COYOTES IN CENTRAL GEORGIA: EFFECTS ON FAWN RECRUITMENT AND EVALUATION OF SURVEY TECHNIQUES

by

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(Under the Direction of Karl V. Miller)

ABSTRACT

Coyotes (*Canis latrans*) have become abundant throughout the southeastern United States during the past two to three decades and evidence suggests they may lower white-tailed deer (*Odocoileus virginianus*) fawn recruitment. Therefore, I assessed the impacts of coyotes on recruitment in two central Georgia deer populations and identified factors contributing to this predator-prey dynamic. From October 2009 to April 2012, I monitored coyote abundance and deer population parameters on B.F. Grant (BFG) and Cedar Creek (CC) Wildlife Management Areas. I estimated coyote abundance using a mark-recapture design based on genotyping feces and obtained deer recruitment rates using infrared-triggered camera surveys. I also conducted scat-deposition and scent-station surveys of coyote abundance during 2010 to compare the utility of these methods to that of mark-recapture surveys. During the springs of 2011 and 2012, trappers removed coyotes from both sites. Point estimates of coyote abundance on BFG after trapping were 81% (2011) and 24% (2012) lower than during pre-removal. I observed a slight decrease in coyote numbers on CC following trapping but confidence limits of abundance estimates overlapped throughout the study. Fawn recruitment on BFG averaged 0.65 fawns/doe before the first removal and 1.01 in the years following the first and second removals. In contrast, estimates of fawn recruitment on CC did not vary among years. Trends indicated an inverse relationship between fawn recruitment and coyote abundance, but effectiveness of trapping differed between study sites and over time on BFG. If coyote removal is decided on, efforts should be intense and focused on removing a significant percentage of the population. Low visitation rates ($\bar{x}$ = 0.04; range = 0 – 0.10) made scent-station surveys an unreliable index of coyote abundance. Similar to 2010 mark-recapture estimates, there was no difference in scat deposition rates between sites ($F_{1,60} = 0.025$, $P = 0.873$), but there was an interaction between site and season ($F_{2,60} = 7.661$, $P = 0.001$). Additionally, I observed significant spatiotemporal trends in coyote scat deposition patterns. Therefore, scat-deposition surveys may provide sufficient information for managers in many situations but timing, scale, and distribution of survey routes are important considerations.

INDEX WORDS: abundance, *Canis latrans*, compositional analysis, eastern coyote, fawn, fecal DNA, Georgia, *Odocoileus virginianus*, recruitment, relative abundance, noninvasive survey, predation, predator, scat deposition, scent station, white-tailed deer

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by

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# DEDICATION

I dedicate my dissertation work to my family. I would have never gotten this far without the upbringing of my wonderful parents, Billy and Darlene Gulsby. They unflinchingly kept me oriented in the right direction in my early years, always expected me to give my best and finish whatever I started, and now serve as mentors and role models to Neva and me as we have begun our own lives together. This journey began a number of years ago on a cool fall morning as my dad sat beside me on our first deer hunt. Those years spent together in the outdoors inspired me to take this route and the dream began to take shape the night I announced my desire to pursue a career in wildlife in their living room.

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TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

# CHAPTER 1

# INTRODUCTION, LITERATURE REVIEW, STUDY AREAS, OBJECTIVES, AND DISSERTATION FORMAT

## INTRODUCTION

Although once restricted to the Great Plains west of the Mississippi River, the geographic distribution of coyotes (*Canis latrans*) has recently expanded to include all of North America except for the far northeastern regions of Canada (Bekoff and Gese 2003). Coyotes colonized areas east of the Mississippi River along a northern and a southern front. The northern front moved across the Great Lakes region and into northeastern states, while the southern front moved across the Southeast (Moore and Parker 1992, Parker 1995), perhaps aided by human translocation (Hill et al. 1987). Since then, coyotes have rapidly increased in number throughout the region (Kilgo et al. 2010a).

Recent observations indicating decreased recruitment rates in some white-tailed deer (*Odocoileus virginianus*) populations coincide with the increase in coyotes throughout the Southeast, leading to growing evidence that coyotes may be responsible (Kilgo et al. 2010). Although much of the research investigating the impacts of coyotes on fawn recruitment has been limited to areas outside of the Southeast (Cook et al. 1971, Beasom 1974, Kie et al. 1979, Stout 1982, Vreeland et al. 2004), emerging research indicates these predators may be responsible for a significant portion of fawn mortality, at least in parts of the region (Saalfeld and Ditchkoff 2007, Howze et al. 2009, VanGilder et al. 2009, Kilgo et al. 2010a).

Despite recently published studies, the literature remains limited in spatial and/or temporal scale, or confounded by problems related to experimental design. Additionally, no robust estimates of coyote abundance exist for the region, a critical component for understanding predator-prey interactions. The purpose of this study was to evaluate the impact of coyotes on fawn recruitment in central Georgia, an area where deer hunting is valued both socially and economically, and where coyote/deer interactions were previously uninvestigated. In addition, I used both traditional and novel methods of estimating coyote abundance, or relative abundance, to further evaluate how changes in these parameters might affect fawn predation rates. The overall objective of this study was to develop methods and guidelines to be used to achieve deer management objectives in the presence of this novel predator.

## LITERATURE REVIEW

### Coyote Predation on White-tailed Deer Neonates

Many studies have investigated neonatal mortality, and its causes, among a wide variety of northern, temperate ungulates. Linnell et al. (1995) reviewed 111 papers and reports and found that across temperate regions, neonatal mortality averaged 47% and that predation accounted for the majority (67%) of this mortality. Species responsible for predation included bobcat (*Lynx rufus*), Canada lynx (*L. canadensis*), coyote, red fox (*Vulpes vulpes*), wolf (*C. lupus*), mountain lion (*Felis concolor*), black bear (*Ursus americana*), and brown bear (*U. arctos*). In contrast, on study sites lacking predators, neonatal mortality averaged only 19%.

Among studies focusing on causes of white-tailed deer fawn mortality, predators were reportedly responsible for as little as 0% of fawn mortalities (Logan 1973, Schultz et al. 1983, Nixon et al. 1991) to as much as all, or nearly all, mortalities (Kunkel and Mech 1994, Garner et al. 1976). Variation in fawn predation rates among deer populations is not surprising given the array of previously identified factors such as climatic conditions (Andelt et al. 1987), prey abundance (VanGilder et al. 2009), predator abundance (Grovenburg et al. 2011, Kilgo et al. 2010a), or the presence of alternative prey in a region (Harrison and Harrison 1984, Andelt et al. 1987). However, even when predators are responsible for 100% of fawn mortalities, the population-level effect will be minimal if mortalities account for an insignificant proportion of the total number of fawns produced. Therefore, research targeting coyote/deer relationships should aim to understand the effect of predation (e.g., lowered fawn recruitment) rather than the fact of predation (Errington 1967), which is well-established for deer.

Neonates of temperate ungulate species, including whitetail fawns, are only seasonally available (Rutberg 1987). Therefore, generalist canid (coyote) and ursid predators (brown and black bear) are typically the most important fawn predators, due to their ability to quickly shift their primary prey choice based on availability. However, bobcats can also be significant fawn predators. For example, in west-central Texas, bobcats removed about 31% of the annual fawn crop (Haskell 2007). On Cumberland Island, Georgia, deer occurred in nearly 50% of bobcat scats during some seasons (Baker et al. 2001). Bobcats also preyed extensively on fawns on two South Carolina coastal islands (Epstein et al. 1983). Because coyotes were rare or absent in all of these studies, which report some of the highest bobcat predation rates in the literature, bobcat predation on fawns may increase in the absence of coyotes. Nevertheless, the specialized felids usually play a lesser role (Linnell et al. 1995), and numerous studies have indicated coyotes as the most significant source of white-tailed deer fawn mortality throughout much of the country.

Coyote food habits studies were likely the first type of study to document that coyotes predate deer in the Southeast. Coyotes are opportunistic generalists and primary food items include soft mast, small mammals, insects, and white-tailed deer in varying degrees, depending on location and season. Deer occurs most frequently in the diet of Southeastern coyotes during the fawning season, which is variable across the region. For example, in northwest Florida, fawns occurred in 29% of scats during fawning (Stratman and Pelton 1997). Deer occurred in 33% of scats in Mississippi and in 71% of scats in Alabama during July and August, which were the peak fawning periods for these areas (Wooding et al. 1984). More recently, fawn remains were present in 15% - 38% of coyote scats in South Carolina during and immediately following the fawning period (May – July; Schrecengost 2008), and deer occurred in 38% of scats during Alabama's fawning season (VanGilder 2009). The evidence from these studies indicates that coyotes exploit fawns when available.

Varying frequencies of occurrence of fawns in coyote diets is likely a product of the respective coyote and deer (i.e., fawn) densities on study areas (Prugh 2005). Some have suggested that coyotes forage optimally (MacCracken and Hansen 1987, Hernández et al. 2002). Optimal foraging theory suggests that animals select the food items in terms of their intrinsic profitability, regardless of density, and lower-ranking food items will be included in the animal's diet in decreasing order of profitability as higher ranking food items fall below a threshold abundance (Charnov 1976, Stephens and Krebs 1986). For example, Kelly (2012) examined coyote diets on two central-Georgia sites with varying deer densities. During the fawning season, fawns occurred in twice as many scats on the site where deer abundance was approximately two-times greater, suggesting that coyotes were opportunistically preying on fawns. Although food habits studies are informative and supplement results of other study designs, it is impossible to quantify the impacts of coyote predation on deer populations from their results.

Studies of fawn mortality offer additional evidence of coyote predation on fawns. Most of these studies are mensurative in that researchers capture fawns shortly after parturition, instrument them with VHF radiocollars equipped with mortality sensors, and use ground-based telemetry to locate fawns and investigate the site of death, should the mortality beacon become active. Vreeland et al. (2004) used this method in Pennsylvania and reported coyotes were responsible for depredating 18 of 218 (8%) radiocollared fawns, accounting for 17% of all mortality. Elsewhere, coyotes were the leading mortality cause in the Midwest (Huegel et al. 1985, Nelson and Woolf 1987, Rohm et al. 2006, Grovenburg et al. 2011), Northeast (Long et al. 1998), and in the South (Cook et al. 1971, Carroll and Brown 1977, Bartush and Lewis 1981, Bowman et al. 1998, Saalfeld and Ditchkoff 2007, Kilgo et al. 2012, McCoy et al. 2013).

Population level impacts cannot be directly inferred from mortality rates and causes. For example, the overall proportion of monitored fawns killed by coyotes in the aforementioned studies varied greatly, ranging from as low as 7% (McCoy et al. 2013) to as high as 62% (Kilgo et al. 2012). Interestingly, both reports are from South Carolina, highlighting the potential for coyote predation rates to vary significantly across small geographic areas. Nonetheless, results from this type of study allow determination of fawn survival and mortality rates, which aid in effective management of white-tailed deer populations (White and Lubow 2002). However, these rates alone cannot predict recruitment rates, which are more important for estimating population trajectory. In addition, determining fawn mortality via radiocollar monitoring may have some inherent biases that must be considered.

The majority of coyote predation on fawns occurs within the first 30 days postpartum (Cook et al. 1971, Porath 1980). In most fawn mortality studies, fawns are not radiocollared immediately after birth. Therefore, it is likely that these studies underestimate predation-induced mortality by missing most early post-partum predation events. For example, most studies report a mean age at capture of approximately 4 days (Huegel et al. 1985, Long et al. 1998, Rohm et al. 2006, Grovenburg et al. 2011), whereas others report a mean age at capture ≥ 6 days (Bartush and Lewis 1981, Nelson and Woolf 1987, McCoy et al. 2013). However, the recent development of vaginal implant transmitters (VITs), has allowed researchers to locate fawns almost immediately after birth, reducing or eliminating bias associated with time lapses between birth and collaring of fawns. VITs are inserted into the vaginal canal of chemically immobilized pregnant does and expulsion during the birthing process is indicated by a change in the radio beacon. Using this technique, Kilgo et al. (2012) reported that 27 of 70 (39%) mortalities occurred during the first week of life, a time when fawn survival rates were lowest in their South Carolina study. Thus, traditional fawn mortality studies may significantly underestimate fawn mortality rates by missing this early period of high neonate mortality.

The time lag between a fawn's death and the arrival of researchers is an additional source of bias in fawn mortality studies, particularly in cases where scavenging has occurred. Scavenging presents difficulties in determining causes of fawn mortalities as well as the predator responsible when predation is suspected. For example, in an Illinois study, cause of death for 23% of fawn mortalities was reported as unknown as was the species responsible for 19% of predator-related mortalities (Rohm et al. 2006). Similarly, 22% of fawn mortalities in south Texas were of undetermined cause although coyotes had fed on the carcasses at some point (Cook et al. 1971). In Pennsylvania, the predator responsible for 25% of predator-related fawn mortalities was undetermined on two separate sites (Vreeland et al. 2004). Finally, estimates of coyote-induced fawn mortality ranged from 37% - 80% in South Carolina as a result of uncertainty in assignment of cause of death (Kilgo et al. 2012). Therefore, scavenging can introduce bias into overall predation estimates and the estimate of mortality attributable to a certain species.

The process of capturing, marking, handling and the occasional temporary flights due to repeated relocations may be a source of stress for fawns (Cook et al. 1971), leading to some maternal abandonment and starvation (Vreeland et al. 2004). However, Rohm et al. (2006) recognized the potential bias resulting from hand-capture of fawns, but believed this potential source of bias was minimal.

Relatively few studies have evaluated fawn predation using a before-and-after experimental design. These studies involve estimation of fawn recruitment rates during fall or winter, before and after an experimental predator removal. Using this method, a northeast Alabama study reported the fawn-to-doe ratio increased from 0.41 pre-removal, to 1.20 in the year following the removal of 22 coyotes and 10 bobcats from an 800-ha study site (VanGilder et al. 2009). Similarly, Howze et al. (2009) removed 23 coyotes and 3 bobcats from a 4,200-ha area, adjacent to a 2,800-ha control area, both located in southwest Georgia. The following fall, the fawn-to-doe ratio was over two-times greater in the area where predators had been removed. In a Texas study, net productivity of deer in predator removal areas were 74% greater than in untreated areas (Beasom 1974), and removal of coyotes from three Oklahoma deer ranges resulted in an increase in the overall fawn-to-doe ratio of 154% (Stout 1982). Thus, all predator removal studies reported to date have documented 2-3 fold increases in fawn recruitment on areas where predators have been removed.

Predator-removal studies provide the most valid measure of the net impact of predation on fawn recruitment and deer populations. Furthermore, these experiments do not depend on a sample of instrumented fawns, as the entire deer herd within an area is surveyed. Finally, the methods used to estimate recruitment rates before and after a coyote removal are generally non-invasive, thereby removing the potential biases associated with capture and handling of fawns.

Because coyotes are a relatively recent invader of the Southeast (Gipson 1978, Hill et al. 1987), only limited studies have investigated the role of coyote predation in white-tailed deer fawn mortality and recruitment (Kilgo et al. 2010a). A few fawn mortality studies (Bowman et al. 1998, Saalfeld and Ditchkoff 2007, Kilgo et al. 2012, McCoy et al. 2013) and coyote removal studies (Howze et al. 2009, VanGilder 2009) have addressed this topic, although many factors necessitate further and more widespread investigation. Kilgo et al. (2010a) posed a series of questions, designed to help guide research and highlight existing information gaps concerning coyotes and fawns in the region. These questions pertained to the level and nature (additive versus compensatory) of coyote-induced mortality, how coyote or deer densities affect predation level, how vegetation structure affects predation level, and whether or not predation differs among years.

**Estimation of Coyote Abundance**

Reliable coyote population estimates may aid our understanding of their potential to impact deer populations and for developing management guidelines if predation level is linked to coyote abundance. However, because large predators are secretive and wide-ranging, population estimates are difficult to obtain. Traditional methods of estimating or indexing coyote abundance include scent-station, scat-deposition, and howling surveys. Of the three, scent-station surveys are the most widely-used (Ray and Zielinski 2008) due to their low cost, ease of implementation, and ability to cover large areas. During a survey, stations are arranged in transects or grids and researchers check each station for predator visits after $\geq 1$ nights. Each station consists of an area of prepared natural or artificial substrate, usually 1 m in diameter, with an attractant placed at the center (Linhart and Knowlton 1975).

Despite their widespread use, scent-station surveys likely are of limited utility for monitoring predator abundance. For example, scent-station indices were positively related to bobcat density in a Georgia study, although predictions of population size had poor precision and it was necessary to conduct ≥ 4 surveys/year to detect population changes ≥ 25% (Diefenbach et al. 1994). Scent-stations have proven similarly unreliable for raccoons (*Procyon lotor*; Smith et al. 1994) and cougars (*Puma concolor*; Choate et al. 2006).

The utility of scent station surveys for indexing coyote abundance is likewise questionable due primarily to low probability of detection. For example, route visitation rates were lower for coyotes than any other predator during a statewide survey of Minnesota (Erb 2006). Similarly, 198 scent-station nights produced a single coyote response in Tennessee (Crawford et al. 1993). Sargeant et al. (1998) evaluated the method for coyotes over several years in Minnesota and concluded that although long-term trends in visitation rates likely reflect population changes, the usefulness of scent-station surveys is limited by poor spatial and temporal resolution, susceptibility to confounding factors, and low statistical power. Furthermore, prints in stations often appear ambiguous, surveys perform poorly under wet conditions, stations may attract species to locations where they normally do not occur, and they do not enable identification of individuals and thus cannot be used to estimate population density (Ray and Zielinski 2008).

Scat surveys are also commonly used to assess relative abundance of coyotes. During a scat survey, coyote scats are collected along a predetermined route, and a scat deposition rate index of abundance (*n* scats deposited/km/day) is calculated. The method is easily conducted by those with relatively little training and is noninvasive. However, the relative difficulty of finding carnivore scats and distinguishing scats of different species based solely upon visual inspection makes them less popular than scent-station surveys (Heinemeyer et al. 2008).

Few studies have attempted to evaluate the scat-survey technique through comparison to independent measures of abundance or density, or quantify associated error rates (Heinemeyer et al. 2008). Nevertheless, scat deposition rates were effective for assessing relative abundance of red fox in Italy (Cavallini 1994), and were positively correlated with swift fox (*V. velox*) density in Colorado (Schauster et al. 2002). In addition, scat deposition surveys had the highest detection probabilities and were most closely related to known swift fox abundance of four survey methods employed in Utah (Dempsey 2013). Scat deposition rates were also positively related to gray wolf (*C. lupus*) density in Canada (Crete and Messier 1987, Atkinson and Janz 1994).

For coyotes, a comparison of scat deposition rates to estimated abundance as determined by fecal genotyping has also yielded promising results (Kays et al. 2008). In that study, the total number of coyote scats per site was directly related to the number of individuals identified on that site. However, only successfully genotyped coyote scats were included in the comparison, potentially biasing the results as many samples failed to yield mtDNA so the species of origin could not be determined. Of those yielding mtDNA, some were inevitably from non-target species, and others could not be genotyped to the individual level. For example, in a California study only 188 of 238 scats (79%) yielded coyote mtDNA and 115 (48%) of these were successfully typed at all microsatellite loci (Kohn et al. 1999). In North Carolina 306 scats were identified to species, 69 (23%) of which belonged to non-target animals (Adams et al. 2003). These sources of potential bias necessitate the inclusion of all suspected coyote scats in a comparison to fecal genotyping results if scat-deposition surveys are to be validated as an effective stand-alone method of assessing coyote abundance.

Incorrect species identification alone may be sufficient to confound results of scat deposition surveys. However, Andelt and Andelt (1984) identify other confounding factors, especially seasonal changes in coyote diets which may impact deposition rate. In their study, scat deposition rates were positively related to the amount of fruit and insects in coyote diets, and inversely related to the quantity of vertebrates in the diet. Although they corrected for dietary differences and coyote abundance remained stable, they could not account for 28-36% of variation in scat deposition rates. Other factors cited as potential confounds in scat surveys include rainfall (Cavallini 1994) and coprophagy or removal of scats from roadways by coyotes or other species (Livingston et al. 2005).

Howl surveys have also been suggested as a method to index coyote abundance. In a howl survey, a siren or recorded howl is sounded, or a human mimics a coyote howl, to elicit coyote responses at locations along a survey route. When compared to scent-station surveys, howl surveys appeared to have more potential and were less labor intensive (Crawford et al. 1993). However, no studies have compared howl survey results to independent measures of coyote abundance. Further, identification of the number of coyotes responding to a siren may be limited to three animals; beyond this number the amount of howling makes estimates difficult (Pyrah 1984). Pack social structure also may influence the rate of coyote vocalizations, as higher response rates are typical of reproductive groups and pairs (Okoniewski and Chambers 1984). In Wyoming, only members of resident packs initiated or participated in howling, howling by transients was never observed, and alpha coyotes howled more than betas or pups (Gese and Ruff 1998). Season also affects vocalizations with peak howling occurring during dispersal and breeding and low levels reported during pup rearing. Finally, coyotes howled more frequently along the periphery, versus the core area, of their territory (Gese and Ruff 1998). As such, low response rates by transient or subordinate coyotes, difficulty in determining pack size, and influence of territorial behavior may bias howl surveys.

Scent-station and howl surveys require that coyotes respond to a stimulus. Over time, repeated exposure to the same stimulus may alter response rates. Traditional mark-recapture studies are invasive, requiring capture and restraint of animals for marking purposes. In contrast, scat-deposition surveys are non-invasive but do not allow identification of individuals. Thus, addition of genetic analysis to scat surveys may enhance the precision and accuracy of deposition surveys.

Genetic fingerprinting of individual animals using DNA extracted from feces (i.e., fecal genotyping) has proven promising for many large predators, including the coyote. Fecal genotyping has been used to estimate coyote abundance in California (Kohn et al. 1999, Fedriani et al. 2001), New York (Kays et al. 2008), and Alaska (Prugh et al. 2005). This method provides greater detectability, as Prugh et al. (2005) identified nearly four times as many individuals versus physical capture. Scat surveys, when backed by genetic confirmation of species of origin, were also effective for surveying coyote presence (Gompper et al. 2006) and monitoring hybridization between coyotes and endangered red wolves (*C. rufus*) in coastal North Carolina (Adams et al. 2003).

Fecal genotyping results are used to construct individual encounter histories when the objective is abundance estimation. Then, mark-recapture models are applied to the data to allow estimation of abundance or population parameters. Closed-population models, which are used to estimate abundance, assume populations are closed to births, deaths, immigration and emigration during the period of interest (Otis et al. 1978). Mark-recapture models also assume that individuals can be distinguished from each other and that genotypes are correct (Prugh et al. 2005). Inability to distinguish individuals typically results in an underestimation of population size (the "shadow effect"; Mills et al. 2000), while genotyping error causes overestimation of population size. Using a sufficient number of microsatellites to distinguish individuals prevents the shadow effect, while requiring that each genotype be replicated at least once helps prevent genotyping error (Schwartz and Monfort 2008).

Non-invasive genetic sampling is unique in that an individual may be captured more than once within a sampling session. Traditional mark-recapture models treat such instances as a single encounter. Rarefaction approaches, however, attempt to take advantage of this feature by expressing the cumulative number of unique genotypes as a function of the number of feces sampled. Researchers used this method to estimate coyote population size in California in the first study to estimate coyote abundance using fecal genotyping (Kohn et al. 1999). However, additional work indicates that rarefaction curves may be biased (Frantz and Roper 2006, Marucco et al. 2011), probably as a result of capture heterogeneity among individuals. As a result, Miller et al. (2005) developed a method, CAPWIRE, which accounts for capture heterogeneity in the model by incorporating individuals of two capture probabilities. Analysis of real data sets revealed that when data contain capture heterogeneity, CAPWIRE provides unbiased estimates with high accuracy and precision (Miller et al. 2005). CAPWIRE also yielded precise estimates of black bear abundance in Alaska (Robinson et al. 2009).

**Factors Affecting Coyote Predation on Fawns**

Although no studies have used fecal genotyping to estimate coyote density on sites where fawn mortality was being simultaneously investigated, several workers have addressed the role coyote (or predator) abundance likely plays in fawn predation. For example, Vreeland et al. (2004) found that, of 2 sites in Pennsylvania, predation was the leading cause of mortality on the site where predators were assumed to be more abundant. Similarly, Grovenburg et al. (2011) concluded that the high fawn survival observed in their study was a product of low coyote density in the region.

Although no robust density estimate for coyotes in the Southeast currently exists, some have proposed that high availability of alternative food items, such as soft mast, small mammals, and lagomorphs, supports higher coyote densities, leading to increased fawn predation (Patterson et al. 1998, VanGilder et al. 2009). In contrast, others have proposed that increased availability of alternate prey may act as a buffer on fawn predation (Harrison and Harrison 1984, Andelt et al. 1987, Pusateri Burroughs et al. 2006). However, findings from multiple coyote food habits studies suggest that coyotes consume fawns when available, despite the presence of abundant alternative prey (Harrison and Harrison 1984, Schrecengost et al. 2008, Kelly 2012). Thus, coyotes likely focus their foraging efforts on fawns during the fawning season because they are more nutritionally or energetically efficient than other prey sources such as small mammals (Harrison and Harrison 1984).

Others have proposed that the composition of the landscape may influence the benefits coyotes derive from capturing fawns. In Illinois, fawn survival was positively associated with the amounts of habitat diversity and edge across the landscape, which may have hindered coyote search efforts and decreased the benefit coyotes derived from searching for and capturing fawns (Rohm et al. 2006). This hypothesis is supported by results in both the western (Gese et al. 1996) and northeastern (Richer et al. 2002) United States that suggest coyotes are less effective predators in forested versus open landscapes. Similarly, predation rates in Texas were lower in years with increased availability of hiding cover for fawns (Carroll and Brown 1971). Conversely, there was no difference in forest composition nor understory density in home ranges of depredated versus surviving fawns in the Coastal Plain of South Carolina (Kilgo et al. 2010b). Therefore, it is possible that coyotes in similar Southeastern habitats, where dense vegetation dominates year-round, use alternate foraging strategies or behaviors than their northern or western counterparts, allowing them to remain effective fawn predators regardless of landscape composition.

Optimal foraging theory suggests that in areas of low deer density, coyotes would have decreased incentive to search for fawns due to the increase in time required to locate them. Nevertheless, deer remained a preferred food item in diets of Northeastern coyotes, regardless of deer density (Patterson et al. 1998). Similarly, coyotes accounted for as much as 80% of fawn mortalities on a South Carolina site with relatively few deer (Kilgo et al. 2012). Therefore, additional factors likely affect coyotes' incentive to target fawns or the nutritional benefit of fawns is so great that the threshold abundance at which they become less profitable is very low.

Gaps remain in our understanding of the complex relationship between coyotes and white-tailed deer in the Southeast. Because many wildlife managers are managing herds under quality deer management guidelines, deer herds in rural landscapes throughout Georgia are typically maintained well below ecological carrying capacity (K), and likely below the population inflection point (I), where predation is likely additive and limiting to population growth. Maintaining traditionally liberal antlerless deer harvest regulations in the face of declining recruitment could have detrimental results for the most economically important game species in the region. Clearly, additional research focusing on the factors affecting coyote fawn predation and its population-level impacts is warranted.

**STUDY AREAS**

This study was conducted from October 2009 to April 2012 on portions of B.F. Grant (BFG) and Cedar Creek (CC) Wildlife Management Areas (WMAs) located in Putnam County, Georgia. Wildlife populations on BFG, owned by the University of Georgia (UGA), and CC, part of the Oconee National Forest, were both managed by the Georgia Department of Natural Resources (GADNR) for hunting, fishing, and outdoor recreation.

B.F. Grant WMA covered approximately 50 $km^2$. Since 1974, this area has been managed for quality, male white-tailed deer by limiting hunter access, and by restricting the harvest of adult males to only those with antlers meeting certain measurement criteria (personal communication, Charlie Killmaster, GADNR). Although wildlife resources on BFG are managed by GADNR, UGA maintains an active timber harvest and management program on the area, consisting primarily of loblolly pine (*Pinus taeda*) plantations managed on approximately 30-35 year rotations. As a result, approximately 14% (700 ha) of BFG's forested area was comprised of early successional habitat, generally lasting from the first growing season following timber harvest until canopy closure at approximately 7 years (Figure 1.1). In addition, UGA maintained an agricultural research station within the property that consisted primarily of fescue (*Schedonorus arundinaceus*) and bermuda grass (*Cynodon dactylon*) pastures and hayfields. These pastures and hayfields accounted for an additional 14% (700 ha) of the area (Figure 1.1). The combination of productive early successional and field-type habitats and limited deer hunting opportunity allowed for an abundant deer herd, and deer occurred at a density ranging from approximately 19-23 deer/$km^2$ (personal communication, Charlie Killmaster, GA DNR).

Cedar Creek WMA covered approximately 160 $km^2$. Research activities, however, were limited to a 60 $km^2$ area located north of Georgia State Highway 212. The GADNR managed the deer population on CC for maximum sustainable yield (MSY), to increase hunter opportunity. The United States Forest Service (USFS) conducted all timber management activities on the area, which were primarily limited to salvaging operations (personal communication, Elizabeth Caldwell). As a result, much of CC consisted of mature, closed canopy forest, and only approximately 7% (420 ha) of the study area consisted of early successional habitat (Figure 1.2). The combination of mature forest and increased deer hunting opportunity on CC resulted in a deer density ranging from approximately 8-12 deer/$km^2$, much lower than that on BFG (personal communication, Charlie Killmaster, GA DNR).

**OBJECTIVES**

The objective of this research was to evaluate the impact of coyotes on fawn recruitment in central Georgia, and to determine the significance of deer and coyote abundance in this relationship. My specific objectives were to: (1) estimate coyote abundance before and after an intensive coyote removal effort by using non-invasive mark recapture methods, (2) compare estimates of fawn recruitment and coyote abundance before and after the removal, (3) evaluate the usefulness of economical, easily-implemented methods of assessing coyote abundance through comparison of results to those of non-invasive mark recapture efforts, and (4) examine spatiotemporal trends in coyote scat deposition and report on the implications of these trends for scat-based coyote surveys.

## DISSERTATION FORMAT

This dissertation is presented in manuscript format. Chapter 1 is an introduction and review of previous studies addressing similar research topics. Chapter 2 presents the results of an experimental coyote removal on fawn recruitment and significant factors affecting this relationship. Chapter 3 presents a comparison of methods used to estimate coyote abundance or relative abundance, including non-invasive mark-recapture using fecal genotyping, scent station surveys and scat deposition surveys. Chapter 4 is an examination of how season and habitat characteristics affect coyote distribution and scat deposition patterns. Finally, chapter 5 presents conclusions and the management implications of the findings of this study.

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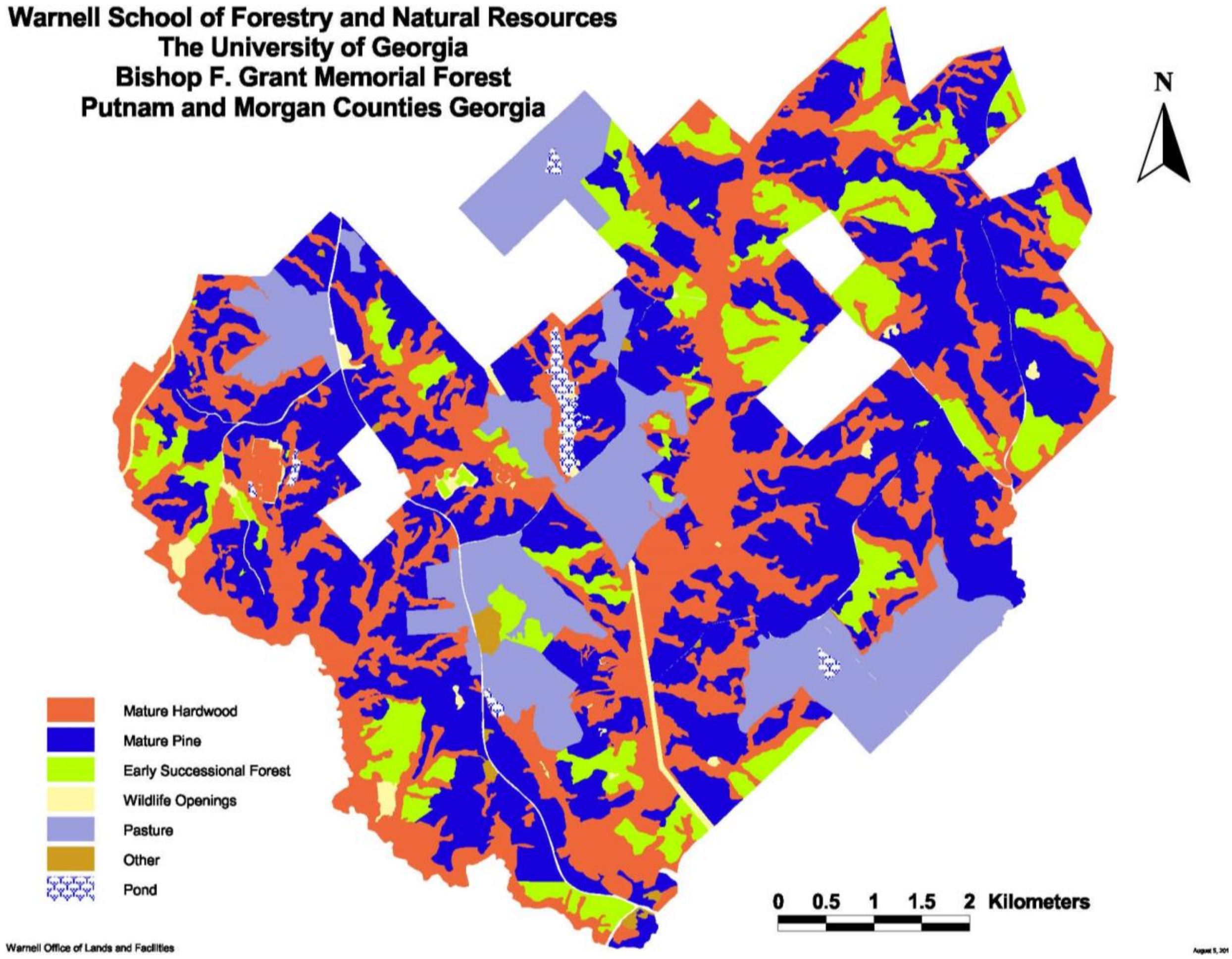


**Figure 1.1** Major habitat classifications for B.F. Grant Wildlife Management Area in Putnam County, Georgia (2009-2012). Productive, early successional, habitats included early successional forest (clearcut < 7 years prior), wildlife openings, and pasture and represented approximately 28% (1400 ha) of the study area.

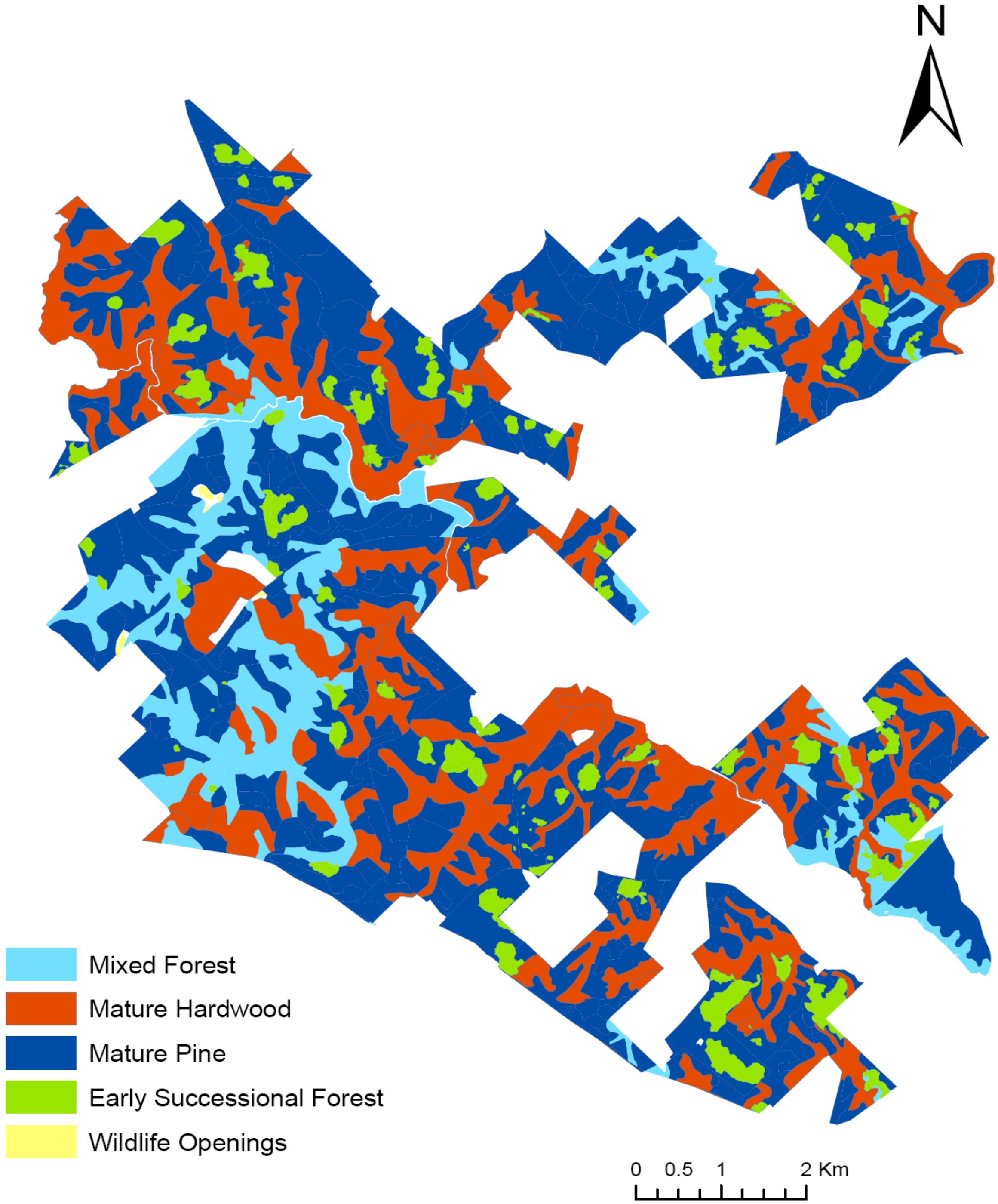


**Figure 1.2** Major habitat classifications for Cedar Creek Wildlife Management Area (north of Highway 212) in Putnam County, Georgia (2009-2012). Productive, early successional, habitats included early successional forest (clearcut < 7 years prior), wildlife openings, and pasture and represented approximately 7% (420 ha) of the study area.

# CHAPTER 2

## WHITE-TAILED DEER FAWN RECRUITMENT BEFORE AND AFTER AN EXPERIMENTAL COYOTE REMOVAL IN CENTRAL GEORGIA[1]

[1] Gulsby, W.D., C.H. Killmaster, J.W. Bowers, J.D. Kelly, B.N. Sacks, and K.V. Miller. 2014. To be submitted to *PLOS ONE*.

**ABSTRACT**

Several recent studies have reported that coyotes (*Canis latrans*) can impact white-tailed deer (*Odocoileus virginianus*) populations in the southeastern United States by lowering fawn recruitment. However, levels of reported impacts are variable, even across small geographic scales, perhaps due to differences in deer and coyote abundance among study sites. Therefore, we assessed the impacts of coyotes on deer recruitment on B.F. Grant (BFG) and Cedar Creek (CC) Wildlife Management Areas in central Georgia and investigated factors contributing to this predator/prey dynamic. We estimated annual coyote abundance during 2010 – 2012 using a mark-recapture design based on genotyping feces and obtained deer population parameters using infrared-triggered camera surveys during January and February of 2010 – 2013. During March to June 2011 and March to April 2012, professional trappers removed coyotes from the two sites. Point estimates of coyote abundance on BFG after trapping were 81% (2011) and 24% (2012) lower than during pre-removal. Although coyote abundance on CC appeared to decrease during 2011 and 2012, low confidence in abundance estimates resulted in significantly overlapping confidence intervals among all years. Fawn recruitment on BFG averaged 0.65 fawns/doe during the two years prior to removal and 1.01 fawns/doe during the years following the first and second removals. In contrast, fawn recruitment on CC did not differ among years, averaging 0.84 and 0.85 fawns/doe during the two years before and two years after the removal, respectively. Because deer densities were approximately 50% lower on CC than BFG, fawns may have been a suboptimal prey choice. We observed differential effectiveness of trapping between study sites and over time on BFG. Therefore, suitability of areas for trapping should be considered prior to conducting coyote removal and, if implemented, the removal should be intense and maintained across years to maintain high levels of fawn recruitment.

**INDEX WORDS:** coyote, *Canis latrans*, fawn, fecal genotyping, *Odocoileus virginianus*, recruitment, predation, predators, trapping, white-tailed deer

## INTRODUCTION

Recent observations of declining white-tailed deer (*Odocoileus virginianus*) fawn recruitment coincident with increasing coyote (*Canis latrans*) abundance in some parts of the southeastern United States has prompted a series of investigations aimed at evaluating the impacts of this relatively novel predator in the Southeast. For example, in a South Carolina study, coyotes depredated as much as 62% of radiocollared fawns (Kilgo et al. 2012). In contrast, coyotes were responsible for depredating only 7% of collared fawns on another South Carolina site (McCoy et al. 2013), and about 28% of fawns in Alabama (Saalfeld and Ditchkoff 2007).

However, the use of radiocollared fawns to assess neonatal mortality may underestimate cause-specific mortality rates due to factors such as elapsed time between a fawn's birth and collaring of the study animal. Although the use of vaginal implant transmitters has reduced time between parturition and collaring in some recent studies (Saalfeld and Ditchkoff 2007, Kilgo et al. 2012, McCoy et al. 2013), scavenging can remain confounding, depending on design and monitoring schedules, as it can present difficulties in defining the cause of death, as well as the predator responsible when predation is suspected. For example, in southern Illinois the cause of death could not be determined for 23% of fawn mortalities and the species responsible for 19% of predator-related mortalities remained unknown (Rohm et al. 2006). Similarly, 22% of fawn mortalities in south Texas were of undetermined origin although coyotes had fed on the carcasses at some point (Cook et al. 1971). Finally, in Pennsylvania, the predator responsible for 25% of predator-related fawn mortalities could not be determined on two separate sites (Vreeland et al. 2004).

Other researchers have employed manipulative study designs to evaluate coyote predation on fawns. Instead of mortality, fawn recruitment is measured on a site before and after coyote removal, or on a control versus a predator-removal site, typically using infrared-triggered cameras. Using this method in southwest Georgia, the fawn-to-doe ratio on an area where coyotes and bobcats had been removed was more than twice that observed on an untreated control site the fall following the removal (Howze et al. 2009). In northeast Alabama the fawn-to-doe ratio increased by 200% following removal of coyotes and bobcats from an 800-ha study site (VanGilder et al. 2009). Similarly, net productivity of deer in predator removal areas were 74% greater than in untreated areas in Texas (Beasom 1974).

Although these findings suggest that coyotes may significantly impact fawn recruitment in some areas of the Southeast, little is known regarding the factors that lead to differences in predation rates, even across relatively small geographic scales. Accordingly, Kilgo et al. (2010) posed a series of questions designed to guide research and highlight information gaps concerning coyotes and fawns in the region. Central to these questions is how coyote and deer densities affect predation levels.

The availability of alternative prey may modulate coyote predation on fawns (Harrison and Harrison 1984, Andelt et al. 1987, Pusateri Burroughs et al. 2006). However, findings from recent coyote food habits studies suggest that coyotes continue to consume fawns when available, despite the presence of abundant alternative prey (Schrecengost et al. 2008, Kelly 2012), as would be suggested by optimal foraging theory (MacArthur and Pianka 1966, Stephens and Krebs 1986). The dietary plasticity of coyotes allows them to shift prey selection toward fawns during the fawning season because they likely are more nutritionally or energetically efficient than other prey sources such as small mammals (Harrison and Harrison 1984). However, in areas of low deer density, search time to locate fawns may decrease the energetic efficiency of this prey item. Nevertheless, fawns remained a preferred food item for coyotes in Canada, regardless of deer density (Patterson et al. 1998) and coyotes depredated as much as 62% of monitored fawns on a South Carolina site with relatively few deer (Kilgo et al. 2012).

Alternative prey availability may be insufficient to overcome the high nutritional benefit coyotes derive from fawns. However, areas with abundant prey, like the Southeast, may support greater coyote densities, leading to increased fawn predation (Patterson et al. 1998, VanGilder et al. 2009). For example, researchers removed coyotes at a rate of 1.6 coyotes/$km^2$ for 3 years, reducing coyote scat deposition rates 71% from pretreatment (Kilgo et al. 2014), from a South Carolina site with one of the highest reported fawn predation rates (Kilgo et al. 2012). Elsewhere, on two sites in Pennsylvania, predation was the leading cause of mortality on the site where predators were assumed to be more abundant (Vreeland et al. 2004). Similarly, researchers in the Midwest concluded that the high fawn survival observed in their study was a product of perceived low coyote density in the region (Grovenburg et al. 2011). Thus, in areas of high coyote abundance predation rates may remain high regardless of deer abundance because the probability of encounters between coyotes and fawns is increased.

To date, only one study has addressed the potential role of coyote abundance in fawn predation. Researchers monitored fawn survival before and during an intensive coyote removal on a study site in South Carolina (Kilgo et al. 2014). Although fawn survival increased and indices of coyote abundance decreased following trapping, fawn survival differed among years during the removal period. Researchers highlighted the need for further investigation on predation effects in areas with greater deer population density. No removal studies have concurrently estimated coyote abundance and fawn recruitment (as measured by infrared camera surveys) in response to predator removal, likely due to the difficulty in obtaining reliable coyote population estimates.

Despite expanding literature concerning the potential for coyotes to affect fawns in the Southeast, our understanding of the factors driving variability in predation rates is incomplete. Therefore, our objectives were to simultaneously monitor fawn recruitment and coyote abundance on two sites in central Georgia with differing deer densities and landscape features, before and after an intensive coyote removal. Our primary goal was to determine the level of coyote predation on fawns and evaluate the interplay of coyote and deer abundance on fawn recruitment rates.

**STUDY AREAS**

Research was conducted on portions of B.F. Grant (BFG) and Cedar Creek (CC) Wildlife Management Areas (WMAs) located in the Piedmont physiographic region of Georgia. Elevations ranged from approximately 120 m to 180 m, and the terrain was gently rolling. Game management on BFG, owned by the University of Georgia (UGA), and CC, part of the Oconee National Forest, was overseen by the Georgia Department of Natural Resources (GADNR) through cooperative agreements for hunting, fishing, and outdoor recreation. Although BFG and CC covered approximately 50 $km^2$ and 160 $km^2$, respectively, research activities were primarily limited to a 2,000 ha block lying in the interior of each WMA.

The majority of BFG's habitat consisted of loblolly pine (*Pinus taeda*) plantations managed on approximately 30-year rotations. As a result, approximately 14% (700 ha) of BFG's forested area was comprised of early successional forest, generally lasting from the first growing season following timber harvest until canopy closure at approximately 7 years (Figure 2.1). In addition, UGA maintained an agricultural research station within the property that consisted primarily of fescue (*Schedonorus arundinaceus*) and bermuda grass (*Cynodon dactylon*) pastures and hayfields, which also contained a variety of forbs. These pastures and hayfields accounted for an additional 14% (700 ha) of the area (Figure 2.1). From 1974 until the conclusion of research activities, GADNR managed BFG for quality, male white-tailed deer by limiting hunter access through a quota system, and by restricting the harvest of adult males to only those with antlers meeting minimal measurement criteria. The combination of productive early successional and field habitats and tightly-regulated deer harvest allowed for a moderate-to-high deer density ranging from approximately 19-23 deer/$km^2$ (Killmaster, unpublished data).

Research on CC was limited to areas north of Georgia State Highway 212. Timber management on CC was primarily limited to salvage operations (personal communication, Elizabeth Caldwell, USFS). As a result, much of CC consisted of mature, closed canopy forest, and only approximately 7% (420 ha) of the study area consisted of early successional habitat (Figure 2.2). The GADNR managed the deer population to afford maximum hunter opportunity by allowing increased harvest of juvenile (≤ 1.5 years old) males and open hunter access during specified dates. The combination of mature forest and increased deer hunting opportunity on CC resulted in a deer density ranging from approximately 8-12 deer/$km^2$, roughly half of that on BFG (Killmaster, unpublished data).

## METHODS

### Estimation of Fawn Recruitment

We used data collected by GADNR at mandatory check stations on each area to calculate an index of fawn recruitment on each area prior to the study period. Specifically, we calculated the ratio of fawns to adult does in the hunter harvest during 10-year periods from 1977 – 2008. We monitored fawn recruitment (fawns/adult doe) during each winter on both sites from January 2010 to February 2013 using infrared-triggered cameras positioned over bait, as described by Jacobson et al. (1997). Surveys were conducted during January and February both to avoid the deer hunting season and because accuracy of fawn crop estimates is increased during this period (McKinley 2002). We arranged Cuddeback Capture® (Non Typical, Inc., Green Bay, WI) digital trail cameras to cover a 2,000-ha grid on each site at a density of approximately 1 camera/65 ha. We positioned cameras in areas with abundant deer sign (e.g., tracks, trails, feces) near the center of each grid cell. Sites were pre-baited with shelled corn for 1 week prior to each survey. After the pre-baiting period, cameras were positioned over bait and set on a 15-minute delay between photographs. Surveys ran for a 10-day period.

We analyzed camera-survey data to estimate fawn recruitment using two methods. We used the Jacobson method (Jacobson et al. 1997) of dividing the total number of fawn pictures by the total number of adult doe pictures, because this technique was frequently used in prior studies of fawn recruitment before and after predator removal. However, this technique provides no measure of uncertainty for recruitment estimates. Therefore, we also estimated recruitment according to Weckel et al. (2011). This method compares the number of raw photographic occurrences (RPO) of each sex-age class to their probability of being photographed (i.e., trap success [TS]) using linear regression and generates a standardized photographic occurrence

(SPO) for each group. Then, SPO estimates are used to generate standardized demographic ratios. Uncertainty of SPO and demographic ratio estimates are estimated using 1,000 nonparametric bootstraps of camera stations, and the distribution of SPO in each demographic group, respectively. The primary objective of this analysis is to account for differences in TS among sex-age classes.

**Coyote Removal**

Professional trappers removed coyotes from the study sites from March to June 2011 and again during March and April 2012. Trapping occurred just prior to and during fawning season, which typically occurs during May and June on our study sites (Killmaster, unpublished data). Traps were located in areas frequented by coyotes (e.g., along dirt roads, intersections, trails, and firebreaks) and all non-target species were released unharmed. Coyotes were euthanized via gunshot. Capture and euthanasia procedures were approved by the University of Georgia Institutional Animal Care and Use Committee (A2009 09-157-Y3-A0).

We recorded the date of capture, sex, and GPS coordinates of the capture location of each coyote trapped. We collected 3-5 g of tongue tissue post-mortem for genetic analysis and placed them into a Fisherbrand® 15-ml polystyrene centrifuge tube (Fisher Scientific, Pittsburgh, PA) filled with 9 ml of 95% EtOH. We extracted the left mandibular canine tooth from each coyote and submitted them to Matson's Laboratory LLC (Missoula, MT) for age determination via cementum annuli analysis as previously described (Linhart and Knowlton 1967).

**Estimation of Coyote Abundance**

Beginning in January 2010, we collected putative coyote scats on a series of permanently identified transects along unpaved roads and trails in each area covered by camera surveys. We drove along each transect approximately weekly and collected all scats detected. We evaluated species of origin in the field through evaluation of scat size, shape, and contents. For each scat we recorded the date, GPS coordinates of its location, and age based on moisture content and degree of decomposition.

For each scat estimated to be ≤ 3-days-old we preserved a sample for genetic confirmation of species of origin and genotyping to the individual level. We placed approximately 3 ml of fecal matter, collected from the outside edges of each scat, into a Fisherbrand® 15-ml polystyrene centrifuge tube (Fisher Scientific, Pittsburgh, PA) filled with 9 ml of 95% EtOH. DNA was extracted from tissue using the Qiagen DNEasy tissue kit and from feces using the Qiagen QiaAmp Stool Kit. Mitochondrial sequencing was used to determine species from fecal samples according to the cytochrome b fragment amplified by primers:

RF14724 (5'-CAACTATAAGAACATTAATGACC-3')

RF15149 (5'-CTCAGAATGATATTTGTCCTC-3')

followed by BLAST search in Genbank. Individual genotypes and genetic sex were determined based on 12 microsatellites (AHT137, AHT142, AHTh171, CPH18, CXX-279, CXX-374, CXX-468, CXX-602, INU055, REN162C04, REN169O18, REN54P11) and a sex marker (based on X and Y chromosome paralogues of the amelogenin gene). All fecal genotypes were replicated at least once. We calculated the allelic dropout rate for heterozygous loci by dividing the number of dropouts by the number of successful replicates for each locus. Finally, we calculated the probability of identity for each locus and for increasing combinations of the 12 loci using GenAlEx 6.5 (Peakall and Smouse 2006, 2012).

Upon completion of genotyping, we constructed encounter histories for each coyote identified on each site. No individual was encountered on both sites. Although scats were collected weekly to minimize degradation of fecal DNA and increase genotyping success, we divided each calendar year into three, biologically-relevant seasons, with each season considered a sampling occasion.  During April 2012, when sampling intensity was increased, samples were collected twice weekly, with each collection considered a sampling occasion.  Seasons were defined as breeding (Jan-Apr), denning/pup rearing (May-Jul), and dispersal (Aug-Dec).

We used a simple closed capture design in Program MARK (White and Burnham 1999) to generate estimates of coyote abundance for each site during three time periods; January 2010 to February 2011 (prior to coyote removal), June 2011 to February 2012 (year following first coyote removal), and during April 2012 (year following second coyote removal).  Although some individuals were encountered more than once during a given sampling occasion, these instances were treated as a single encounter.  Because closed-population capture-recapture models assume no immigration or emigration across periods, we analyzed encounter histories for each year using program CloseTest (Stanley and Richards 2005) to test for violations of this assumption.  CloseTest is a Microsoft® Windows-based program that computes the Otis et al. (1978) and Stanley and Burnham (1999) closure tests for capture-recapture data sets.

We also analyzed encounter histories during the previously-described periods using a rarefaction approach in CAPWIRE (Miller et al. 2005).  This method of population estimation takes advantage of multiple captures of an individual within a session and provides estimates with small bias and good coverage, along with high accuracy and precision, even when the data contain capture heterogeneity.  Estimates of coyote abundance were intended to represent the approximate number of coyotes using each site during a given time period, rather than a density estimate.

## RESULTS

### Fawn Recruitment Estimates

Check station data indicated a hunter harvest of 0.83 fawns/adult doe on CC between 1977 and 1986 (Figure 2.3a). Although this ratio appeared to decline to 0.65 fawns/adult doe between 1997 and 2008, confidence limits overlapped. Jacobson estimates of fawn recruitment on CC averaged 0.83 during the two years prior to coyote removal and 0.77 fawns/doe following removal. Weckel estimates similarly averaged 0.84 fawns/doe before removal and 0.85 fawns/doe after removal. Both estimators indicated that throughout the study recruitment on CC was similar to the average ratio of fawns to does in the harvest for each 10-year period from 1977 to 2008 (Figure 2.3a).

Between 1977 and 1996, check station data on BFG indicated an average hunter harvest of 0.87-0.89 fawns per adult doe (Figure 2.3b). However, from 1997 to 2008, concurrent with coyote expansion in the region, the ratio of fawns to adult does in the harvest declined to an average of 0.63 fawns/doe. Jacobson estimates of fawn recruitment on BFG averaged 0.54 fawns/doe during the two years before coyote removal and 0.85 fawns/doe after removal (Figure 2.3b). Weckel estimates averaged 0.65 fawns/doe before removal and 1.01 fawns/doe after coyote removal. Recruitment estimates on BFG during 2012 (year following first removal) were significantly greater than during pre-removal (Weckel = 1.07 fawns/doe; Jacobson = 0.93 fawns/doe). Recruitment declined during 2013, and did not differ from pretreatment levels.

### Coyote Removal

Trappers removed 9 coyotes from CC in 2011. Seven (78%) were captured during March. Six (67%) were male and the remaining three (33%) were female. Ages of 8 of the animals ranged from <1 year old to 6 years old (Table 2.1). Four (44%) of the captured coyotes had been previously detected via fecal genotyping. The number of previous encounters of these four coyotes ranged from one to four. Only one coyote, a yearling female, was captured on CC during 2012. She was captured during March and had never been previously encountered.

Trappers removed 15 coyotes from BFG during 2011 and 6 during 2012. During 2011, 12 of the 15 (80%) were captured during March. Seven (47%) of the coyotes were female and eight (53%) were male. Ages of 14 of the animals ranged from <1 year old to 5 years old (Table 2.1). Ten (67%) of the coyotes had not been detected via fecal genotyping prior to the removal. Of the five (33%) that were previously detected, the number of previous detections ranged from one to seven. All six coyotes removed from BFG in 2012 were captured during March. Three were male, three were female, and all six were one-year-old or younger. One of the coyotes was previously detected via fecal genotyping on two occasions prior to capture; the others were never previously encountered.

**Coyote Abundance Estimates**

We collected 340 scats on BFG over the course of the study. Of the scats collected, 238 (70%) were sufficiently fresh for genetic analysis. The species of origin could not be determined for 72 (30%) of those scats. Of the remaining 166 scats, 51 (31%) were from bobcats (*Lynx rufus*), 13 (8%) were from gray foxes (*Urocyon cinereoargenteus*), and 102 (61%) were from coyotes. Genetic analysis of these scats yielded 68 useable coyote genotypes. Thus, 29% of scats collected on BFG and submitted for analysis were confirmed as coyote scats and successfully genotyped to the individual level (Table 2.2).

Of the 235 scats collected on CC, 196 (83%) were submitted for genetic analysis. The species of origin could not be determined for 46 (23%) of those scats. Of the remaining 150 scats, 3 (2%) were from bobcats, 30 (20%) were from gray foxes, and 117 (78%) were from coyotes. Genetic analysis of these scats yielded 68 useable coyote genotypes. Thus, 35% of scats collected on CC and submitted for analysis were confirmed as coyote scats and genotyped to the individual level (Table 2.2).

The mean allelic dropout rate across loci was 0.28 alleles/replicate. On average, individual genotypes were constructed from genotyping results at 11.24 microsatellite loci (range = 7-12). Using all 12 loci, probability of identity was $5.8 \times 10^{-15}$ and probability of identity for siblings was $6.4 \times 10^{-6}$. Probability of identity at 7 loci (minimum number of loci at which an individual was genotyped) was $5.0 \times 10^{-8}$ overall and $9.4 \times 10^{-4}$ for siblings.

Program CloseTest indicated population closure within each period for which we estimated coyote abundance. Estimates of pre-removal coyote abundance were similar between sites (Table 2.3). Both closed and CAPWIRE population estimates indicated that the coyote population on BFG declined from 2010 to 2011, following the initial trapping period. Although confidence intervals were wide in 2012 due to small sample size, both estimators suggested that coyote numbers increased from 2011 to 2012. Based on point estimates from the closed population model, coyote numbers on BFG decreased approximately 80% from 2010 to 2011, then increased by 75% from 2011 to 2012 to levels similar to those observed prior to coyote removal (Table 2.3). Both abundance estimators indicated a moderate decline in coyote numbers on CC following both trapping periods, although 95% confidence limits overlapped across years (Table 2.3). Thus it appeared that trapping efforts were more successful on BFG than CC, resulting in a greater reduction in coyote numbers, particularly during 2011.

## DISCUSSION

Fawn recruitment increased in response to coyote removal on BFG, particularly during 2012, but not on CC, likely due to differential effectiveness of trapping between sites. BFG contained a wider availability of secondary roads and trails ideal for coyote trapping. Further, many of these roads followed edges between differing habitat types. Similar areas were unavailable on CC. As a result, abundance estimates indicated an 80% reduction in coyote numbers on BFG during 2011 while coyote abundance on CC declined by <50% during the same period.

Although recruitment rates differed between sites and among years, recruitment appeared to be inversely related to coyote abundance. On BFG, recruitment increased during 2012 following the reduction in coyote numbers, but declined again during 2013 when less-effective trapping resulted in increases in coyote numbers to near pretreatment levels. In contrast, trapping was less effective at reducing coyote abundance on CC and therefore recruitment remained relatively stable throughout the study period. Although ours is the first study to estimate fawn recruitment concurrent with coyote abundance, others have indicated a possible link between the two. For example, researchers in both the Northeast (Vreeland et al. 2004) and Midwest (Grovenburg et al. 2011) speculated that fawn predation was related to predator abundance, and fawn survival in South Carolina was inversely related to indices of predator abundance (McCoy et al. 2013). However, on another South Carolina site, fawn survival increased following the first year of coyote removal, but varied during the second and third years despite lowered indices of coyote abundance (Kilgo et al. 2014).

Pre-removal recruitment estimates were greater on CC despite similar coyote abundance between sites. Optimal foraging theory suggests that animals select food items according to their profitability, and lower-ranking food items are consumed in order of decreasing profitability as higher-ranking food items fall below a threshold abundance (Charnov 1976, Stephens and Krebs 1986). Because deer density on BFG was approximately twice that of CC, profitability of fawns as a coyote food item likely was greater on BFG, leading to increased targeting of fawns by coyotes. Coyote food habits on our study area support this hypothesis; during fawning 62% and 27% of coyote scats contained fawn remains on BFG and CC, respectively (Kelly 2012). However, on a study site in South Carolina with very low deer density (4-8 deer/km$^2$) and an abundant coyote population (1.5 coyotes/km$^2$; Schrecengost 2007), coyote predation accounted for as much as 80% of fawn mortality (Kilgo et al. 2012). In contrast, coyote density from our closed-model estimates of abundance indicated a lower density of coyotes (0.45-0.80 coyotes/km$^2$). Thus, coyote abundance appears to be more important than deer density in determining fawn predation rates.

Landscape variables may have affected coyote use of each site and, thus, pre-removal recruitment rates as well as coyote population resilience to trapping. Coyotes prefer edges, early successional habitats, and agricultural areas (Holzman et al. 1992, Chamberlain et al. 2000, Kays et al. 2008, Schrecengost et al. 2009), which were more abundant on BFG. Many small mammal species are also more abundant on these areas (Atkeson and Johnson 1979). This disproportionate amount of preferred habitat and inferred prey abundance on BFG may have concentrated coyote movements on the site. Thus, the functional density of coyotes on BFG may have been greater, despite similarities in absolute abundance between sites.

Our findings on BFG are similar to those of previous coyote removal studies in Georgia (Howze et al. 2009), Texas (Beasom 1974), and Alabama (VanGilder et al. 2009), which reported an increase in fawn recruitment following intensive coyote removal. However, despite intensive trapping efforts, we were not able to significantly decrease coyote abundance on CC throughout the study period or on BFG during 2012. This led to unequal responses in recruitment rates between sites and among years. Factors such as landscape variables, deer abundance, coyote abundance, and the suitability of areas for trapping all have the potential to modulate the effectiveness of coyote removal or its ability to elicit an increase in fawn recruitment.

## MANAGEMENT IMPLICATIONS

Recent increases in coyote abundance throughout the Southeast have created concern among deer managers and state wildlife agencies that coyotes may be negatively impacting deer populations. Our results indicate that coyote predation can vary across relatively small spatial scales, given the proximity of our study sites, with a variety of factors potentially playing a role in this dynamic. The expense and difficulty associated with intensive coyote removal, as well as the suitability of areas for trapping, should be considered before initiating an intensive predator removal. If coyote trapping is implemented, our data indicate that trapping should be intense, focused on the removal of a significant percentage of the coyote population, and be maintained annually to maintain levels of fawn recruitment observed prior to the establishment of abundant coyote populations. The variable results we obtained on the two study areas suggest that larger-scale evaluation of coyote use of landscapes in this region are justified and will likely improve understanding of factors driving coyote predation rates on white-tailed deer fawns.

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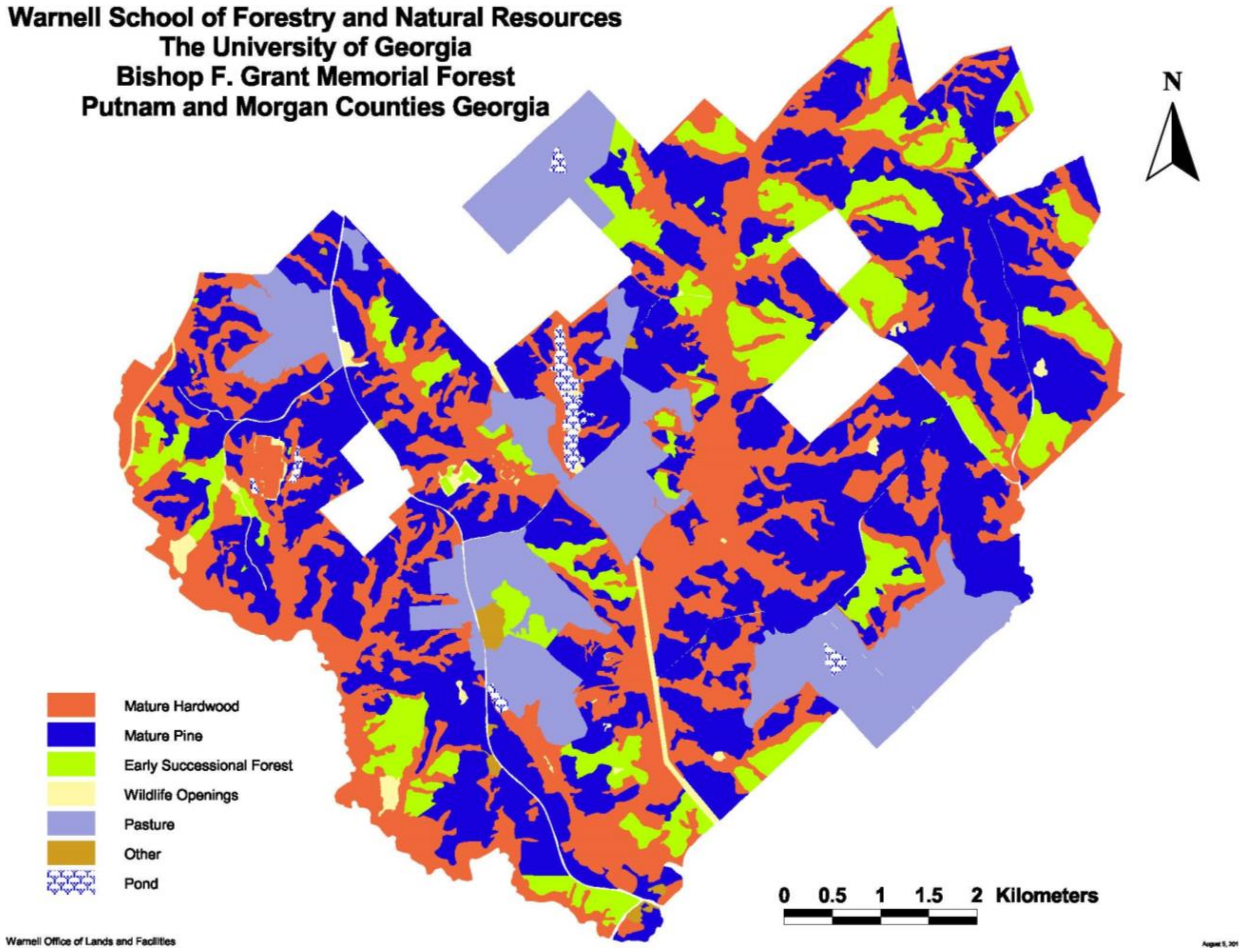


**Figure 2.1** Major habitat classifications for B.F. Grant Wildlife Management Area in Putnam County, Georgia (2009-2012). Productive, early successional, habitats included early successional forest (clearcut < 7 years prior), wildlife openings, and pasture and represented approximately 28% (1400 ha) of the study area.

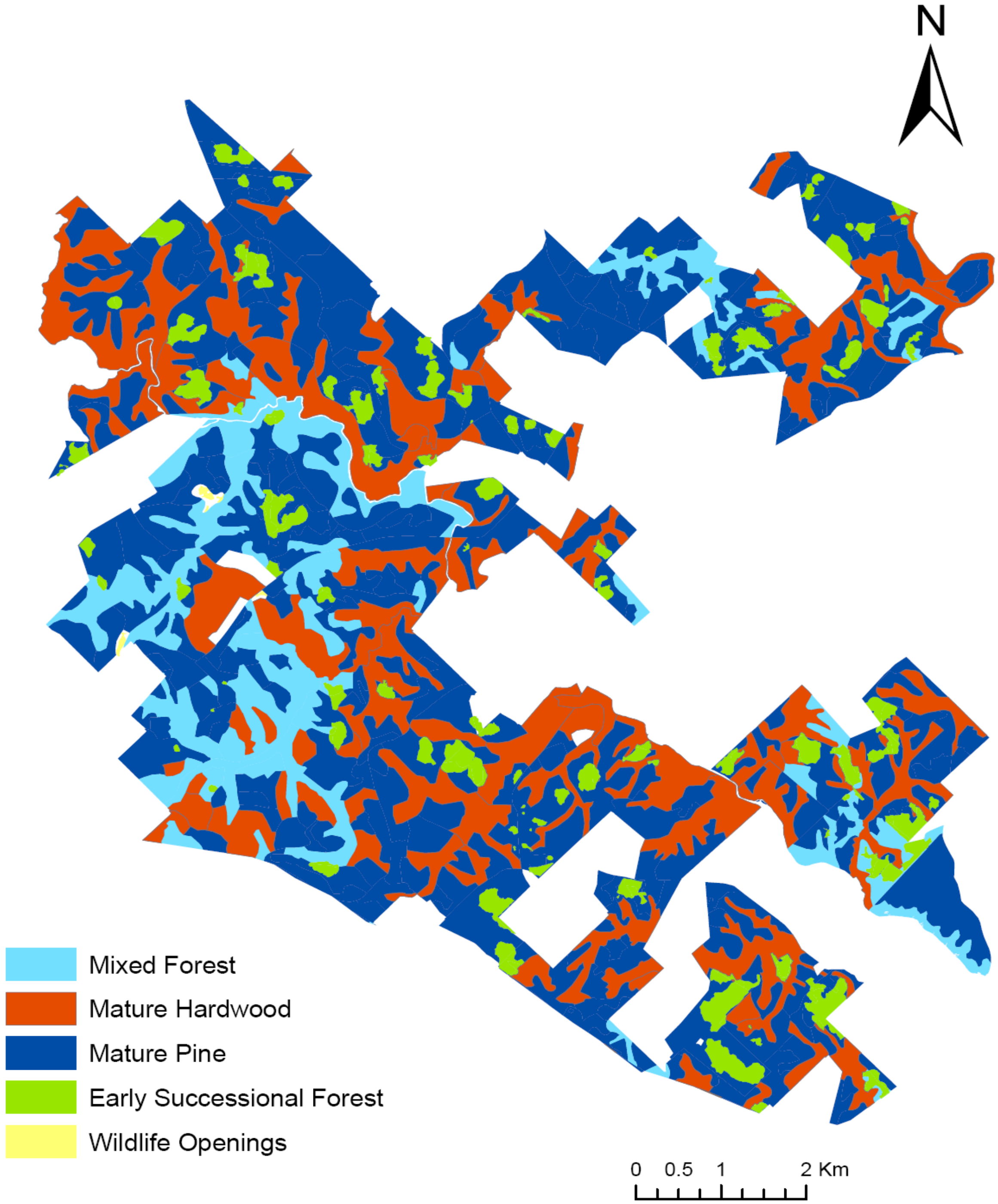


**Figure 2.2** Major habitat classifications for Cedar Creek Wildlife Management Area (north of Highway 212) in Putnam County, Georgia (2009-2012). Productive, early successional, habitats included early successional forest (clearcut < 7 years prior), wildlife openings, and pasture and represented approximately 7% (420 ha) of the study area.

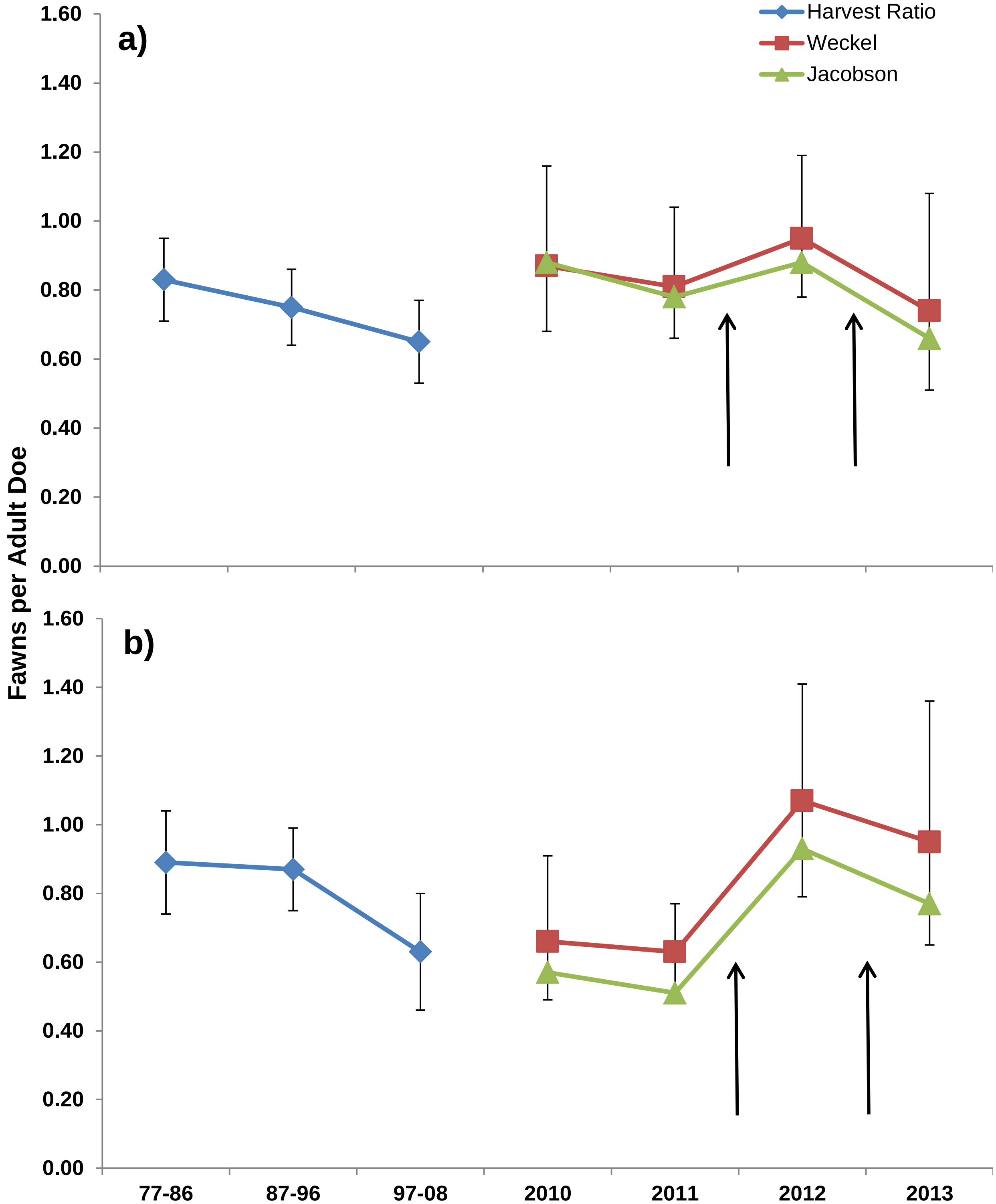


**Figure 2.3** Estimates of fawn recruitment on a) Cedar Creek and b) B.F. Grant Wildlife Management Areas in Putnam County, Georgia. Camera surveys were conducted according to Jacobson et al. (1997) and results were analyzed according to Jacobson et al. (1997) and Weckel et al. (2011). Error bars represent 95% confidence limits and black arrows indicate timing of coyote removals.

**Table 2.1** Sex and age of coyotes removed from B.F. Grant and Cedar Creek Wildlife Management Areas in Putnam County, Georgia during 2011 and 2012. Coyotes were trapped and euthanized by professional trappers and ages determined via cementum annuli analysis of the left lower canine tooth.

| | **Male** | | | | | | | | **Female** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Age** | **0*** | **1** | **2** | **3** | **4** | **5** | **6** | **Unknown** | **0*** | **1** | **2** | **3** | **4** | **5** | **6** | **Total** |
| **B.F. Grant** | | | | | | | | | | | | | | | | |
| **2011** | 4 | 1 | | | 1 | 1 | | 1 | 3 | 1 | 2 | 1 | | | | **15** |
| **2012** | 2 | 1 | | | | | | | 3 | | | | | | | **6** |
| **Cedar Creek** | | | | | | | | | | | | | | | | |
| **2011** | 2 | 1 | | | | 1 | 2 | 1 | 1 | 1 | | | | | | **9** |
| **2012** | | | | | | | | | | 1 | | | | | | **1** |

*****Coyotes less than 1-year-old

**Table 2.2** Number of predator scats collected and submitted for genetic analysis on B.F. Grant and Cedar Creek Wildlife Management Areas in Putnam County, Georgia during 2010-2011. Only scats estimated to be ≤ 3-days-old were submitted for analysis.

| | Total | Analyzed | Species[a] | Bobcat | Grey Fox | Coyote | Genotype[b] |
|---|---|---|---|---|---|---|---|
| **B.F. Grant** | 340 | 238 | 166 | 51 | 13 | 102 | 68 |
| **Cedar Creek** | 235 | 196 | 150 | 3 | 30 | 117 | 68 |

[a]Scats for which species of origin was successfully determined
[b]Coyote scats genotyped at a sufficient number of microsatellite loci to allow for individual identification

**Table 2.3** Closed population and CAPWIRE estimates of coyote abundance on B.F. Grant and Cedar Creek Wildlife Management Areas in Putnam County, Georgia from 2010 to 2012.

| | **Closed Model** | | | **CAPWIRE** | | |
|---|---|---|---|---|---|---|
| | **N** | **Lower 95%** | **Upper 95%** | **N** | **Lower 95%** | **Upper 95%** |
| **B.F. Grant** | | | | | | |
| **2010** | 21 | 19 | 33 | 24 | 18 | 32 |
| **2011** | 4 | 4 | 17 | 8 | 4 | 14 |
| **2012** | 16 | 7 | 82 | 18 | 6 | 50 |
| **Cedar Creek** | | | | | | |
| **2010** | 16 | 15 | 28 | 22 | 15 | 30 |
| **2011** | 9 | 5 | 40 | 16 | 6 | 36 |
| **2012** | 9 | 7 | 22 | 14 | 8 | 22 |

# CHAPTER 3

# AN EVALUATION OF METHODS FOR ESTIMATING COYOTE ABUNDANCE IN THE SOUTHEASTERN UNITED STATES[2]

[2] Gulsby, W.D., B.N. Sacks, C.H. Killmaster, J.W. Bowers, J.D. Kelly, and K.V. Miller. 2014. To be submitted to *Wildlife Society Bulletin*.

**ABSTRACT**

Coyotes (*Canis latrans*) are a relatively recent addition to the fauna of the southeastern United States. Understanding their ecological impacts or developing management strategies requires indices or estimates of abundance. Scent-station and scat-deposition surveys have been used to index predator abundance but evaluations of these techniques are scarce in the literature, especially for the Southeast. Therefore, we evaluated these indices of coyote abundance on two sites in central Georgia during February through December 2010. We concurrently used fecal genotyping to noninvasively mark and recapture individual coyotes and generate abundance estimates. Mark-recapture estimates were precise and indicated similar coyote abundance between sites. We recorded 18 scent-station visits by coyotes during 430 total scent-station nights. Low visitation rates ($\bar{x}$ = 0.04; range = 0 – 0.10) indicate that scent-station surveys are an unreliable index of coyote abundance. Similar to mark-recapture estimates, there was no difference in scat deposition rates between sites ($F_{1,60} = 0.026$, $P = 0.873$). However, there was an interaction between site and season ($F_{2,60} = 7.661$, $P = 0.001$). Deposition rates were similar between sites during summer, greater on BFG during winter and spring, and greater on CC during late summer and fall. The number of scats collected each month was positively related to the number of individual coyotes identified via genotyping ($r^2 = 0.91$, $P < 0.001$). Although fecal genotyping allows estimation of actual abundance, it is expensive and requires large sample sizes. In contrast, scat-deposition surveys are inexpensive, intuitive, and may also allow comparison of coyote relative abundance at a finer temporal scale. Thus, scat-deposition surveys may provide sufficient information for management decisions in many situations. Conversely, costs of fecal genotyping may be justified when more precise population estimates are necessary.

**INDEX WORDS:** abundance, *Canis latrans*, eastern coyote, fecal DNA, Georgia, relative abundance, noninvasive survey, predator, scat deposition, scent station

## INTRODUCTION

Although once restricted to the Great Plains, the distribution of coyotes (*Canis latrans*) has expanded over the past two centuries to include all of North America except for the far northeastern regions of Canada (Bekoff and Gese 2003). Coyotes colonized areas east of the Mississippi River along a northern and a southern front. The northern front moved across the Great Lakes region and into northeastern states, while the southern front moved across the Southeast (Moore and Parker 1992, Parker 1995), perhaps aided by human translocation (Hill et al. 1987). Since then, coyotes have rapidly increased in number throughout the region (Kilgo et al. 2010).

Very little is known about the ecology of coyotes within this region, or its ecological impacts. Most attention has focused on interactions between white-tailed deer (*Odocoileus virginianus*) and coyotes. Declining recruitment rates in some deer populations coincide with increasing coyote abundance in the Southeast (Kilgo et al. 2010) and fawn predation rates are apparently related to relative coyote abundance (Vreeland et al. 2004, Grovenburg et al. 2011). Therefore, reliable estimates or indices of coyote abundance are necessary to understand their impacts on deer and other species, but these measures are difficult to obtain due to the coyote's cryptic and wide-ranging nature.

Until recently, scent station lines (Linhart and Knowlton 1975) and scat surveys were the primary methods used to estimate relative abundance of coyotes. Scent stations consist of a 1-m diameter circle of powdered lime or sifted soil, with a bait or lure placed in the center. Stations are established along roads or transects and operated for $\geq 1$ night, with each station examined for predator tracks each morning. Scent-station surveys are inexpensive, can be set up to cover large areas, and can be implemented with little training. However, evaluations of this popular and widely used method for estimating furbearer abundance (Ray and Zielinski 2008) indicate limited utility. For example, visitation rates by bobcats (*Lynx rufus*) were related to density in a Georgia study, but predictions of population size were imprecise and detecting population changes ≥ 25% required ≥ 4 surveys/year (Diefenbach et al. 1994). Scent-station surveys also have been reported to be unreliable for raccoons (*Procyon lotor*; Smith et al. 1994) and cougars (*Puma concolor*; Choate et al. 2006).

Evaluations of scent stations as an index of coyote abundance are scarce in the literature, but low probability of detection is routinely reported. For example, visitation rates by coyotes were lower than those of any other predator during a statewide survey of Minnesota (Erb 2006), while 198 scent-station nights produced a single coyote response in Tennessee (Crawford et al. 1993). Sargeant et al. (1998) evaluated the method for use with coyotes and concluded that although long-term trends in visitation rates likely reflect population changes, the usefulness of scent-station surveys is limited by poor spatial and temporal resolution, susceptibility to confounding factors, and low statistical power. Other problems associated with scent stations include potential misidentification of ambiguous prints, weather related failures, and inability to estimate population density (Ray and Zielinski 2008).

Scat surveys are another commonly used method to assess relative abundance of coyotes. During a scat survey, coyote scats are collected along a predetermined route, and a scat deposition rate index of abundance is calculated. The method is easily conducted by those with relatively little training. However, the relative difficulty of finding carnivore scats and distinguishing scats of different species based solely upon visual inspection makes them less popular than scent-station surveys (Heinemeyer et al. 2008).

Published reports on carnivore scat surveys are even scarcer than those for scent-station surveys. In addition, very few have attempted to test the method through comparison to independent measures of abundance or density (Heinemeyer et al. 2008). Misidentification of scats may pose a significant problem in areas where other carnivore species are abundant. For example, in North Carolina 23% of scats collected and identified to species belonged to species other than coyotes or red wolves (*Canis rufus*), which were the focal species (Adams et al. 2003). Additionally, seasonal changes in coyote diets (Andelt and Andelt 1984), rainfall (Cavallini 1994), and coprophagy or removal of scats from roadways by coyotes or other species (Livingston et al. 2005) have been cited as potential sources of bias in scat deposition surveys.

While scat-deposition surveys have the advantage of being non-invasive, they are like scent-stations in that they do not allow identification of individuals. Thus, addition of genetic analysis to scat surveys is becoming increasingly popular. For example, researchers in New York coupled the two methods and found that the number of coyote scats collected on a site was closely related to the number of individual coyotes occupying the site (Kays et al. 2008). Fecal genotyping also enables researchers to construct individual encounter histories and apply population models to the data to estimate abundance (i.e., non-invasive mark-recapture). This method was successfully used to estimate coyote abundance in California (Kohn et al. 1999, Fedriani et al. 2001), New York (Kays et al. 2008), and Alaska, where researchers identified nearly four times as many individuals as with physical capture (Prugh et al. 2005). Although Adams et al. (2003) used fecal genotyping to monitor hybridization between coyotes and red wolves in North Carolina, we are not aware of a study in which fecal genotyping has been used to estimate coyote abundance in the Southeast.

Despite its advantages, fecal genotyping is more expensive and technically demanding than either scat- or scent-station surveys. Additionally, it is difficult to adequately sample populations to generate abundance estimates such that sampling typically occurs over extended time periods. Even when large numbers of scats are collected, effective sample size is often decreased by misidentification of scats and inability to identify unique individuals using the scarce and low-quality DNA contained in feces. Due to the caveats associated with fecal genotyping, scent-stations, and scat surveys, as well as the lack of studies comparing traditional methods to an independent measure of abundance, we concurrently implemented and evaluated all three methods on two study sites in central Georgia.

**STUDY AREAS**

Research was conducted on portions of B.F. Grant (BFG) and Cedar Creek (CC) wildlife management areas (WMAs) located in the Piedmont physiographic region of Georgia. Elevations ranged from approximately 120 m to 180 m, and the terrain was gently rolling. Game management on BFG, owned by the University of Georgia (UGA), and CC, part of the Oconee National Forest, was overseen by the Georgia Department of Natural Resources (GADNR) through cooperative agreements for hunting, fishing, and outdoor recreation. Although BFG and CC covered approximately 50 $km^2$ and 160 $km^2$, respectively, research activities were primarily limited to a 2,000 ha block lying in the interior of each WMA.

The majority of BFG's habitat consisted of loblolly pine (*Pinus taeda*) plantations managed on approximately 30-year rotations. As a result, approximately 14% (700 ha) of BFG's forested area was comprised of early successional forest, generally lasting from the first growing season following timber harvest until canopy closure at approximately 7 years (Figure 3.1). In addition, UGA maintained an agricultural research station within the property that consisted primarily of fescue (*Schedonorus arundinaceus*) and bermuda grass (*Cynodon dactylon*) pastures and hayfields, which also contained a variety of forbs. These pastures and hayfields accounted for an additional 14% (700 ha) of the area (Figure 3.1).

Research on CC was limited to areas located north of Georgia State Highway 212. Timber management on CC was primarily limited to salvage operations (personal communication, Elizabeth Caldwell, USFS). As a result, much of CC consisted of mature, closed canopy forest, and only approximately 7% (420 ha) of the study area consisted of early successional habitat (Figure 3.2).

## METHODS

### Scent Station Surveys

We conducted scent-station surveys approximately bimonthly from February – December 2010. Scent stations were located along unpaved roads and trails traversing representative cover types on each area and the minimum distance between scent stations was 0.5 km (Figures 3.3, 3.4). The number of stations on each area during surveys was approximately equal but was limited by the length of accessible roads and minimum spacing requirements. Stations were placed on alternating sides of the road to account for wind direction. Each station consisted of a 1.0-m diameter circle of powdered hydrated limestone with a fatty-acid scent tablet (U.S. Dept. Agric., Pocatello Supply Depot, Pocatello, ID) placed at the center (Linhart and Knowlton 1975). Transects were operated for one night, as suggested by Roughton and Sweeny (1982), and the presence or absence of coyote tracks was recorded the following morning. To avoid issues associated with dependence of stations or lines of stations, we treated the overall visitation rate for each site during a survey as a single data point (Diefenbach et al. 1994, Sargeant et al. 1998).

**Scat Surveys**

We collected putative coyote scats approximately weekly on each study area from February – December 2010 along permanently-identified survey routes that consisted of unpaved roads and trails, and approximately overlapped areas covered by scent station surveys. Survey routes totaled 28 km on BFG (Figure 3.3) and 20 km on CC (Figure 3.4). We differentiated coyote scats from other species based on published criteria of size, shape, contents, and odor (Murie 1974). We placed each sample into a container labeled with the date and the approximate age of the scat, based on moisture content and degree of decomposition. We calculated the scat deposition rate (scats/km/day) for each session on each site by dividing the number of scats collected by the length of the survey route and the number of days since the previous sampling session.

We used a two-way ANOVA with pairwise comparisons in R 2.15.1 (R Core Team 2012) to compare deposition rates between sites and among seasons. Scat deposition rates are greater when diets are primarily composed of vegetation or fruits (Andelt and Andelt 1984). Therefore we divided each year into three seasons based on results from a 2010 coyote food habits study on both sites which indicated that diets were primarily composed of mammal species (*Odocoileus virginianus* and *Sylvilagus* spp.) during December-May, early-successional soft mast species (*Rubus* spp.) during June-August, and later-successional soft mast species (*Diospyros virginiana* and *Vitis* spp.) during September-November (Kelly 2012).

**Estimation of Coyote Abundance via Fecal Genotyping**

For each scat estimated to be ≤ 3-days-old we preserved a sample for genetic confirmation of species of origin and genotyping to the individual level. We placed approximately 3 ml of fecal matter, collected from the outside edges of each scat, into a Fisherbrand® 15-ml polystyrene centrifuge tube (Fisher Scientific, Pittsburgh, PA) filled with 9 ml of 95% EtOH. Each tube was labeled with a unique identification number, the date of collection, and the approximate age of the scat when collected.

DNA was extracted from feces using the Qiagen QiaAmp Stool Kit. Mitochondrial sequencing was used to determine species according to the cytochrome b fragment amplified by primers:

RF14724 (5'-CAACTATAAGAACATTAATGACC-3')

RF15149 (5'-CTCAGAATGATATTTGTCCTC-3')

followed by BLAST search in Genbank. Individual genotypes and genetic sex were determined based on 12 microsatellites (AHT137, AHT142, AHTh171, CPH18, CXX-279, CXX-374, CXX-468, CXX-602, INU055, REN162C04, REN169O18, REN54P11) and a sex marker (based on X and Y chromosome paralogues of the amelogenin gene). All fecal genotypes were replicated at least once. We calculated the allelic dropout rate for heterozygous loci by dividing the number of dropouts by the number of successful replicates for each locus. Finally, we calculated the probability of identity for each locus and for increasing combinations of the 12 loci using GenAlEx 6.5 (Peakall and Smouse 2006, 2012).

Upon completion of genotyping, we constructed encounter histories for each coyote identified on each site. No individual was encountered on both sites. Although scats were collected weekly to minimize degradation of fecal DNA and increase genotyping success, we divided 2010 into three biologically-relevant seasons, with each season considered a sampling occasion. Seasons were defined as breeding (Feb-Apr), denning/pup rearing (May-Jul), and dispersal (Aug-Dec).

We used a simple closed capture design in Program MARK (White and Burnham 1999) to generate estimates of coyote abundance for each site during 2010. Although some individuals were encountered more than once during a given sampling occasion, these instances were treated as a single encounter. Because closed-population capture-recapture models assume no immigration or emigration across periods, we analyzed encounter histories for each period of interest using program CloseTest (Stanley and Richards 2005) to test for violations of this assumption. CloseTest is a Microsoft® Windows-based program that computes the Otis et al. (1978) and Stanley and Burnham (1999) closure tests for capture-recapture data sets.

We also analyzed encounter histories during 2010 using a rarefaction approach in CAPWIRE (Miller et al. 2005). This method of population estimation takes advantage of multiple captures of an individual within a session and provides estimates with small bias and good coverage, along with high accuracy and precision, even when the data contain capture heterogeneity. Estimates of coyote abundance were intended to represent the approximate number of coyotes using each site during a given time period, rather than a density estimate.

Finally, we compared the number of unique coyote genotypes identified during each month to the total number of suspected coyote scats collected during that month using linear regression in the R software. The purpose of this analysis was to further evaluate the usefulness of scat deposition rates as an index of relative abundance.

## RESULTS

### Scent-Station Surveys

We conducted five scent-station surveys on each site during 2010. We recorded a total of seven coyote visits during 234 scent-station nights on BFG and 11 coyote visits during 196 scent-station nights on CC (Table 3.1). During two surveys on BFG and one survey on CC we detected no coyote visits. Due to low overall visitation rates, we observed no apparent trend in scent-station data.

### Scat Surveys

We collected a total of 216 suspected coyote scats during 34 sampling occasions on BFG during 2010. The mean scat deposition rate was 0.030 scats/km/day and ranged from 0.004-0.089 scats/km/day. On CC we collected 142 scats during 27 sampling occasions. The mean scat deposition rate was 0.034 scats/km/day and ranged from 0.004-0.133 scats/km/day. Visual inspection of scat deposition rates prior to analysis indicated the data were non-normally distributed, clustered near zero with a positive skew. Therefore we used a log transformation to meet the assumption of normality prior to analysis.

There was no difference in scat deposition rates between sites ($F_{1,60} = 0.026$, $P = 0.873$). However, there was an interaction between site and season ($F_{2,60} = 7.661$, $P = 0.001$). Therefore, we used a series of t-tests to compare deposition rates between sites during each season. Deposition rates were similar between sites during June-August ($t_{19.8} = 0.653$, $P = 0.521$), but were greater on BFG during December-May ($t_{15.2} = 2.617$, $P = 0.019$), and greater on CC during September-November ($t_{13.1} = -2.647$, $P = 0.020$; Figure 3.5).

**Non-invasive Mark Recapture**

We collected 216 total scats on BFG during 2010. Of the scats collected, 133 (62%) were sufficiently fresh for genetic analysis. The species of origin could not be determined for 43 (32%) of those scats. Of the remaining 90 scats, 12 (13%) were from bobcats, 6 (7%) were from gray fox (*Urocyon cinereoargenteus*), and 72 (80%) were from coyotes. Genetic analysis of these scats yielded 45 useable coyote genotypes representing 18 unique individuals. Thus, 34% of scats collected on BFG and submitted for analysis were confirmed as coyote scats and successfully genotyped to the individual level (Table 3.2).

Of the 142 scats collected on CC during 2010, 114 (80%) were submitted for genetic analysis. The species of origin could not be determined for 39 (34%) of those scats. Of the remaining 75 scats, 6 (8%) were from gray foxes and 69 (92%) were from coyotes. Genetic analysis of these scats yielded 35 useable coyote genotypes representing 15 unique individuals. Thus, 31% of scats collected on CC and submitted for analysis were confirmed as coyote scats and genotyped to the individual level (Table 3.2).

The mean allelic dropout rate across loci was 0.28 alleles/replicate. On average, individual genotypes were constructed from genotyping results at 11.24 microsatellite loci (range = 7-12). Using all 12 loci, probability of identity was $5.8 \times 10^{-15}$ and probability of identity for siblings was $6.4 \times 10^{-6}$. Probability of identity at 7 loci (minimum number of loci at which an individual was genotyped) was $5.0 \times 10^{-8}$ overall and $9.4 \times 10^{-4}$ for siblings.

Program CloseTest indicated population closure on both sites so we applied the closed population model in program MARK to estimate coyote abundance. Point estimates of coyote abundance were similar between sites, but estimates generated using CAPWIRE were more similar than those for the closed model. Overall, the closed model in program MARK and the rarefaction approach implemented in CAPWIRE produced very similar results (Figure 3.6).

We failed to genotype any scats to the individual level during three months on BFG and four months on CC. Thus we compared the number of suspected coyote scats to the number of coyote genotypes during 15 total months. The number of coyote genotypes was positively related to the total number of suspected coyote scats collected during each month (Figure 3.7). The relationship was best fit by the linear function $y = 0.17994x$ ($r^2 = 0.91$, $P < 0.001$). Thus, the number of individual coyotes identified during each sampling session increased by one individual for every 5.56 additional scats detected.

## DISCUSSION

Although the low cost and ease of implementation makes scent-station surveys a potentially attractive method of indexing coyote abundance, our data clearly suggest that they are ill suited for such applications. Visitation rates were low, varied substantially among surveys, and we recorded no coyote visits during three of 10 surveys, making comparison of visitation rates among seasons or between sites uninformative. Similarly, Zielinski and Stauffer (1996) reported that it may be necessary to conduct scent-station surveys composed of hundreds of lines of many stations to obtain reliable results for infrequently detected species such as coyotes.

While scent-stations require coyotes to respond to a stimulus, scat-deposition surveys are noninvasive. Although misidentification of scats may be a source of bias, we correctly identified 85% of scats assigned to species, similar to results in a New York study (89% of coyote scats assigned correctly; Kays et al. 2008). Therefore bias associated with misidentification in scat-deposition surveys may be overstated as other carnivore species were well represented on both of our study areas.

To our knowledge, we are the first in the Southeast to compare coyote scat-deposition rates to fecal genotyping results. Although the data intensiveness of mark-recapture models precluded our ability to estimate coyote abundance at temporal scales < 1 year, both closed and CAPWIRE population models indicated similar abundance between sites during 2010. Scat deposition rates also indicated similar coyote abundance between sites.

Scat deposition rates differed seasonally on the two study areas. Deposition rates were greater on BFG during winter and spring and on CC during September-November. These differences are likely related to changes in food availability that affects either intensity of use of areas by coyotes, or seasonal coyote abundance within an area. For example, deposition rates on BFG were greater during December-May when 70-80% of coyote scats contained small mammal remains (Kelly 2012). BFG contained more early successional habitat (28%) than CC (7%). These habitat types are preferred by both coyotes (Holzman et al. 1992, Chamberlain et al. 2000, Schrecengost et al. 2009) and a variety of mammalian prey species (Atkeson and Johnson 1979). In contrast, deposition rates were greater on CC during late summer and fall when muscadine (*Vitis rotundifolia*) and persimmon (*Diospyros virginiana*), which are more prevalent in later successional areas (Andelt et al. 1987), were the most important food items on both sites (Kelly 2012).

The relationship between the number of coyote genotypes and the number of suspected coyote scats collected during each month offers further evidence to support the use of scat-deposition surveys as an index of coyote abundance. Kays et al. (2008) similarly reported that the total number of coyote scats along transects was directly related to the number of individual coyotes inhabiting their study sites in northern New York. However, in that study only the number of successfully genotyped coyote scats was compared to the number of resulting genotypes. We propose that our analysis is more realistic. Field application of a scat-deposition survey certainly must rely on all suspected scats, not only those identified via fecal genotyping.

Our results clearly indicate that scat-deposition surveys can be influenced by seasonal habitat use, particularly during December-May and September-November. Thus, we suggest standardization of surveys during summer/early fall when we observed the least variability between study sites related to seasonally abundant foods. However, regional differences in coyote diets and landscape composition may affect optimal times to minimize habitat- and diet-driven effects.

Fecal genotyping capitalizes on the noninvasiveness of scat collection but also allows for estimation of actual abundance. Although fecal genotyping allowed us to generate relatively precise estimates of coyote abundance on each site, there are several factors to consider related to this technique. We were able to reach consensus genotypes for only 32% of analyzed scats. Inability to determine species of origin, incorrect species identification, and inability to reach a consensus genotype all contributed to the decrease in sample size. In New York, researchers obtained usable three-marker coyote genotypes for 26% scats (Kays et al. 2008). Success rates were higher in California with 48% of putative coyote scats successfully typed at three markers (Kohn et al. 1999).

Climatic conditions influence microsatellite amplification success and reliability due to the sensitivity of DNA to environmental exposure (Panasci et al. 2011). Therefore, genotyping success is typically greater in areas with cold and/or dry climates. However, our success rates were similar to those of others despite Georgia’s hot, humid climate, relatively abundant non-target species, and the fact that we typed DNA at 13 microsatellite loci. Thus, these findings are encouraging for the future applicability of fecal genotyping in the Southeast. Nevertheless, the low success rates in genotyping feces, coupled with the data intensiveness of mark-recapture models, often limits abundance estimation to longer time periods.

Solberg et al. (2006) recommended collection of 2.5-3 times as many fecal samples as the "assumed" number of animals in the study population. Analysis of such large numbers of samples can be cost prohibitive. For example, total cost of genotyping the 247 samples analyzed during 2010 was approximately $6,000 USD. Overall, scent-station and scat-deposition surveys are more economical, but these methods incur similar costs with regards to manpower and fuel and do not allow estimation of abundance. Nevertheless, results from such surveys are often used to inform significantly more expensive management or research decisions and, thus, fecal genotyping costs may be justified.

## MANAGEMENT IMPLICATIONS

Our results and those of others indicate that scent-station surveys may be of little use except in monitoring long-term trends over large geographical areas. In contrast, our results indicate that scat-deposition surveys do enable rough comparisons between areas provided that the potential effects of seasonal changes in diet are taken into account. Furthermore, we were able to compare relative abundance of coyotes, or relative coyote use, between sites at finer temporal scales than with genotyping. In contrast, fecal genotyping can be a useful technique for providing precise abundance estimates in the Southeast, albeit across longer temporal scales. However, fecal genotyping was the most expensive abundance estimator we used, although costs for genetic analyses likely will decline, especially for high-throughput applications.

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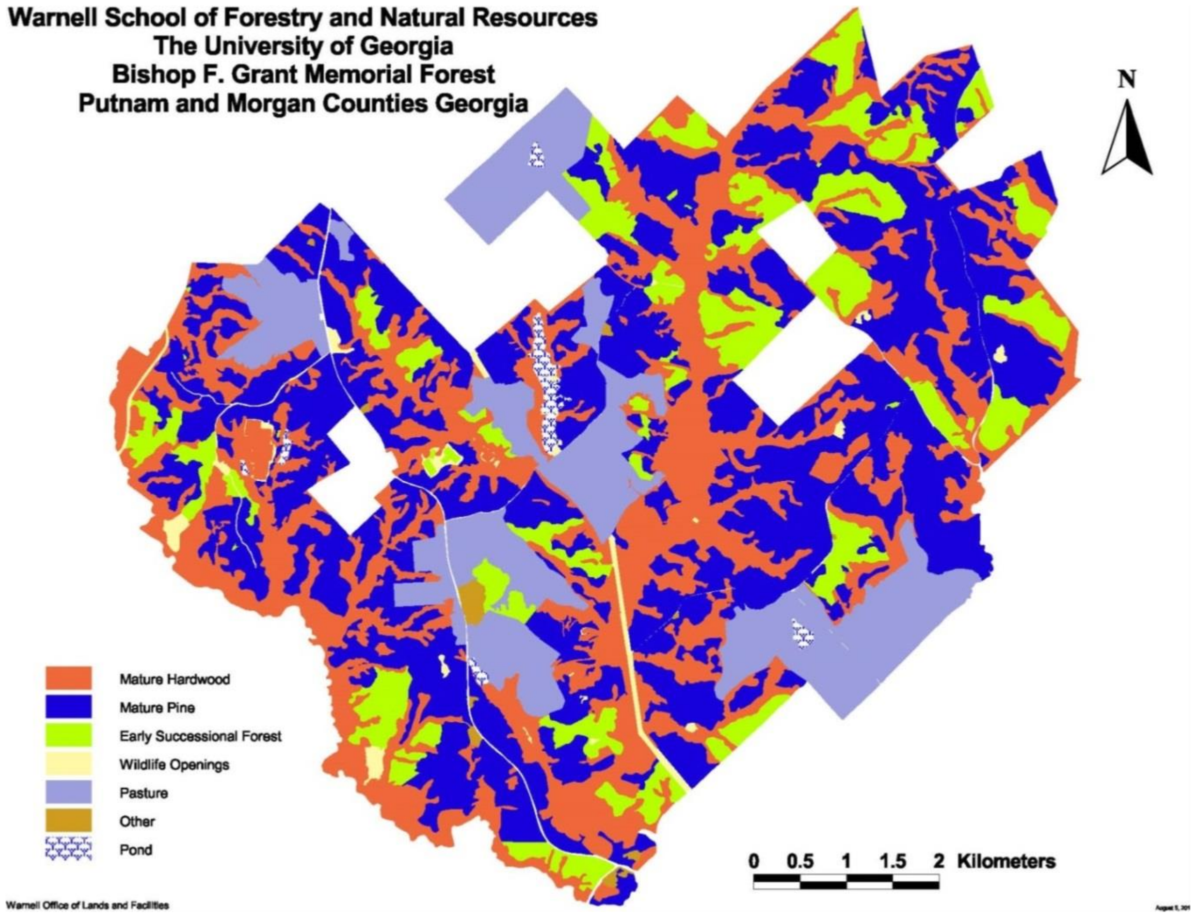


**Figure 3.1** Major habitat classifications for B.F. Grant Wildlife Management Area in Putnam County, Georgia (2010). Productive, early successional, habitats included early successional forest (clearcut < 7 years prior), wildlife openings, and pasture and represented approximately 28% (1400 ha) of the study area.

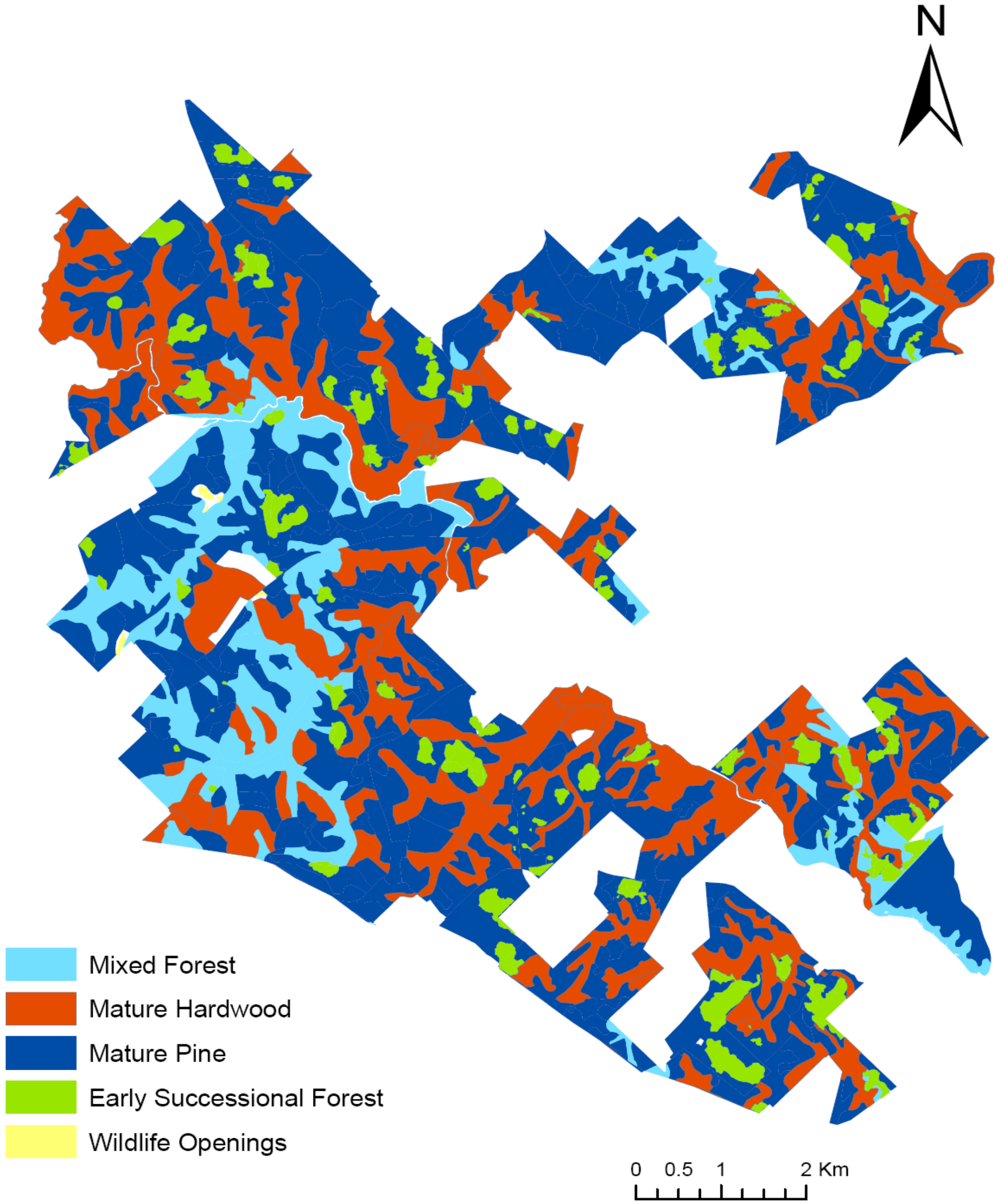


**Figure 3.2** Major habitat classifications for Cedar Creek Wildlife Management Area (north of Highway 212) in Putnam County, Georgia (2009-2012). Productive, early successional, habitats included early successional forest (clearcut < 7 years prior), wildlife openings, and pasture and represented approximately 7% (420 ha) of the study area.

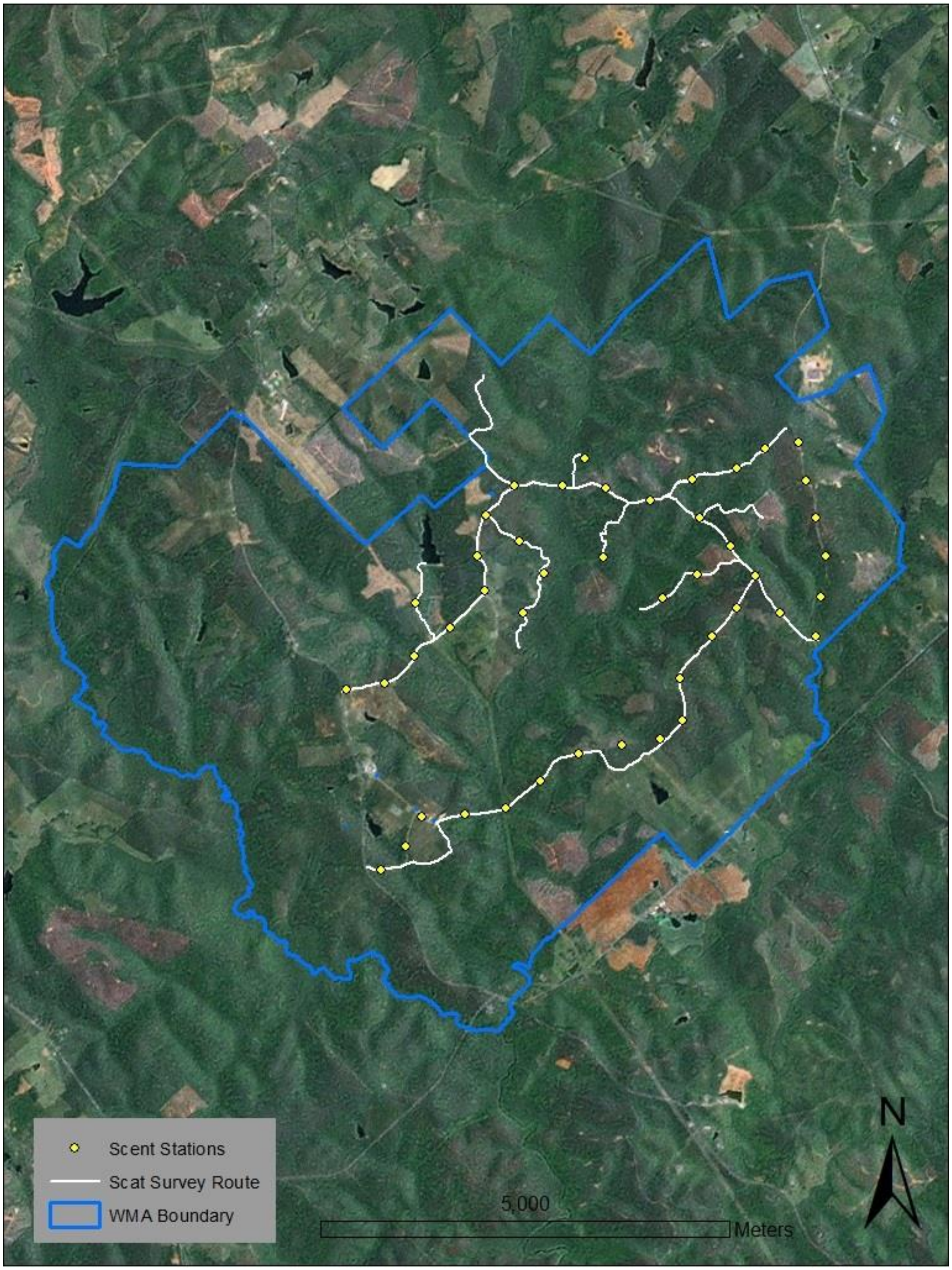

**Figure 3.3** Scent-station locations and scat-survey routes on B.F. Grant Wildlife Management Area in Putnam County, Georgia during February-December 2010.

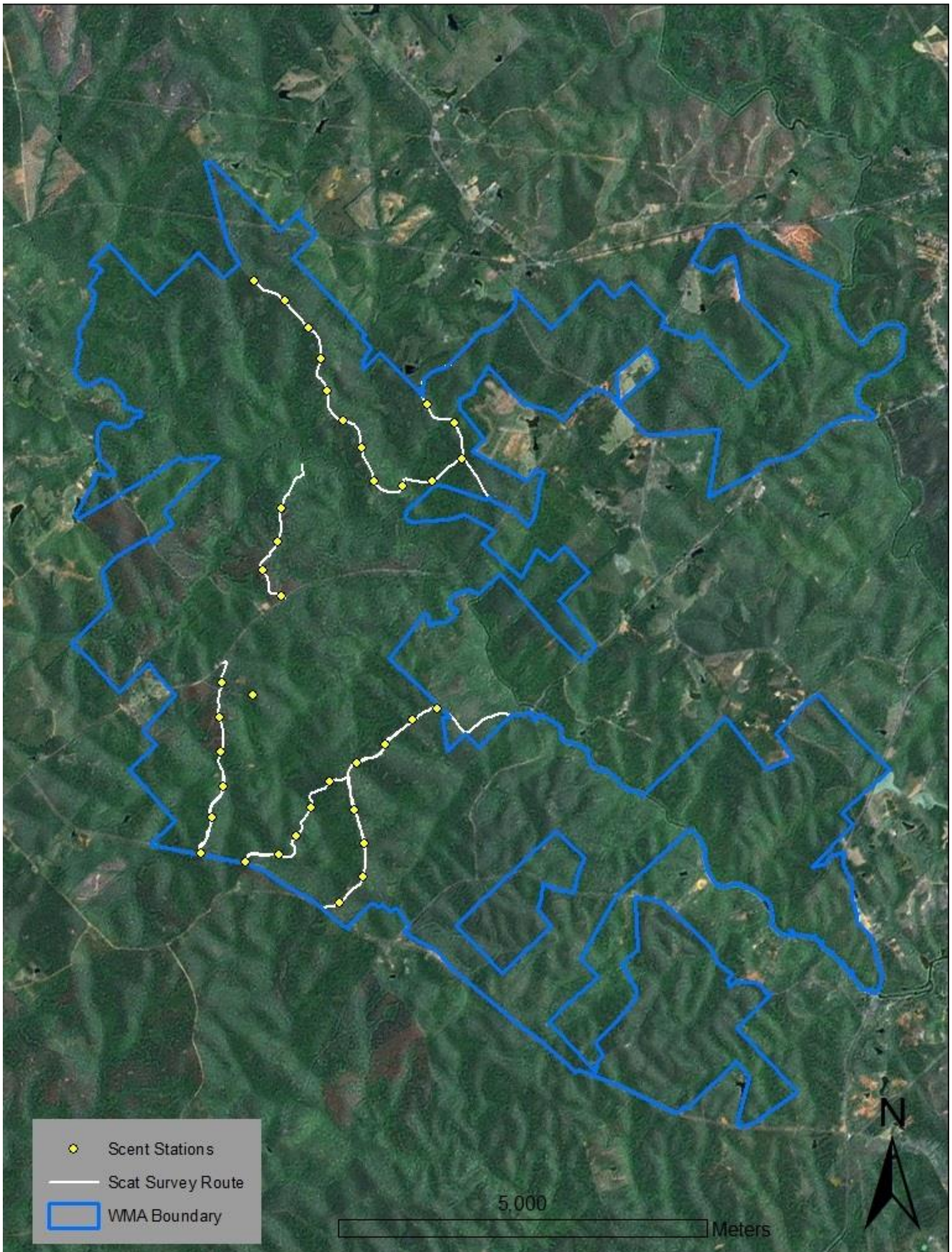


**Figure 3.4** Scent-station locations and scat-survey routes on Cedar Creek Wildlife Management Area in Putnam County, Georgia during February-December 2010.

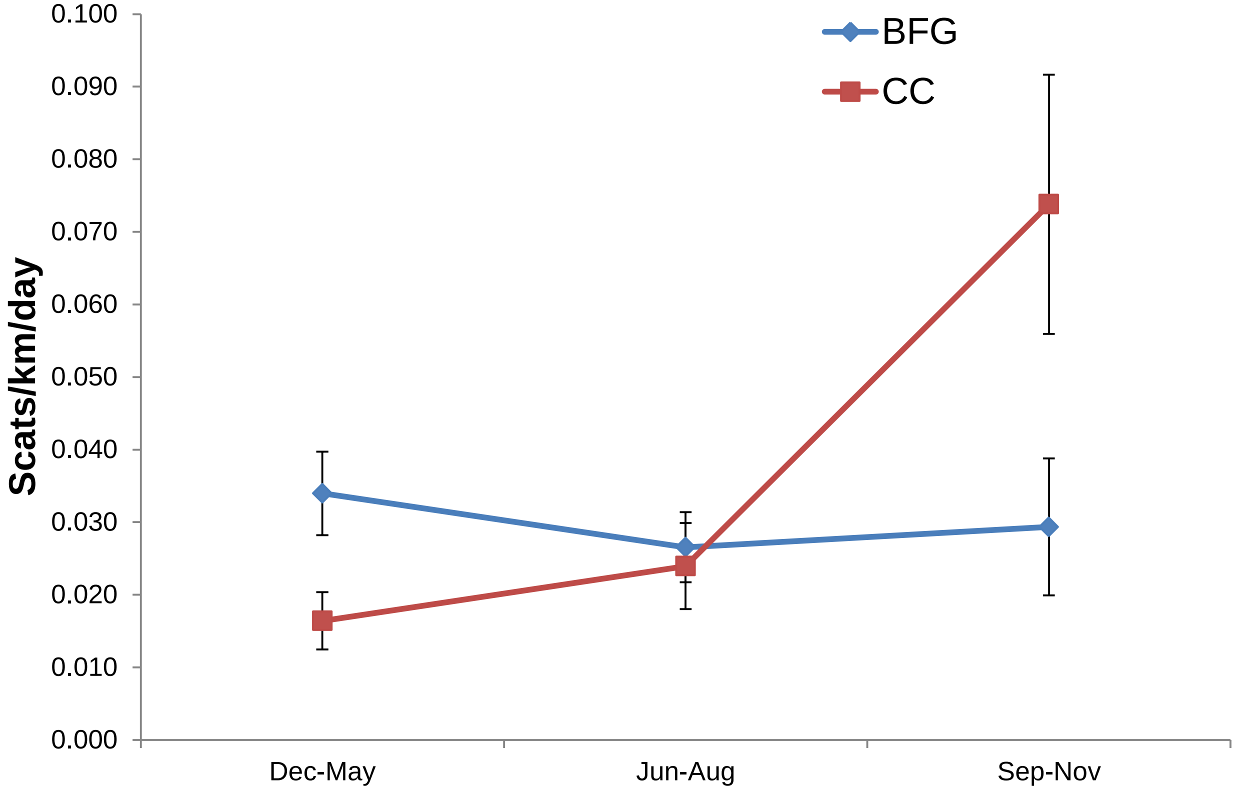


**Figure 3.5** Mean seasonal coyote scat deposition rates on B.F. Grant and Cedar Creek Wildlife Management Areas in Putnam County, GA during 2010. Error bars indicate standard error of the means.

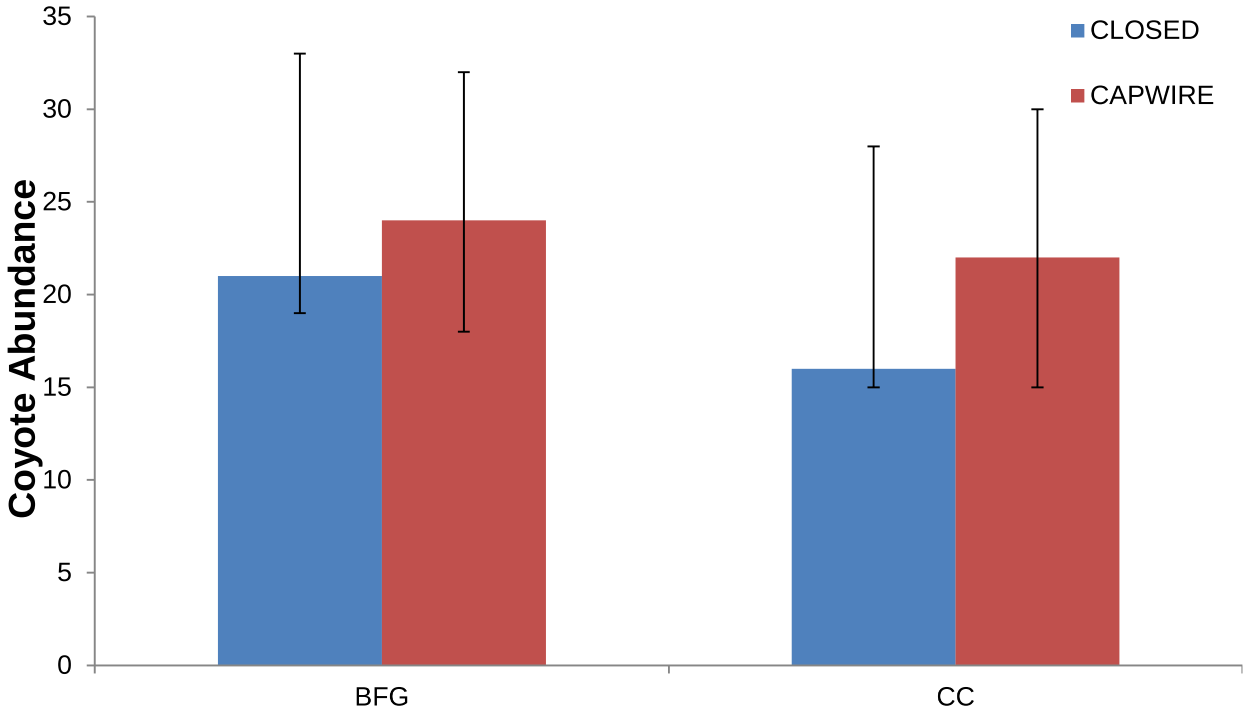


**Figure 3.6** Closed population and CAPWIRE estimates of coyote abundance on B.F. Grant and Cedar Creek Wildlife Management areas in Putnam County, Georgia during 2010. Population estimates were based on mark-recapture using fecal genotyping. Error bars represent 95% confidence intervals.

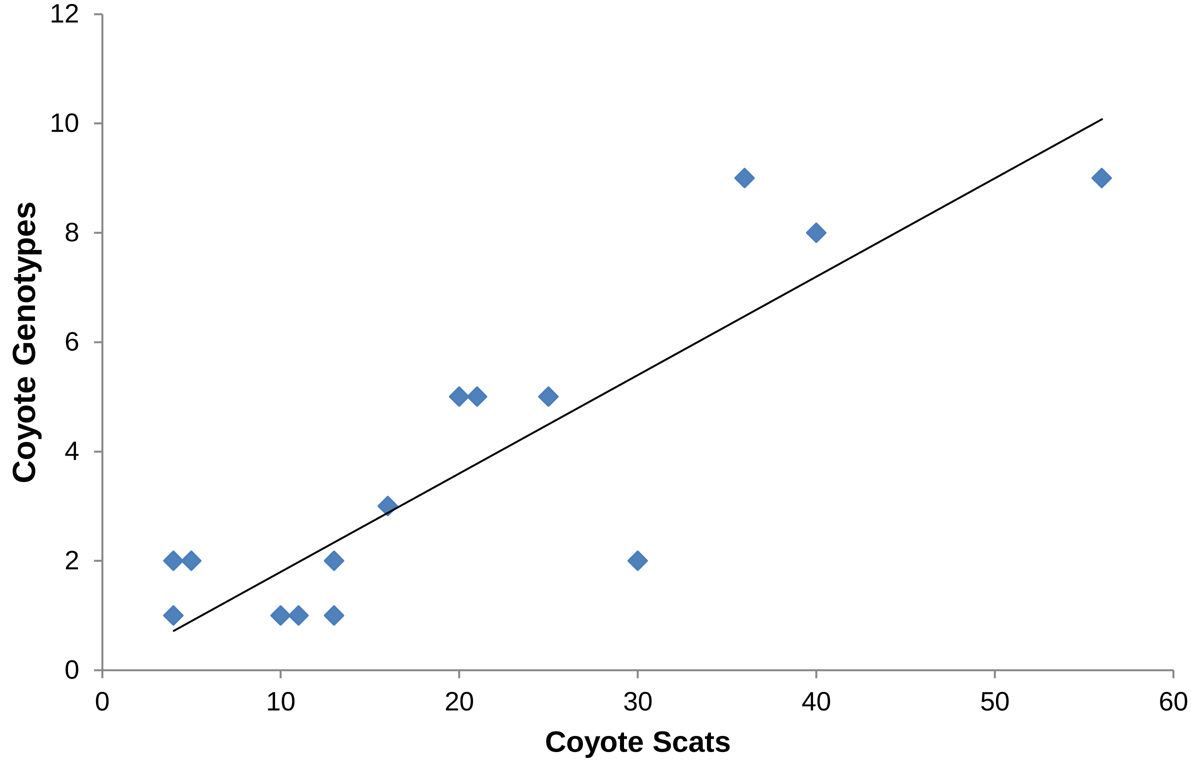


**Figure 3.7** Comparison between the total number of suspected coyote scats and coyote genotypes identified during February – December 2010 on survey routes throughout B.F. Grant and Cedar Creek Wildlife Management Areas in Putnam County, GA. The relationship was best fit by the linear function $y = 0.17994x$ ($r^2 = 0.91$, $P < 0.001$). The number of individual coyotes identified during each sampling session increased by one individual for every 5.56 additional scats detected.

**Table 3.1** Results from scent-station surveys of coyote abundance on B.F. Grant and Cedar Creek Wildlife Management Areas in Putnam County, Georgia during 2010.

| | No. Stations | Coyote Visits | Visitation Rate |
|---|---|---|---|
| **B.F. Grant** | | | |
| February | 47 | 4 | 0.09 |
| April | 46 | 0 | NA |
| July | 48 | 1 | 0.02 |
| September | 45 | 0 | NA |
| December | 48 | 2 | 0.04 |
| **Total** | **234** | **7** | |
| | | | |
| **Cedar Creek** | | | |
| February | 39 | 2 | 0.05 |
| April | 40 | 2 | 0.05 |
| July | 39 | 0 | NA |
| September | 40 | 4 | 0.10 |
| December | 38 | 3 | 0.08 |
| **Total** | **196** | **11** | |

**Table 3.2** Number of predator scats collected and submitted for genetic analysis on B.F. Grant and Cedar Creek Wildlife Management Areas in Putnam County, Georgia during February – December 2010. Only scats estimated to be ≤ 3-days-old were submitted for analysis.

| | Total | Analyzed | Species[a] | Bobcat | Grey Fox | Coyote | Genotype[b] |
|---|---|---|---|---|---|---|---|
| **B.F. Grant** | 216 | 133 | 90 | 12 | 6 | 72 | 45 |
| **Cedar Creek** | 142 | 114 | 75 | 0 | 6 | 69 | 35 |
| **Total** | **358** | **247** | **165** | **12** | **12** | **141** | **80** |

[a]Scats for which species of origin was successfully determined
[b]Coyote scats genotyped at a sufficient number of microsatellite loci to allow for individual identification

# CHAPTER 4

# EFFECTS OF SEASON AND HABITAT CHARACTERISTICS ON COYOTE SCAT DEPOSITION PATTERNS[3]

[3] Gulsby, W.D., C.H. Killmaster, J.W. Bowers, J.D. Kelly, and K.V. Miller. 2014. To be submitted to *Southeastern Association of Fish and Wildlife Agencies*.

## ABSTRACT

Scat-based surveys are commonly used to index coyote (*Canis latrans*) abundance or spatial distribution. However, seasonal changes in coyote diets can influence rates and spatial patterns of scat deposition due to unequal prey distribution among habitat types. We used compositional analysis to evaluate spatiotemporal patterns in coyote scat deposition on B.F. Grant (BFG) and Cedar Creek (CC) Wildlife Management Areas in central Georgia during January 2010-April 2012. We collected 283 coyote scats on BFG and 206 on CC. Seasons were based on seasonal prey selection and included December-May, June-August, and September-November. We identified the habitat types available within 100-m of survey routes and scat locations and observed significant habitat-specific spatial patterns in coyote scat deposition among seasons. Landscape context affected scat locations on the two areas. Scats were disproportionately located in open and/or early successional habitats on the diverse, fragmented landscape of BFG, whereas mature forest was the highest-ranking habitat on the relatively homogenous landscape of CC. Distribution of survey routes along with timing and scale of surveys are important when planning scat-based coyote surveys. However, the relative importance of each factor may vary depending on habitat composition and landscape characteristics within sites. Spatiotemporal trends in scat deposition were similar to previous telemetry-based reports of seasonal habitat selection by coyotes and may provide information on broad-scale habitat selection at a lower cost than capture and telemetry.

**INDEX WORDS:** abundance, *Canis latrans*, compositional analysis, eastern coyote, Georgia, habitat, relative abundance, noninvasive survey, predator, scat deposition

## INTRODUCTION

Coyotes (*Canis latrans*) have occupied the majority of the southeastern U.S. since the 1980s (Hill et al. 1987), but have only recently become abundant throughout the region (Kilgo et al. 2010). Although little is known about the ecology of this predator in the region, or its ecological impacts, interactions between white-tailed deer (*Odocoileus virginianus*) and coyotes have received much attention in recent literature. Declining recruitment rates in some deer populations coincide with increasing coyote abundance in the Southeast (Kilgo et al. 2010) and fawn predation rates are apparently related to relative coyote abundance (Vreeland et al. 2004, Grovenburg et al. 2011). Therefore, reliable estimates or indices of coyote abundance are necessary to understand their impacts on deer and other species, but these measures are difficult to obtain.

Researchers have frequently taken advantage of coyotes' tendency to defecate along roads and trails to develop indices of coyote abundance and/or distribution (Andelt and Andelt 1984, Fedriani et al. 2001, Gompper et al. 2006, Kays et al. 2008), either through scat-deposition or noninvasive mark-recapture surveys. During a scat-deposition survey, coyote scats are collected along a predetermined route, and a scat deposition rate index of abundance is calculated. Although published reports evaluating scat surveys are scarce, these surveys were effective for assessing relative abundance of red fox (*Vulpes vulpes*) in Italy (Cavallini 1994), and were positively correlated with swift fox (*V. velox*) density in Colorado (Schauster et al. 2002) and Utah (Dempsey 2013). Scat deposition rates were also positively related to gray wolf (*C. lupus*) density in Canada (Crete and Messier 1987, Atkinson and Janz 1994).

Scat-deposition surveys do not allow identification of individuals and therefore abundance estimates cannot be derived from their results. Thus, some have used fecal genotyping in combination with scat surveys to estimate coyote abundance (Kohn et al. 1999, Fedriani et al. 2001, Prugh et al. 2005, Kays et al. 2008). Additionally, because scat-deposition surveys can be confounded by misidentification of the species associated with each scat, genetic confirmation of species identity can be helpful when surveying coyote presence (Gompper et al. 2006).

Both scat-deposition surveys and fecal genotyping estimation of abundance can be influenced by spatiotemporal factors. For example, scat deposition rates are affected by seasonal changes in coyote diets (Andelt and Andelt 1984). Dietary preferences may influence the spatial distribution of coyotes as well. In many areas of the Southeast, coyotes primarily consume mammals (e.g., white-tailed deer and *Sylvilagus* spp.) during winter and spring, and soft mast species (e.g., *Diospyros virginiana* and *Vitis* spp.) during late summer and fall (Schrecengost 2008, Kelly 2012). While mammal species often prefer edge and early successional habitats (Atkeson and Johnson 1979), muscadine and persimmon are more prevalent in later successional areas (Andelt et al. 1987). These seasonal shifts in availability of food items among habitats affect coyote habitat selection and thus scat distribution, which must be considered in developing scat surveys.

Although scat-deposition surveys may be timed to avoid seasonal effects, they are sometimes used to monitor local trends in coyote populations across seasons. Timing fecal genotyping surveys to avoid seasonal bias is more difficult because longer surveys are often required to sufficiently sample populations. Therefore we used compositional analysis to evaluate spatiotemporal trends in coyote scat deposition among habitat types, and its implications for scat-based coyote surveys, on two study areas in central Georgia.

**STUDY AREAS**

Research was conducted on portions of B.F. Grant (BFG) and Cedar Creek (CC) wildlife management areas (WMAs) located in the Piedmont physiographic region of Georgia. Elevations ranged from approximately 120 m to 180 m, and the terrain was gently rolling. Game management on BFG, owned by the University of Georgia (UGA), and CC, part of the Oconee National Forest, was overseen by the Georgia Department of Natural Resources (GADNR) through cooperative agreements for hunting, fishing, and outdoor recreation. Although BFG and CC covered approximately 50 $km^2$ and 160 $km^2$, respectively, research activities were primarily limited to a 2,000 ha block lying in the interior of each WMA.

The majority of habitat on BFG consisted of loblolly pine (*Pinus taeda*) plantations managed on approximately 30-year rotations. As a result, approximately 14% (700 ha) of BFG's forested area was comprised of early successional forest ≤7 years of age (Figure 4.1). An additional 14% (700 ha) of the area consisted of fescue (*Schedonorus arundinaceus*) and bermuda grass (*Cynodon dactylon*) pastures and hayfields which seasonally contained a variety of forbs (Figure 4.1).

Research on CC was limited to areas located north of Georgia State Highway 212. Timber management on CC was primarily limited to salvage operations (personal communication, Elizabeth Caldwell, USFS). As a result, much of CC consisted of mature, closed canopy forest, and only approximately 7% (420 ha) of the study area consisted of early successional habitat (Figure 4.2).

## METHODS

During January 2010-April 2012, we collected putative coyote scats on survey routes along unpaved roads and trails traversing representative cover types on each study area (Figures 4.1, 4.2). We drove each route approximately weekly and collected all scats detected. We differentiated coyote scats from those deposited by other species based on published criteria of size, shape, contents, and odor (Murie 1974). For each scat we recorded the date and GPS coordinates of its location. Lengths of survey routes totaled 28 km and 20 km on BFG and CC, respectively.

We digitized habitat types within 150 m of each side of survey routes in ArcMap 10 (Environmental Systems Research Institute, Inc., Redlands, CA) by overlaying survey routes on 2010 National Agriculture Imagery Program (NAIP) data and creating polygons around each habitat type. We then transformed polygon layers into a raster image. We separated habitats into five classes: mature forest, open, early successional, pine plantations and other. Mature forest was defined as hardwood, pine, and mixed forest types >10 years old with some understory vegetation. Open habitats included pastures, hay fields, and small fallow fields consisting primarily of fescue and Bermuda grasses. Early successional habitats consisted of recently thinned pine stands, regenerating clear cuts, and pine plantations ≤7 years old. Pine plantations were densely planted pine forests of mixed ages with little to no vegetation in the understory. The 'other' habitat class primarily consisted of bodies of water and areas inaccessible to coyotes. We verified habitat classification by on-site inspection of the survey routes.

We placed a 100-m buffer along each side of survey routes and a 100-m radius buffer around each scat location. We then used the command isectpolyrst in the Geospatial Modelling

Environment (GME) version 0.7.2.0 (Beyer 2012) to obtain the proportion of each habitat type within the 100-m buffer along each survey route and around each scat location. We identified biologically meaningful seasons based on a coyote food habits study conducted on both sites during 2010 (Kelly 2012). Coyote diets were primarily composed of mammal species (e.g., *Odocoileus virginianus* and *Sylvilagus* spp.) during December-May, early-successional soft mast species (primarily *Rubus* spp.) during June-August, and later-successional soft mast species (primarily *Diospyros virginiana* and *Vitis* spp.) during September-November. We used compositional analysis (Aebisher et al. 1993) to identify spatial patterns in coyote scat deposition during these three seasons.

Because compositional analysis utilizes log-ratios, a use value of zero is problematic as it increases the risk of a type-one error. Therefore, we substituted a value of 0.7% for data points where the percentage of any habitat type contained in the buffer was <0.7%, as recommended by Bingham and Brennan (2004). We examined the data for significant evidence of habitat selection within sites and seasons using the Wilkes lambda test. If the value of $P$ was $\leq 0.05$ for the lambda score during any season, we used a ranking matrix of t-tests to assess both the order of habitat preference and statistical differences in selection between habitat types.

## RESULTS

We collected 283 coyote scats on BFG and 206 on CC during January 2010-April 2012. We identified significant habitat-specific spatial patterns in coyote scat deposition during all three seasons on both sites. On BFG, coyotes disproportionately deposited scats near open habitats during December-May (Table 4.1). Early successional areas and pine plantations were ranked second and third, respectively, during the same period, but were not statistically different based on results from the ranking matrix. Open and early successional habitat types were the first- and second-ranked habitat types, respectively, during June-August, but were not statistically different from each other. During September-November on BFG, coyotes disproportionately deposited scats in areas containing early successional habitat, while there was no evidence for selection among the remaining three habitat types (Table 4.1).

The 100-m buffer surrounding the survey route on CC was comprised of nearly 90% mature forest (Figure 4.3). The disproportionate representation of this habitat type along the CC survey route was reflected in the results as mature forest was the top-ranking habitat among all seasons. During December-May early successional areas and pine plantations were ranked second and third, respectively, but did not differ statistically. Early successional habitat was the second ranked habitat type during June-August and differed from pine plantations and open habitats. During September-November, pine plantations and early successional areas were ranked second and third, respectively, but did not differ statistically.

## DISCUSSION

Coyote scat deposition on BFG reflected obvious spatiotemporal trends. Open and early successional habitat types were disproportionately associated with scat locations, as would be expected. In the Southeast, coyote home ranges typically contain open and early successional areas disproportionate to their availability (Holzman et al. 1992, Schrecengost et al. 2009). Selection for these, and similar, habitat types is likely related to food availability (Holzman et al. 1992, Chamberlain et al. 2000, Schrecengost et al. 2009).

Spatiotemporal trends in scat deposition were not as apparent on CC. Mature forest was the top-ranking habitat type during all seasons, with early successional areas ranked second, or tied for second, during all seasons. This finding likely resulted from the very limited amount of open and early successional habitat types on CC. Combined, these two habitat types represented 33% of the area within the 100-m survey buffer on BFG and only 7% on CC. Therefore seasonal deposition patterns within sites may be less variable on sites with more homogenous landscapes.

Our results, particularly the differences between sites, highlight two important considerations for scat surveys. In areas with diverse habitats like BFG, distribution of survey routes throughout the area and timing of surveys are important considerations due to high spatiotemporal variability in coyote scat deposition. In contrast, the scale at which sampling occurs is more important on sites with homogenous landscapes like CC. Findings from a concurrent study on both sites revealed that scat deposition rates were lower on CC than BFG during December-May 2010, a period when coyotes were primarily consuming mammalian prey (unpublished data). Partially due to this potential bias, Long and Zielinski (2008) recommend sampling both within and outside of target areas when the area of interest is smaller than the average home range size of the target species.

Our results emphasize the importance of considering spatiotemporal patterns in coyote scat deposition when planning scat surveys. However, by analyzing habitat types surrounding scat locations, we were also able to infer seasonal habitat selection by coyotes. Our results were similar to those of previous studies that used telemetry to accomplish similar objectives (e.g., Holzman et al. 1992, Chamberlain et al. 2000, Schrecengost et al. 2009). Therefore researchers who desire to evaluate seasonal habitat selection by coyotes over large geographic scales may consider similar study designs to accomplish research objectives at a much lower cost than with telemetry.

## MANAGEMENT IMPLICATIONS

Coyote scat deposition patterns vary spatially and temporally as related to seasonal food availability. Therefore, scat-deposition surveys should consider timing and scale of surveys to avoid bias. In diverse habitats, timing of surveys should be confined within one- to three-month periods during which no major shifts in coyote prey selection occur, based on results from site- or region-specific reports of coyote food habits. For noninvasive mark-recapture studies sampling often must take place over longer time intervals. In these situations, the distribution of survey routes should be planned so that routes represent all habitats within the study area as evenly as possible. Conversely, scale may be a more important consideration for scat surveys on areas where habitat is more homogenous because coyotes may spend less time on areas during certain seasons when prey availability is greater in habitat types unavailable within the site.

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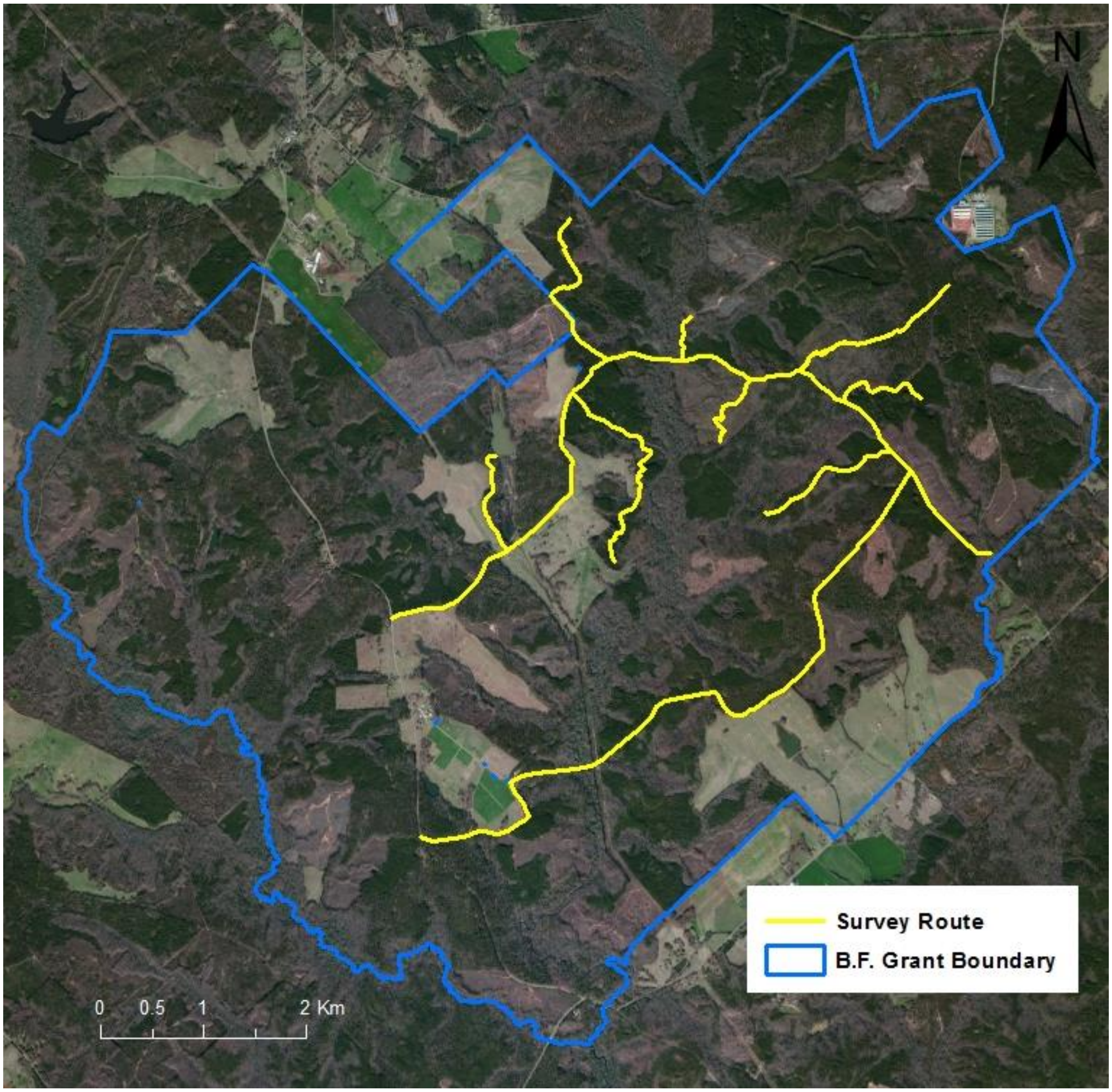

**Figure 4.1** 28-km coyote scat collection route on B.F. Grant Wildlife Management Area in Putnam County, Georgia January 2010-April 2012.

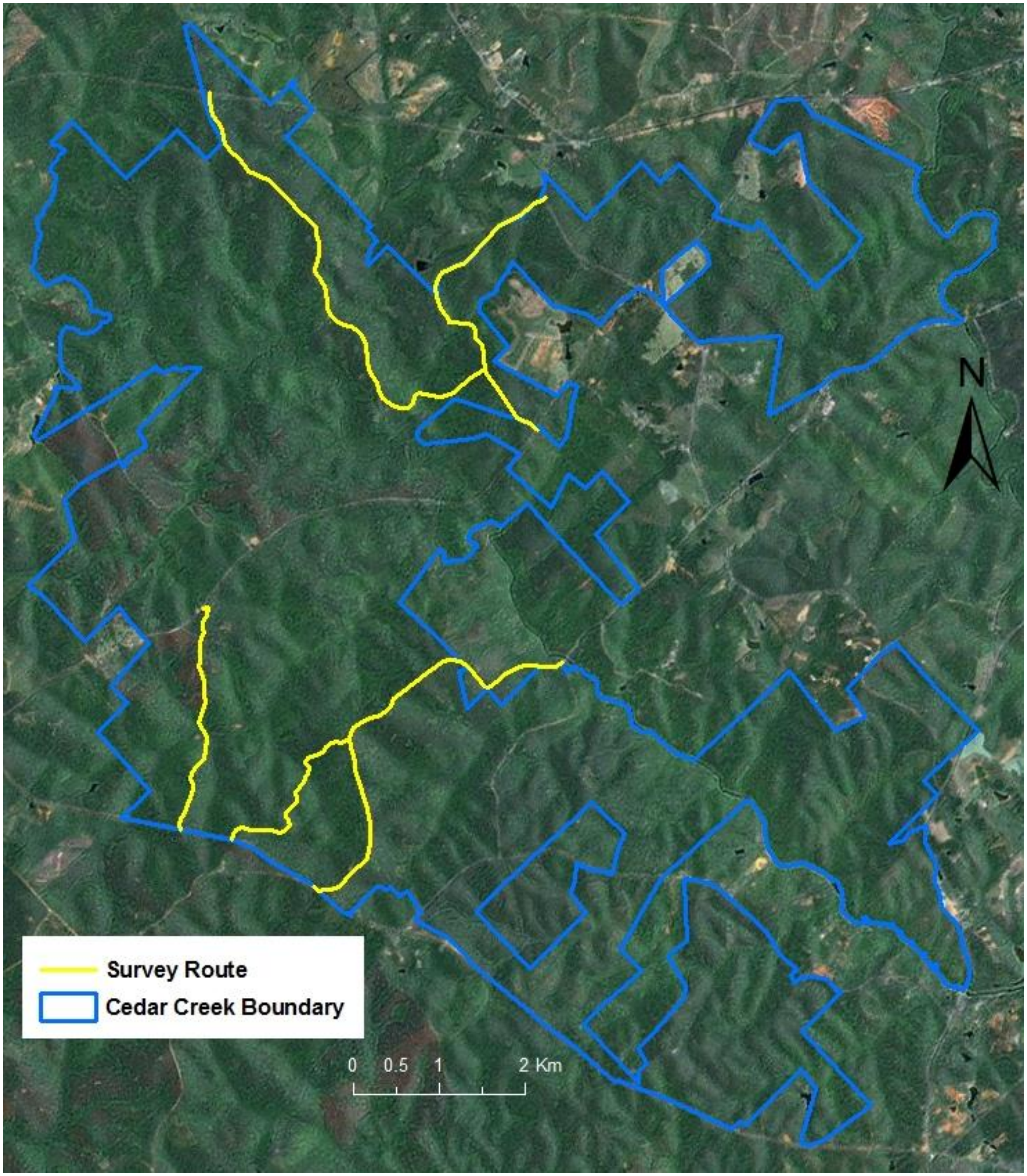


**Figure 4.2** 20-km coyote scat collection route on Cedar Creek Wildlife Management Area in Putnam County, Georgia January 2010-April 2012.

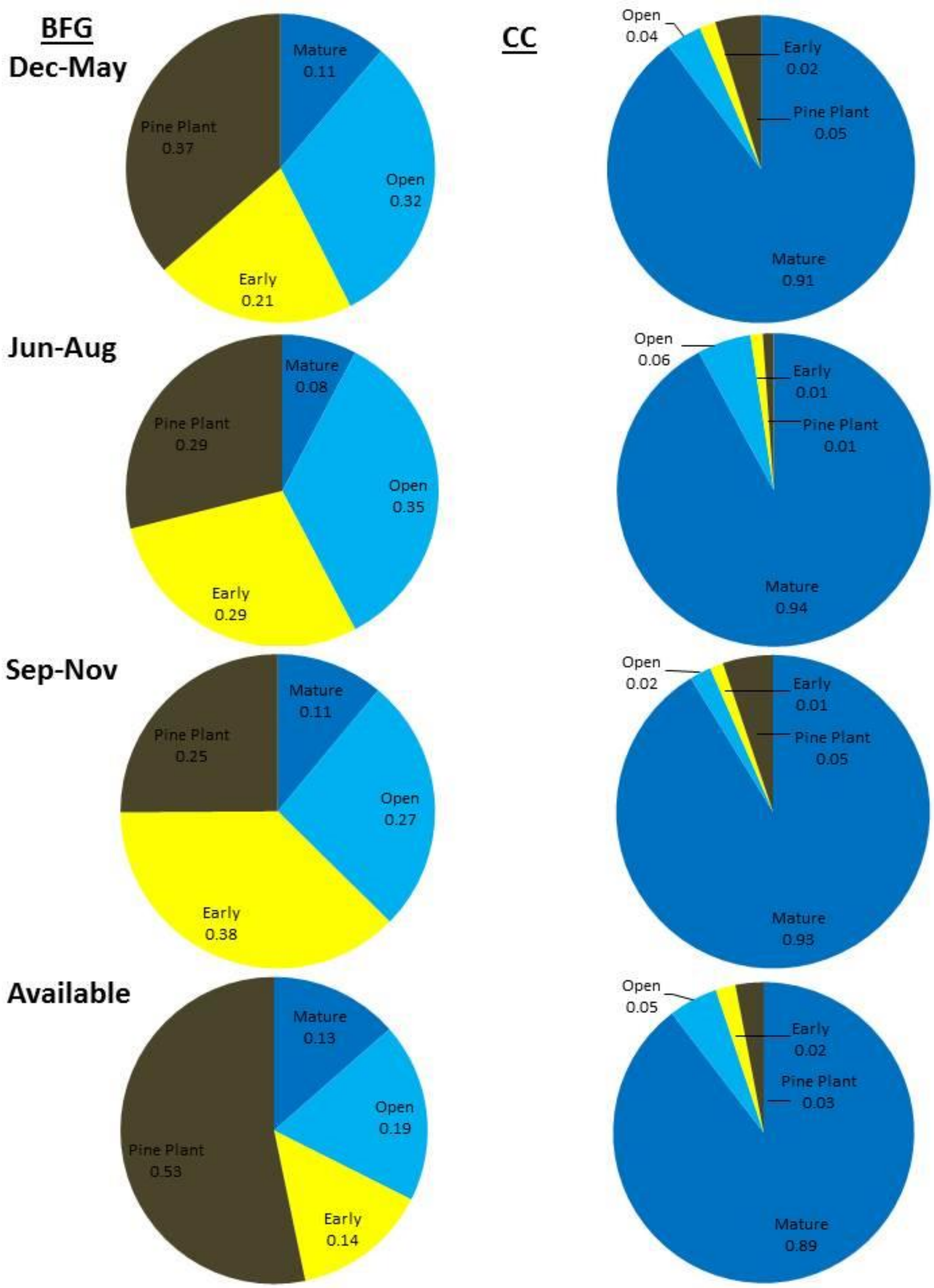


**Figure 4.3** Seasonal proportion of mature forest, open, early successional, and pine plantation habitat types within 100 m of coyote scat locations versus their availability along survey routes on B.F. Grant (BFG) and Cedar Creek (CC) Wildlife Management Areas, Putnam County, Georgia January 2010-April 2012.

**Table 4.1** Ranking matrix of habitat types surrounding coyote scats on B.F. Grant (BFG) and Cedar Creek (CC) Wildlife Management Areas in Putnam County, Georgia, January 2010-April 2012. The ranking matrix for each site and season was constructed following compositional analysis comparing the proportion of habitat within 100 m of scat locations to habitat availability within 100 m of survey routes. *P* values represent the value for the Wilkes lambda test.

| | December-May | June-August | September-November |
|---|---|---|---|
| **BFG** | $n = 114$, $P < 0.001$ | $n = 89$, $P < 0.001$ | $n = 80$, $P < 0.001$ |
| Mature | $4^{c}$ | $4^{c}$ | $3^{b}$ |
| Open | $1^{a}$ | $1^{a}$ | $2^{b}$ |
| Early Successional | $3^{b,c}$ | $2^{a}$ | $1^{a}$ |
| Young Pine | $2^{b}$ | $3^{b}$ | $4^{b}$ |
| **CC** | $n = 73$, $P < 0.001$ | $n = 51$, $P < 0.001$ | $n = 82$, $P < 0.001$ |
| Mature | $1^{a}$ | $1^{a}$ | $1^{a}$ |
| Open | $4^{c}$ | $4^{c}$ | $4^{c}$ |
| Early Successional | $2^{b}$ | $2^{b}$ | $3^{b}$ |
| Young Pine | $3^{b}$ | $3^{c}$ | $2^{b}$ |

Rankings with different superscript letters were statistically different

# CHAPTER 5

# CONCLUSIONS AND MANAGEMENT IMPLICATIONS

## CONCLUSIONS

**The results from this study suggest the following conclusions:**

### Fawn Recruitment Before and After Coyote Removal

1. Fawn recruitment is inversely related to coyote abundance. However, there appeared to be differential effectiveness of trapping between the two study sites and over time on B.F. Grant.
2. Suitability of areas for trapping may influence the effectiveness of coyote removal efforts.
3. Removals must be intense and conducted on an annual basis to significantly increase fawn recruitment.
4. Coyote abundance appears to be the primary factor affecting coyote predation rates on fawns. However, deer abundance may play a secondary role as pretreatment fawn recruitment was greater on Cedar Creek where deer densities were approximately 50% lower than on B.F. Grant.

### Evaluation of Methods for Estimating Coyote Abundance in the Southeast

1. Mark-recapture estimates of coyote abundance based on fecal genotyping data were precise and indicated similar coyote abundance between B.F. Grant and Cedar Creek.
2. Low scent-station visitation rates indicate that scent-station surveys are an unreliable index of coyote abundance.

3. Similar to mark-recapture estimates, scat-deposition surveys indicated similar coyote abundance between sites. However, there was an interaction between site and season. Deposition rates were similar between sites during summer, greater on B.F. Grant during winter and spring, and greater on Cedar Creek during summer and fall.
4. The number of suspected coyote scats collected during each month was positively related to the number of unique coyote genotypes, adding further evidence to support the use of scat-deposition surveys as an index of coyote relative abundance.

**Effects of Season and Habitat on Coyote Scat Deposition Patterns**

1. Landscape context affected coyote scat locations on B.F. Grant and Cedar Creek. Scats were disproportionately located in open and/or early successional habitats on the diverse, fragmented landscape of B.F. Grant, whereas mature forest was the highest-ranking habitat on Cedar Creek.
2. Distribution of survey routes along with timing and scale of surveys are important considerations when planning scat-based coyote surveys.
3. The relative importance of survey route distribution and scale of surveys may vary depending on habitat composition and landscape characteristics within sites.
4. Spatiotemporal trends in scat deposition were similar to previous telemetry-based reports of seasonal habitat selection by coyotes.

## MANAGEMENT IMPLICATIONS

1. Although coyote predation can negatively impact deer populations by lowering fawn recruitment, the expense and difficulty associated with intensive coyote removal, as well as the suitability of areas for trapping, should be considered before initiating removal.

2. If coyote trapping is implemented, trapping should be intense, focused on the removal of a significant percentage of the coyote population, and be maintained annually to maintain levels of fawn recruitment observed prior to the arrival of abundant coyote populations.
3. The variable results between the two study areas suggest that larger-scale evaluation of coyote use of landscapes in the Southeast are justified and will likely improve understanding of factors driving coyote predation rates on fawns.
4. Scent-station surveys are not a reliable index of coyote abundance.
5. Scat-deposition surveys enable rough comparisons between areas, but potential biases such as seasonal changes in diet should be considered. In diverse habitats, timing of surveys should be confined to one- to three-month periods during which no major shifts in coyote prey selection occur, based on results from site- or region-specific reports of coyote food habits.
6. Fecal genotyping provides precise coyote abundance estimates, but may be limited to estimation of abundance over longer temporal scales. Although fecal genotyping was the most expensive abundance estimator we used, costs will likely decline, especially for high-throughput applications.