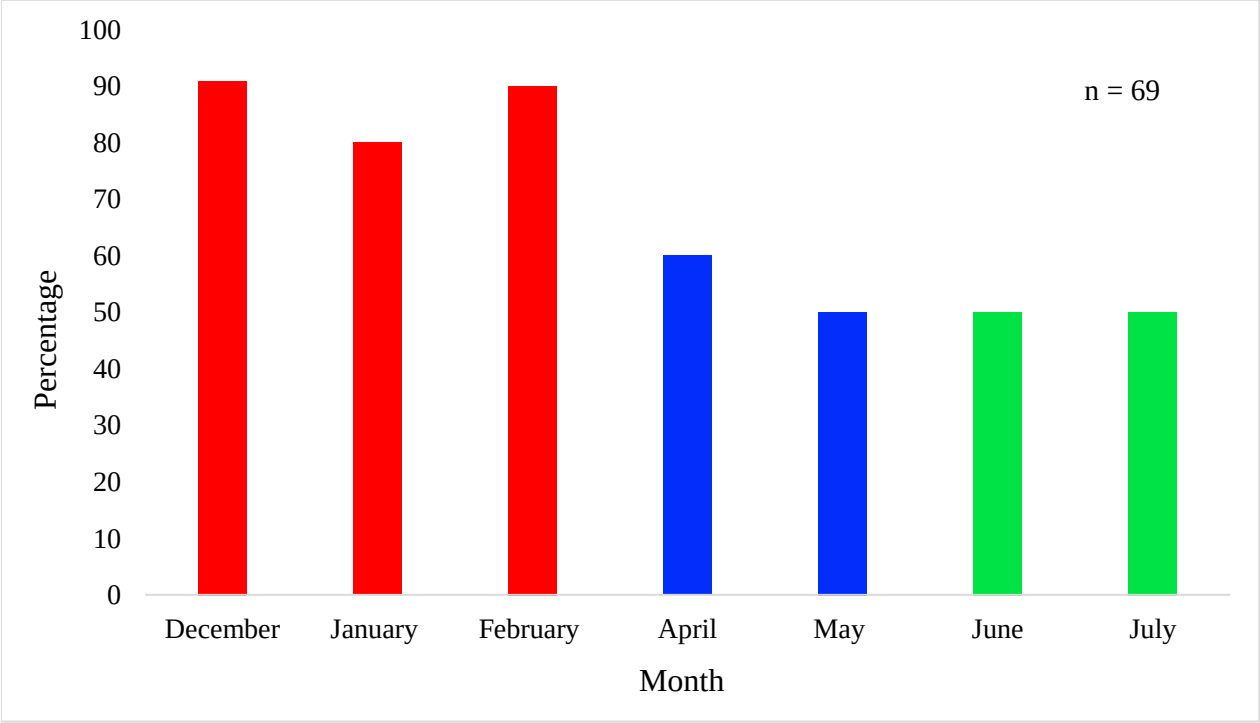


Figure 8: Monthly Percentage of Coyote Scats Containing Deer Hair at Black Rock Forest from December 2017 to June 2018. This bar graph illustrates the declining trend over the course of the year of the proportional amount of deer hair found in coyote scat samples per month. The percentage represented by each month is the percent of samples collected that month that contained deer hair. The three colors represent the three seasons sampled, winter (December, January, February), spring (April and May) and summer (June and July).

In addition to identifying deer, I identified ten other species, or genera, by examining hair samples, Eastern gray squirrel (*Sciurus caroliniensis*), muskrat (*Ondatra zibethicus*), groundhog (*Marmota monax*), northern raccoon (*Procyon lotor*), vole (*Microtus* spp.), striped skunk (*Mephitis mephitis*), rabbit (*Sylvilagus floridanus*), masked shrew (*Sorex cinereus cinereus*), American beaver (*Castor canadensis*), and Virginia opossum (*Didelphis virginiana*; Table 1).

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Table 1: Species Detected in Scat via Hair Analysis. This table gives the presence/absence results for all species found in the scat by identifying hair samples. The "Number of Times Observed" column reflects the number of scats that each group was observed in and the "% of Scats Observed in" column is the number of scats each item was found in divided by the total number of scats analyzed (n = 69).

Type of Animal Observed	Number of Times Observed	% of Scats Observed in
Deer	47	68.1
Squirrel	18	26.1
Muskrat	13	18.8
Groundhog	6	8.7
Raccoon	5	7.3
Vole	4	5.8
Skunk	3	4.4
Rabbit	2	2.9
Shrew	2	2.9
Beaver	1	1.5
Opossum	1	1.5

b. Results of Bone Examination

The bone examinations confirmed most of the groups identified by hair samples and revealed one additional species, the chipmunk (*Tamias striatus*) and the presence of bird remains. Depending on the type of bone evidence in the scat, sometimes only a genus or order level analysis was possible, and therefore I erred on the side of caution rather than attempt a species identification that might be incorrect. This is why there are "Rodent" and "Mammal" categories; oftentimes I would find an incisor and only be able to say rodent, or a mammalian claw and identify it only as mammal. In addition to the bones I was able to classify only broadly as "Rodent" or "Mammal", there were many bone fragments that were broken up to the point that they were only identifiable as animal bones. Some of these were found alongside identifiable bones. There were 21 samples, however, that contained only unidentifiable bone fragments.

Table 2: Species Detected in Scat via Bone Analysis. This table gives the presence/absence results for all species or animal groups found in the coyote scat by identifying bone remains. The "Number of Times Observed" column reflects the number of scats that each group was observed in and "% of Scats Observed in" column is the number of scats each item was found in divided by the total number of scats analyzed (n = 69).

Type of Animal Observed	Number of Times Observed	% of Scats Observed in
Squirrel	15	21.7
Rodent	11	15.9
Bird	8	11.6
Mammal	7	10.1
Muskrat	6	8.7
Vole	6	8.7
Rabbit	4	5.8
Shrew	3	4.4
Raccoon	2	2.9
Chipmunk	1	1.5

c. Combined Results of Hair and Bone Examination

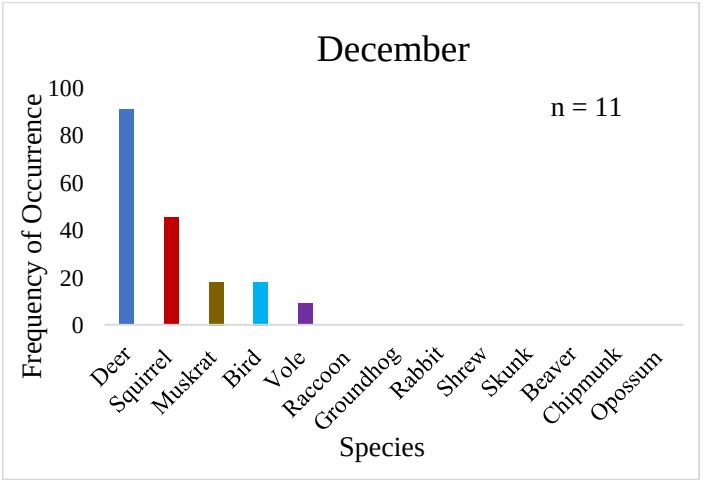
I combined the results of my bone and hair identification to get a more comprehensive set of species identified in the scats throughout the study period (Table 3). I did this by looking at both the hair and bone remains in each scat and if there was overlapping evidence in one scat sample, for example both a muskrat tooth and muskrat hair, I would assume these came from the same animal and only count that species once to avoid double counting.

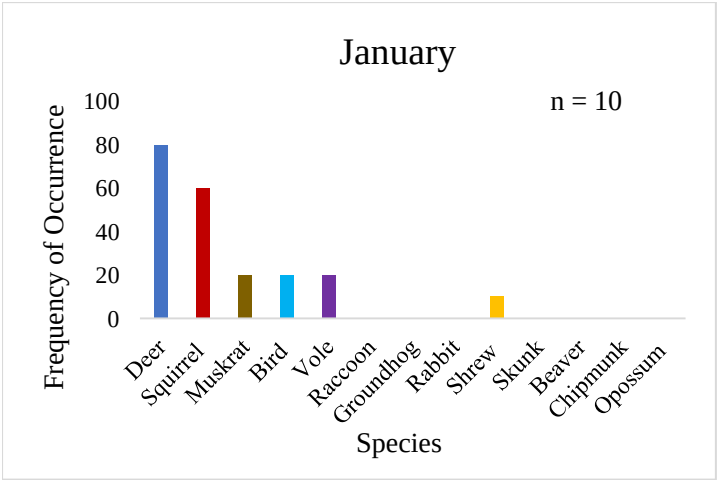
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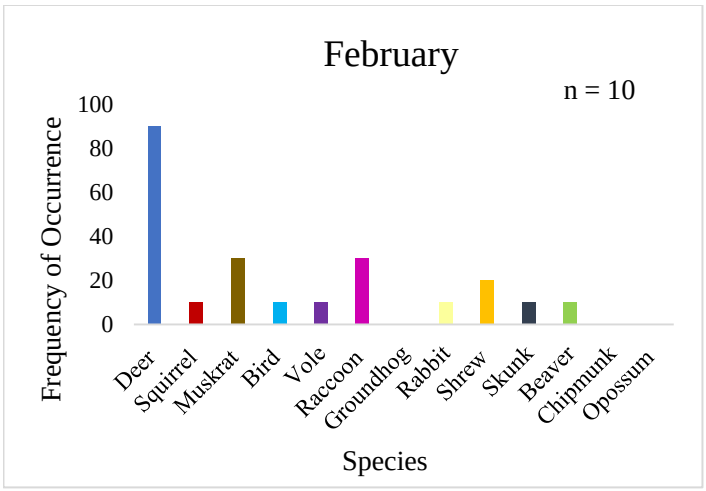
Table 3: All Species Detected in the Scats via Both Hair and Bone Analysis. This table gives the presence/absence results for all species found in the scat by identifying bone and hair remains. "Number of Times Observed" column reflects the number of scats that each group was observed in and "% of Scats Observed in" column is the number of scats each item was found in divided by the total number of scats analyzed (n = 69).

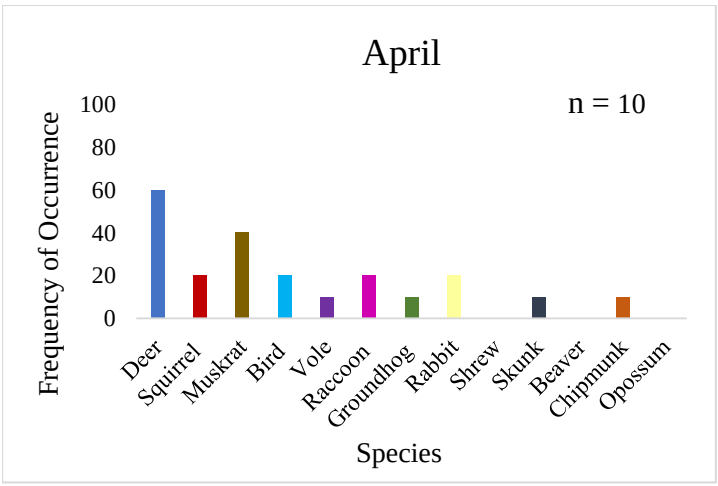
Type of Animal Observed	Number of Times Observed	% of Scats Observed in
Deer	47	68.1
Squirrel	24	34.8
Muskrat	13	18.8
Bird	8	11.6
Vole	7	10.1
Raccoon	7	10.1
Groundhog	6	8.7
Rabbit	5	7.3
Shrew	4	5.8
Skunk	3	4.4
Beaver	1	1.5
Chipmunk	1	1.5
Opossum	1	1.5

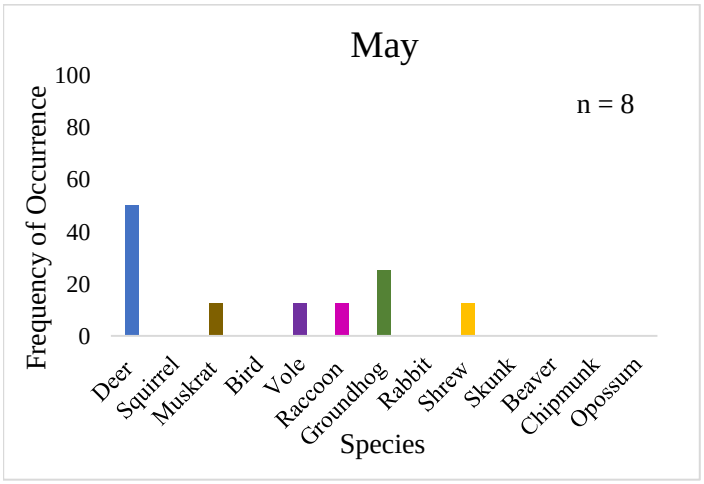
Figure 9 shows 7 graphs each showing the frequency of occurrence of each species on a monthly basis starting with December ending with July. Because the sample sizes differed slightly between months (December had 11 samples, May had 8 and the rest of the months had 10), for these figures frequency of occurrence for each species was calculated by month. For example, the deer column in December shows 91% of scats this month contained deer hair, calculated as ten divided by eleven.

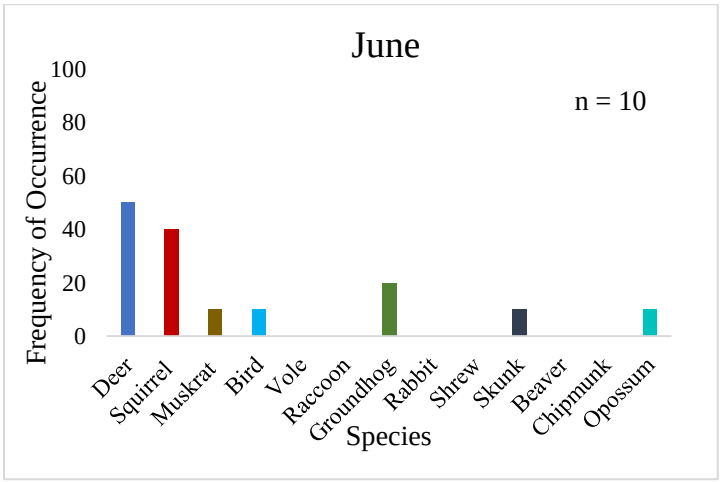












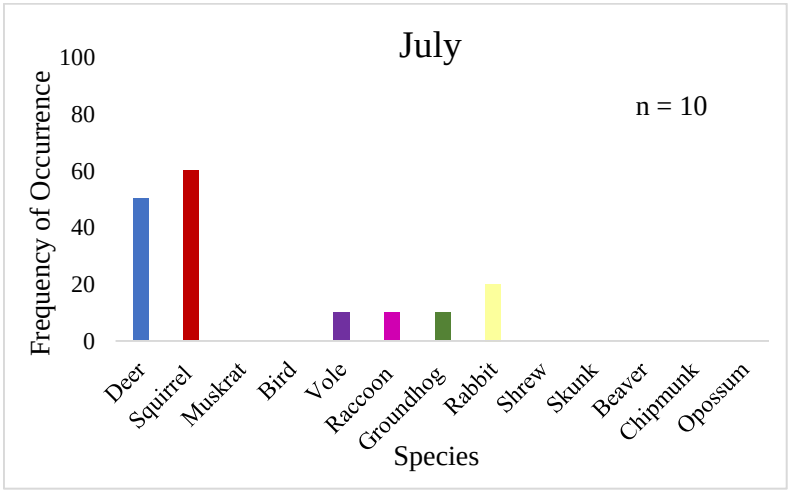


Figure 9. Monthly Frequency of Occurrence of all Species from December 2017 to July 2018. Frequency of occurrence for each species every month as the number of scats that species was observed in that month divided by the total number of scats collected that month.

d. Non-Mammalian Diet Items

In addition to the animal species I identified in the scat, I also observed many instances of plant consumption by coyotes. A variety of seed types and nut shells were frequently observed in the scats throughout the entire study period. Plant matter was most frequently observed in the scat in the mid-late summer months, with some processed scat samples consisting almost entirely of huckleberry or blueberry remains. Although the vast majority of diet items I observed were natural, I did observe anthropogenic materials in the form of some type of duct tape/foil material in one scat collected in June.

e. Statistical Analysis Results

I performed a binomial regression on presence/absence data of deer hair in the scat for each of the three seasons: winter, spring, and summer, using the "rethinking" and "dplyr" packages in R. The regression and linear model were performed according to explanations in Richard McElreath's *Statistical Rethinking* (McElreath, 2015).

I created density plots showing the posterior distribution of the probability of deer hair within the scat for each season (Figure 10). A density plot is very similar to a histogram, it is graphing all of the posterior probability samples produced by the model for each season for the predicted likelihood of finding deer hair in the scat. I used the logistic function to translate the 99% highest posterior density intervals (HPDIs) for each season, which are originally in log odds, into probability values (which is what is illustrated in Figure 10). The posterior probability distributions of deer hair in scat across the seasons are: .54 to .97 for winter, .21 to .86 for spring, and .19 to .81for summer. The mean values of these distributions are: .76 for winter, .53 for spring, and 0.5 for summer.

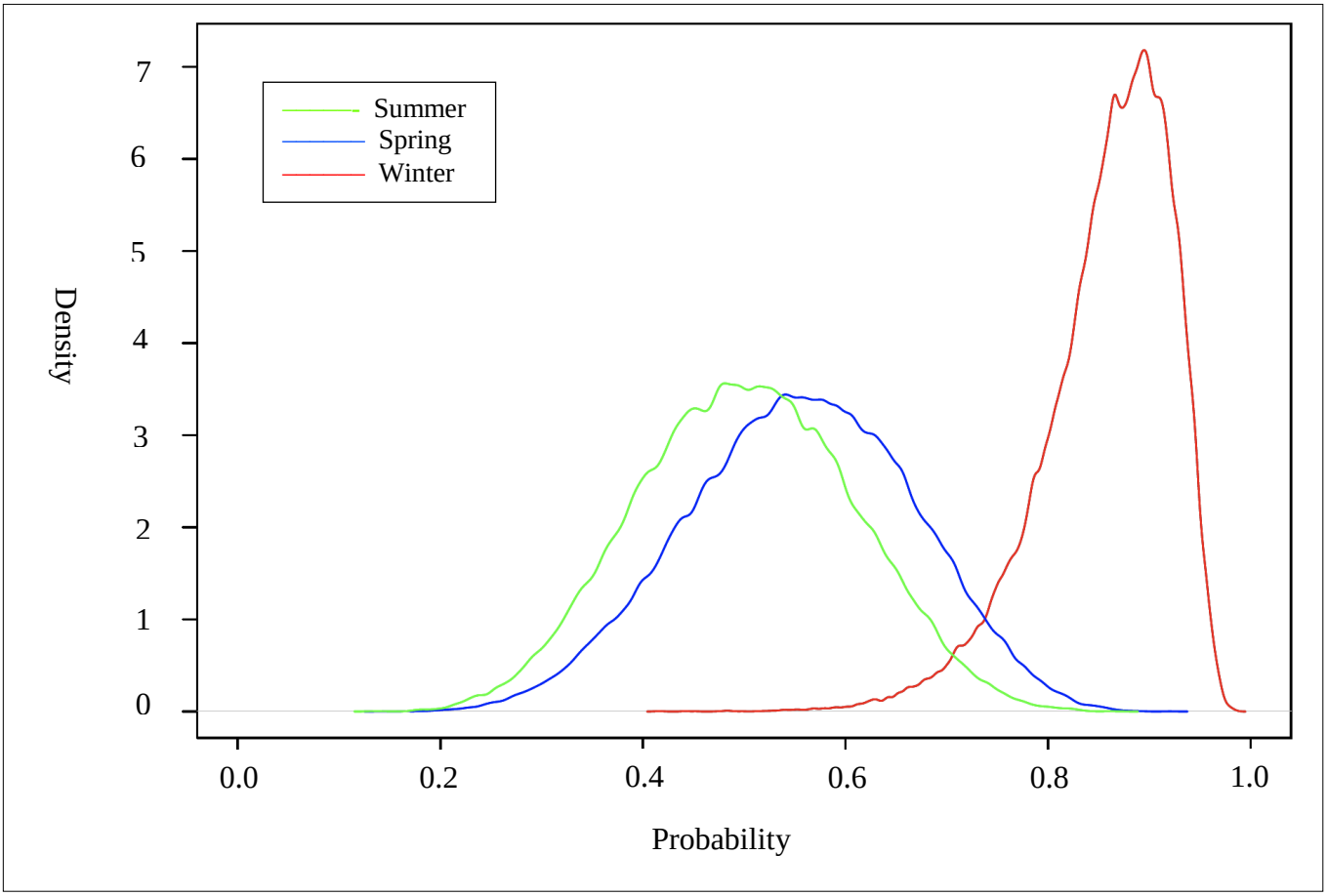


Figure 10: Probability of Observing Deer Hair in the Scat per Season. The seasonal density plots of the posterior probability distributions implied by the binomial generalized linear model estimates (distributions generated by drawing 50,000 posterior samples from the model). The large overlap between the spring and summer distributions indicates similar probabilities of observing deer hair in scats collected in those seasons, while the minimal overlap between these two seasons and winter indicates there is a significant difference in the probability of observing deer hair in the winter versus the later seasons. The position of winter to the right of the other two seasons on the x-axis indicates a higher probability of observing deer hair in the winter scats. The narrower width and higher peak of the winter distribution reflects the model's higher confidence that the probability of observing deer hair in the scats this season will fall in this range, which is the result of this season have a larger sample size (n = 31) as opposed to spring (n = 18) and summer (n = 20).

To further illustrate the fact there is a significant difference in the probability of observing deer hair in the scats between spring and winter, and summer and winter, but not between spring and summer, I calculated the differences in the probability of deer hair between each season and summarized these distributions of differences using 97% HPDIs. The range of the difference between winter and spring was, (-0.59, -0.04; Figure 11), the range of the difference between summer and winter was (-0.61,

-0.08; Figure 12), and the range of the difference between spring and summer was (-0.39, 0.26; Figure 13). The significance of these numerical ranges was visualized in Figure 10. If the distribution of the differences in the probabilities of two ranges of values falls completely on either side of 0, that is the range is entirely negative or entirely positive, the model predicts there will be no to minimal overlap in the values of these 2 groups, implying they are significantly different. If the distribution of the differences in the probabilities of two value ranges spans 0, the range goes from negative to positive, this means there is substantial overlap between the values of these two groups and that they are not statistically different. Looking back at the ranges of difference between the three seasons, we see the distribution is entirely negative for the differences between winter and spring, and winter and summer, but that the distribution spans 0 for the difference between summer and spring.

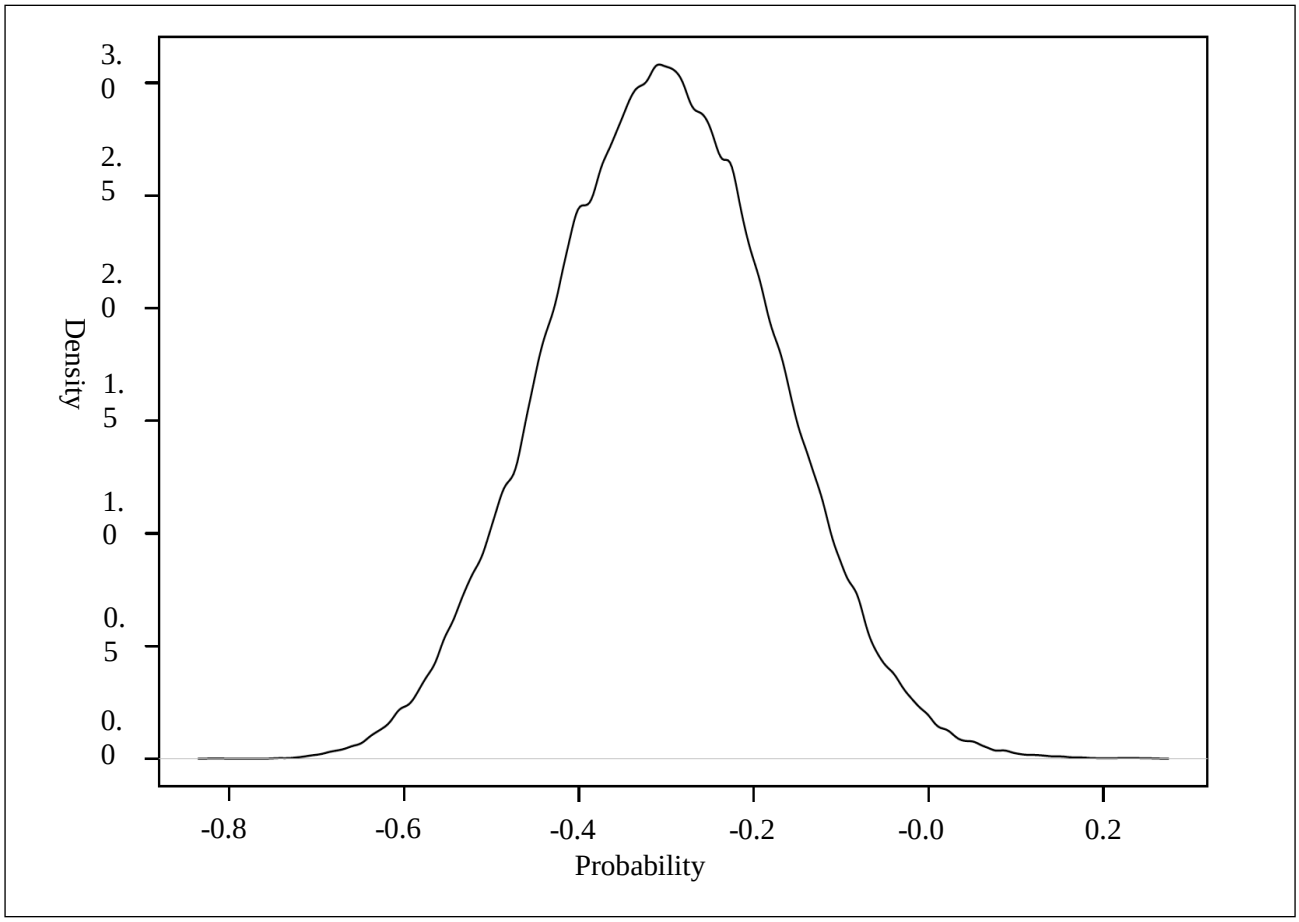


Figure 11: Distribution of the Differences in the Probability of Deer Hair between Winter and Spring. Shows the entire range of the distribution of the differences in the probability of observing deer hair in the scats in winter and in spring. Nearly the entire range is negative, suggesting this difference is significant.

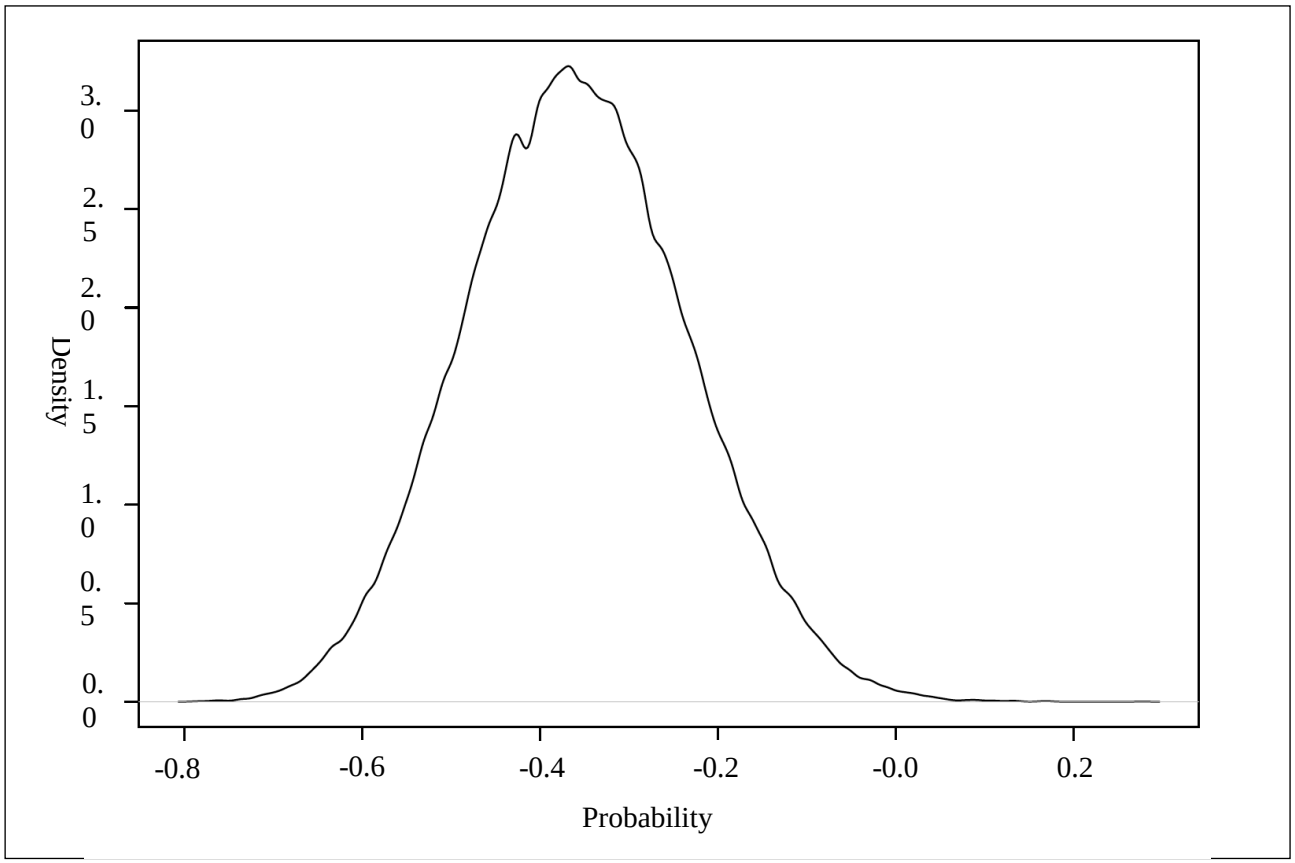


Figure 12: Distribution of the Differences in the Probability of Deer Hair between Winter and Spring. Shows the entire range of the distribution of the differences in the probability of observing deer hair in the scats in winter and in summer. Nearly the entire range is negative, suggesting this difference is significant.

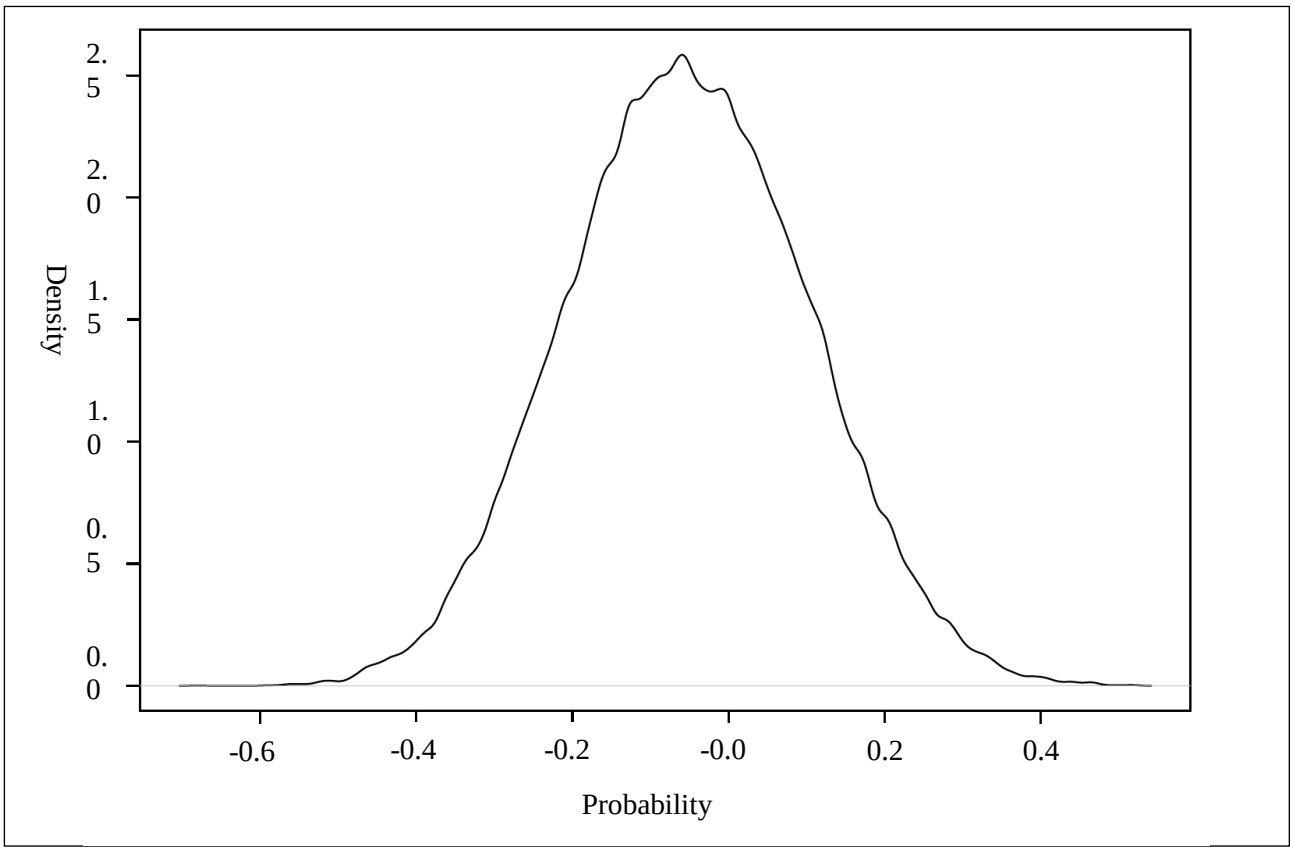


Figure 13: Distribution of the Differences in the Probability of Deer Hair between Spring and Summer. Shows the entire range of the distribution of the differences in the probability of observing deer hair in the scats in spring and in summer. The range goes from negative to positive, demonstrating this difference is not significant.

IV. DISCUSSION

The data on deer hair frequency of occurrence in the coyote scat do not support my previous hypothesis that coyote predation on deer would peak during fawning season (May 20th-June 20th). Instead there is an unexpected trend of a decreasing amount of deer hair in the scat from winter to spring and summer. The large variety of species consumed by coyotes in this study period supports the literature that the coyote is a generalist and seasonal predator with the potential to impact a number of species with their predation in BRF, chief among which appear to be white-tailed deer and eastern gray squirrels (Samson and Crête, 1997; Gompper, 2002; Huff, 2015).

The results of my dietary analysis agree with several other coyote dietary studies conducted in the eastern Unites States that show white-tailed deer are one of the most common prey items for northeastern coyotes. A study conducted in the Cuyahoga Valley National Park in Ohio found that the most important coyote prey items were meadow vole (*Microtus pennsylvanicus*), white-tail deer, and eastern cottontail, occurring at frequencies of occurrence of 28%, 20%, and 20% respectively (Cepak, 2004). A study conducted in the surrounding Chicago Metropolitan area on 4 study sites across a human land-use gradient examining two public forest preserves, one private preserve and several city parks, found that across all locations small rodents were the most frequently observed prey item (41.8%), followed by white-tailed deer (22.0%), followed by fruit (22.7%) and eastern cottontails (17.7%) (Morey, Gese & Gehrt, 2007). Lastly, another study monitored the diet of coyote populations via scat examination from June 2007 to August 2008 in central New York state at two locations, one in Steuben County and one in Ostego County (Boser, 2009). Boser also found that white-tailed deer made up more of the coyote diet in the winter, with 53% to 74% of the diet being deer, than in the summer when this amount dropped to 29 to 50% (2009).

Similar to my results, the last study by Boser, observed a higher proportion of deer remains in the winter scats versus the summer scats. There are several potential explanations for why, contrary to my expectations, coyotes may be consuming more deer in the winter than the summer. The first potential explanation is that the majority of deer being consumed by coyotes are actually carrion, and carrion is potentially more available in the winter months. Coyotes consume carrion throughout the year and it therefore likely makes up a large portion of their diet (Huff, 2015). Coyotes scavenge leftover kills, and in the winter due to the hunting season and increased road kill activity, there are many opportunities for humans to inadvertently provide coyotes with dead deer (Huff, 2015). In fact, in his study, Cepak (2004) attributes most of the white-tailed deer consumption by coyotes to be the result of carrion, and not predation.

A second potential factor is that white-tailed deer, excluding newly born fawns, tend to be more vulnerable to coyote predation in the winter. Deer mortality from coyotes can be higher in severe winters when deer yard together, a behavioral adaptation where by grouping together in clusters they can all benefit from high quality food sources and take advantage of group warmth (Huff, 2015). Additionally, heavy snow cover in the winter can impede the mobility of deer making them more susceptible to predation (Huff, 2015).

A last, and related reason, for why we might see a decrease in the proportion of deer remains in the coyote scat as the seasons transition from winter to spring to summer is that as winter ends, a greater variety of food sources become available. This is demonstrated by looking at Figure 9 where starting around February and April, there begin to be more species observed in the scat. A specific example of this is that groundhogs begin to appear in the scat beginning around April as they come out of hibernation. Additionally, in spring and summer plant resources become more readily available. From the increasing proportion of scats with seeds, nuts and particularly berries as spring turns into summer, it

is demonstrated that coyotes are indeed taking advantage of this resources as well.

These three theories potentially address the refutation of my primary hypothesis, why I did not observe the trend of peak deer consumption in the spring that I expected. In fact, the results indicate that deer seem to be well adapted to minimizing coyote predation in the fawn phase. Of the deer hair observed in scats, there was a higher ratio of fawn to adult deer hair observed in the scat starting in late spring/early summer, but it was less than I expected and if coyotes were limiting the deer population I would expect to see a higher proportion of deer remains in the coyote scat during the deer populations' most vulnerable time of year.

This leads to the second question I was hoping to answer with my results, which was whether the the coyotes at Black Rock had the potential to limit the local white-tailed deer population. This hypothesis was inspired by historical records at the forest that noted a peak deer population density in the 1970s and 1980s of around 30 deer per square mile, which then decreased in the 90s and 00s to 20 or fewer deer per square mile, and since 2013 the deer density has appeared to stabilize at 11 to 13 deer per square mile (pers. comm. Bill Schuster, BRF Executive Director, April 2019). This decreasing trend in deer population in conjunction with the arrival and establishment of a coyote population at the forest seems to suggest a connection. Additionally, overgrazing by white-tailed deer has been a problem in the forest, particularly by preventing the growth of important tree species saplings like oak, and with the decrease in deer abundance during the past few decades, the forest has seen a resurgence in these previously suppressed species (pers. comm. Bill Schuster, April 2019). This beneficial change was assumed to be in part the result of the newly established coyote species and therefore current forest management prevents any hunting of coyotes on forest property. But the question still remains if coyotes really are limiting white-tailed deer at BRF?

If coyotes are preying on live deer in the forest, then they are probably at least in part responsible

for this change in ecosystem effects. It has been well documented, that carnivores, and specifically coyotes can have cascading effects throughout the ecosystem (Thompson and Geese, 2007; Levi and Wilmers, 2012). However, as previously stated, evidence of deer remains in coyote scat does not directly support coyote predation of deer in the forest. So although deer do constitute a significant portion of the coyote's diet, as demonstrated by the fact deer remains were observed in 68.1% of the coyote scats throughout the study, the effect of coyote predation on the deer population is uncertain since deer remains in coyote scat are not direct evidence of coyote predation on deer. Coyotes can take down and kill fully grown deer, especially those that might be weak or injured, and this past winter BRF's previous forest manager, John Brady, found deer kill evidence of at least one example of coyote predation of deer at Black Rock (Huff, 2015; pers. comm. John Brady, April 2019). The results from my study; however, are insufficient to prove on their own that coyotes are limiting the deer population at Black Rock. To determine this more directly, an experiment would need to closely document deer fawn population numbers and coyote population numbers from year to year, as well as physically track fawns and locate them as soon as possible when they die to determine if coyotes were the source of death, or is some other cause of mortality was responsible, as performed by Kilgo et al. (2012) in South Carolina. Additionally, while it has been widely acknowledged that coyotes can limit deer population numbers, and many studies such as Kilgo et al. have proved this phenomenon on a local forest level, a recently conducted, region wide study produced contradicting results. Bragina et al. (2019) examined county level deer harvest records across 6 eastern states (New York, New Jersey, Ohio, North Carolina, South Carolina and Florida) from 1930-2016, the time of the coyote's colonization of the eastern U.S. Surprisingly their results demonstrated that the establishment of coyotes in these areas had little to no negative affect on the deer populations.

In addition to white-tailed deer, eleven other species/groups of animals were observed in the scat.

Because of their diverse diet coyotes are preying on species relied upon by other mesocarnivores in the forest, such as foxes and bobcats, and I therefore predicted my results could indicate some competition between these species and theorize the subsequent possible impacts of coyotes on these mesocarnivore populations. Similar to the limitations involved in answering directly the question of coyote's limiting the deer population at Black Rock, this question can't fully be answered without having population numbers of these carnivores on an annual basis for comparison and without observing interactions between these carnivores, especially over resources use such as food or territories. However, camera trap data from the forest this winter suggested healthy and thriving populations of both bobcats and red foxes at the forest (pers. comm. Bill Schuster and John Brady, April 2019). Although my data seems to suggest the potential for competition between coyotes and these mesocarnivores exists at BRF, with the potential to negatively affect pre-existing mesocarnivore populations, there appears to be other factors at play enabling these three carnivore species to coexist. This could be due to resource partitioning, perhaps by consuming so much deer the coyotes are taking away fewer resources from these smaller predators than they could be.

Although my study cannot directly answer these important questions about the way the coyote population at BRF is impacting the deer population and bobcat and fox populations, the results of this study provide important information for better understanding the ecology of the coyote in this northeastern forest and for informing future forest management decisions. From these results we know the coyote diet at BRF is quite varied and that they consume a lot of deer and squirrel. The unexpected result that coyotes are consuming significantly more deer in the winter than in the spring and summer is important to know for predicting how coyotes will potentially affect BRF white-tailed deer population demographics in the future. For example, knowing that deer is a primary source of food for coyotes in the forest, if in the future the deer populations were to decrease substantially, forest management would

likely have to consider permitting coyote hunting to control their populations to prevent deer from being extirpated.

Limitations of this study

Despite all the necessary precautions taken to ensure data collected was as accurate as possible, there is still room for error in the hair and bone identifications; however, the high proportion of deer remains found in the scats lends confidence to the sampling methods.

Klare et al. (2011) points out a couple important flaws with the frequency of occurrence method. This is because frequency of occurrence gives the same weight to the presence of small and large food items in a scat. For example, a sample might have a couple of shrew mandibles in it, 10 squirrel claws, 8 squirrel teeth and a few squirrel incisors, and the entire sample might consist of ninety-percent deer hair; however, occurring to frequency of occurrence, which is based on presence/absence of a specimen in a scat, they are all weighted the same. Therefore, results based on this method tend to imply that small prey species are a more important/prevalent part of the species' diet than they really are (Klare et al., 2011). This is because a scat containing a larger prey item, such as deer, is more likely to be made up entirely of that one species, while a greater number of small prey food items is likely to occur in one scat (Klare et al., 2011).

On the other hand, this method can be valuable for discovering information about rare food items, contributing to a more robust understanding of a predator's diet composition and ecology (Klare et al., 2011). When possible, in addition to qualitative methods, quantitative methods should be implemented, such as using volume or mass measurements to calculate the relative scat composition (Klare et al., 2011). Weighing/measuring every scat is very time consuming, however, and is complicated by the fact that all scats come in different shapes and sizes with varying proportions of prey remains to fecal matrix, so sometimes this step is not feasible (Klare et al., 2011). Because of time and

resource constraints, I did not collect mass or volume measurements. Therefore, following the suggestion of Klare et al., who cautioned against interpreting too far into results based solely on the frequency of occurrence method, the results of this study should be interpreted with caution when trying to use the data to answer questions on a broader ecological scale, such as predicting the degree of niche overlap with other predators in the forest or determining the direct impact of predation on prey populations, such as deer (Klare et al., 2011).

Additionally my animal identification method was mammalian biased because of the important role of hair in my identification methods. It is very likely that coyotes at BRF consume many more than just the twelve species I identified, but because of my relatively small sample size and mammalian biased methods I likely missed some prey species.

V. CONCLUSIONS

Paramount to understanding how coyotes are influencing this ecosystem is first developing a foundation of basic biological and ecological information about how this species lives in this southeastern NY forest. This project represents the first time data have systematically been collected on the coyote diet at Black Rock Forest throughout different times of the year. This study determined that white-tailed deer do constitute a large part of the coyotes diet throughout the year, and that there is a significant difference in the amount of deer consumed by these coyotes in the winter compared to spring and summer, with winter representing much higher consumption of deer. The prevalence of white-tailed deer, a large prey item, in the diet of this northeastern coyote population supports the growing literature that coyote-wolf hybrids, known as the northeastern coyote, are adapting to fill what used to be the wolf's niche in these ecosystems. Although the historical decreasing deer population trend in conjunction with the coyotes arrival implies coyotes could be limiting the deer population in this forest, further studies are necessary to prove this, and as Kilgo et al (2012) and Bragina (2019) demonstrated, it

is important to analyze this question on several spatial scales before taking management action. In addition to white-tailed deer coyotes consume 11 other species/animal groups in the forest, yet this large breadth of diet items does not appear to negatively affect the bobcat or fox populations at the forest. This study recognizes its limitations in answering broader ecological questions about how the Black Rock Forest ecosystem functions but hopes to provide useful information and recommendations for future studies at the forest. Hopefully this work sets the foundation for further dietary analysis on the *Canis latrans* population, as we continue to develop an understanding of the role of coyotes within the BRF ecosystem. Future results, depending on what they yield, could have management implications for regulating both the coyote and deer populations at BRF.

VI. RECOMMENDATIONS

Because of the limitations of a purely qualitative analysis, it would be beneficial for future studies trying to characterize the diet of the coyote at Black Rock to include a quantitative component, in the form of mass or volume measurements. Similarly, genetic analysis has now become much more widely available and feasible. I would recommend that future studies incorporate a genetic component into their analysis, and if they don't have the means to do so at the time of their research, to at least save a subsample of scat from every sample instead of cleaning them fully so that that sample can be available for future genetic analysis which could then be used to corroborate or refute the results of hair and bone analyses. Another area for improvement would be more exhaustive field sampling. I recommend future studies obtain a larger total sample size, that the samples are collected more evenly across the months (i.e the same sample size for all the months), and that a full year round analysis is conducted. This study is missing all of fall and the month of March, which would have been interesting to include.

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VIII. REFERENCES

Adorjan, A.S., 1969, A Manual for the Identification of Hairs of Selected Ontario Mammals: Research Branch, Ontario Dept. of Lands and Forests, p. 1–64.

Ballard, W.B., Whitlaw, H.A., Young, S.J., Jenkins, R.A., and Forbes, G.J., 1999, Predation and survival of white-tailed deer fawns in northcentral New Brunswick: Journal of Wildlife Management, v. 63, p. 574 –579, doi:10.2307/3802645.

Bekoff, M., and Gese, E.M., 2003, Coyotes (*Canis latrans*): USDA National Wildlife Research Center – Staff Publications, v.224, p. 467–481.

Berger, K.M., and Gese, E.M., 2007, Does interference competition with wolves limit the distribution and abundance of coyotes?: Journal of Animal Ecology, v. 76, p. 1075–1085, doi:10.1111/j.1365-2656.2007.01287.x.

Boser, C.L., 2009, Diet and hunting behavior of coyotes in agricultural-forest landscapes of New York state [Master of Science thesis]: Syracuse, State University of New York, p.12–28.

Bragina, E.V., Kays, R., Hody, A., Moorman, C.E., Deperno, C.S., and Mills, L.S., 2019, Effects on white-tailed deer following eastern coyote colonization: The Journal of Wildlife Management, v. 0, p. 1–9, doi:10.1002/jwmg.21651.

Cepak, J.D., 2004, Diet Composition of Coyotes in the Cuyahoga Valley National Park, Ohio: Ohio Journal of Science, v.104, p. 60–64.

Chambers, R.E., 2006, The Coyote in New York State: Department of Environmental and Forest Biology, SUNY-ESF, https://www.esf.edu/pubprog/brochure/coyote/coyote.htm (accessed March 2019).

Colangelo, L.L., 2018, Gotham Coyote Project tracking coyotes across NYC, studying behavior: https://www.amny.com/news/coyotes-new-york-bronx-1.19712404 (accessed March 2019).

Cove, M.V., Pardo, L.E.P, Spínola, R.M., Jackson, V.I., and Sáenz, J.C., 2012, Coyote *Canis latrans*

(Carnivora: Canidae) range extension in northeastern Costa Rica: possible explanations and consequences: Latin American Journal of Conservation, v. 3, p. 82–86.

Dibello, F., Arthur, S., and Krohn, W., 1990, Food-habits of sympatric coyotes, Canis-latrans, red foxes, Vulpes-vulpes, and bobcats, Lynx-rufus, in Maine: Canadian Field-Naturalist, v. 104, p. 403–408.

Ehrlich, P.R., 1988, The loss of diversity causes and consequences, *in* Wilson, E.O., Peter F.M., eds., Biodiversity: National Academies Press (US), chp. 2, https://www.ncbi.nlm.nih.gov/books/NBK219310/ (accessed March 2019).

Elbroch, M., 2006, Animal Skulls: A Guide to North American Species: Mechanicsburg, PA, Stackpole Books, p. 1–740.

Fener, H.M., Ginsberg, J.R., Sanderson, E.W., and Gompper, M.E., 2005, Chronology of range expansion of the coyote, *Canis latrans*, in New York: The Canadian Field-Naturalist, v. 119, p. 1–5, doi:10.22621/cfn.v119i1.74.

Gompper, M.E., 2002, Top Carnivores in the Suburbs? Ecological and Conservation Issues Raised by Colonization of North eastern North America by Coyotes: BioScience, v. 52, p. 185, doi:10.1641/0006-3568(2002)052[0185:TCITSE]2.0.CO;2.

Gompper, M.E., Kays, R.W., Ray, J.C., Lapoint, S.D., Bogan, D.A., and Cryan, J.R., 2006, A Comparison of Noninvasive Techniques to Survey Carnivore Communities in Northeastern North America: Wildlife Society Bulletin (1973-2006), v. 34, p. 1142–1151.

Harrison, D.J., Bissonette, J.A., and Sherburne, J.A., 1989, Spatial relationships between coyotes and red foxes in eastern Maine: The Journal of Wildlife Management, v. 53, p. 181–185, doi:10.2307/3801327.

Hody, J.W., and Kays, R., 2018, Mapping the expansion of coyotes (*Canis latrans*) across North and Central America: ZooKeys, v. 759, p. 81–97, doi:10.3897/zookeys.759.15149.

Huff, M., 2015, Understanding Coyotes: The Comprehensive Guide for Hunters, Photographers and Wildlife

Observers: United States, CreateSpace Independent Publishing Platform, p. 1–122.

Kamler, J.F., and Gipson, P.S., 2004, Survival and cause-specific mortality among furbearers in a protected area: The American Midland Naturalist, v. 151, p. 27–34, doi:10.1674/0003-0031(2004)151[0027:SACMAF]2.0.CO;2.

Kays, R., Curtis, A., and Kirchman, J.J., 2010, Rapid adaptive evolution of northeastern coyotes via hybridization with wolves: Biology Letters, v. 6, p. 89–93, doi:10.1098/rsbl.2009.0575.

Kilgo, J.C., Ray, H.S., Vukovich, M., Goode, M.J., and Ruth, C., 2012, Predation by coyotes on white-tailed deer neonates in South Carolina: The Journal of Wildlife Management, v. 76, p. 1420–1430, doi:10.1002/jwmg.393.

Klare, U., Kamler, J.F., and Macdonald, D.W., 2011, A comparison and critique of different scat-analysis methods for determining carnivore diet: Mammal Review, v. 41, p. 294–312, doi:10.1111/j.1365-2907.2011.00183.x.

Knox Jones, J.Jr., and Manning, R.W., 1992, Illustrated Key to Skulls of Genera of North American Land Mammals: Lubbock, Tex, Texas Tech University Press, p. 1–75.

Koblmüller, S., Nord, M., Wayne, R. K. & Leonard, J. A., 2009, Origin and status of the Great Lakes wolf: Molecular Ecology, v. 11, p. 2313–2326.

Laliberte A.S., and Ripple W.J., 2004, Range contractions of North American carnivores and ungulates: BioScience, v. 54, p. 123–138, https://doi.org/10.1641/0006-3568(2004)054[0123:RC ONAC]2.0.CO;2.

Levi, T., and Wilmers, C.C., 2012, Wolves-coyotes-foxes: a cascade among carnivores: Ecology, v. 93, p 697–703.

Litvaitis, J.A., and Harrison, D.J., 1989, Bobcat–coyote niche relationships during a period of coyote population increase: Canadian Journal of Zoology, v. 67, p. 1180–1188, doi:10.1139/z89-170.

Maher, N., 1999, “A very pleasant place to build a towne on”: an environmental history of land preservation in New York’s Hudson Highlands: Hudson Valley Regional Review, v. 16, p. 21–39.

McElreath, R., 2015, Statistical Rethinking: A Bayesian Course with Examples in R and Stan: Boca Raton, Florida, CRC Press, p. 267–292.

Morey, P.S., Gese, E.M., and Gehrt, S., 2007, Spatial and temporal variation in the diet of coyotes in the Chicago metropolitan area: The American Midland Naturalist, v. 158, p. 147–161, doi:10.1674/0003-0031(2007)158[147:SATVIT]2.0.CO;2.

Naeem, S., Prager, C., Weeks, B., Varga, A., Flynn, D.F.B., Griffin, K., Muscarella, R., Palmer, M., Wood, S., and Schuster, W., 2016, Biodiversity as a multidimensional construct: a review, framework and case study of herbivory’s impact on plant biodiversity: Proc. R. Soc. B, v. 283, p. 1–10, doi:10.1098/rspb.2015.3005.

Palomares, F., and Caro, T.M., 1999, Interspecific killing among mammalian carnivores: The American Naturalist, v. 153 p. 492–508.

Patterson, B.R., and Messier, F., 2000, Factors influencing killing rates of white-tailed deer by coyotes in eastern Canada: The Journal of Wildlife Management, v. 64, p. 721–732, doi:10.2307/3802742.

Pimm, S.L., Russell, G.J., Gittleman, J.L., and Brooks, T.M., 1995, The future of biodiversity: Science, v. 269, p. 347–350.

Ray, J.C., 2000, Mesocarnivores of Northeastern North America: Status and Conservation Issues: Wildlife Conservation Working Paper No.15, p. 6–85.

Roest, A.I., 1986, Key-Guide to Mammal Skulls and Lower Jaws: Eureka, CA, Mad River Press, p. 1–37.

Samson, C., and Crête, M., 1997, Summer food habits and population density of coyotes, *Canis latrans*, in boreal forests of southeastern Québec: Canadian Field-Naturalist, v. 111, p. 227–233.

Schuster, W.S.F., Griffin, K.L., Roth, H., Turnbull, M.H., Whitehead, D., and Tissue, D.T., 2008, Changes in composition, structure and aboveground biomass over seventy-six years (1930-2006) in the Black Rock Forest, Hudson Highlands, southeastern New York State: Tree Physiology, v. 28, p. 537–549, doi:10.1093/treephys/28.4.537.

Thornton, D.H., and Murray, D.L., 2014, Influence of hybridization on niche shifts in expanding coyote populations: Diversity and Distributions, v. 20, p. 1355–1364, doi:10.1111/ddi.12253.

Thompson, C.M., and Gese, E.M., 2007, Food webs and intraguild predation: community interactions of a native mesocarnivore: Ecology, v. 88, p. 334–346, doi:10.1890/0012-9658(2007)88[334:FWAIPC]2.0.CO;2.

Tremblay, J.P., Crête, M., and Huot, J., 1998, Summer foraging behavior of eastern coyotes in rural versus forest landscape: a possible mechanism of source-sink dynamics: Ecoscience, v. 5, p. 172–182.

Trezza, J., 2016, Where coyotes, foxes and bobolinks find a new home: Freshkills Park: the New York Times, https://www.nytimes.com/2016/06/10/nyregion/where-coyotes-foxes-and-bobolinks-find-a-new-home-freshkills-park.html (accessed March 2019).

Vaughan, C., 1983, Coyote range extension in Costa Rica and Panama: Brenesia, v. 21, p. 27–32.

Vitousek, P.M., Mooney, H.A., Lubchenco, J., and Melillo, J.M., 1997, Human domination of earth's ecosystems: Science, v. 277, p. 494–499.

vonHoldt, B.M., Pollinger, J.P, Earl, D. A., Knowles, J.C., Boyko, A.R., Parker, H., Geffen, E., Pilot, M., Jedrzejewski, W., Jedrzejewski, B., Sidorovich, V., Greco, C., Randi, E., Musiani, M., Kays, R., Bustamante, C.D, Ostrander, E.A., Novembre, J., and Wayne, R.K., 2011, A genome-wide perspective on the evolutionary history of enigmatic wolf-like canids: Genome Research, v. 21, p. 1294–1305, doi:10.1101/gr.116301.110.

Wheeldon, T., and White, B. N., 2009, Genetic analysis of historic western Great Lakes region wolf samples reveals early *Canis lupus*/*lycaon* hybridization. Biol. Lett. 5, 101–109, doi:10.1098/rsbl.2008.0516.

Wilcove, D.S., and Master, L.L., 2005, How many endangered species are there in the United States?: Frontiers in Ecology and the Environment, v. 3, p. 414–420, doi:10.1890/1540-9295(2005)003[0414:HMESAT]2.0.CO;2.

Wilcove, D.S., Rothstein, D., Dubow, J., Phillips, A., and Losos, E., 1998, Quantifying threats to imperiled species in the United States: BioScience, v. 48, p. 607–615, doi:10.2307/1313420.