

**HOME RANGE, HABITAT USE, AND MOVEMENT PATTERNS OF FEMALE  
COYOTES IN THE PIEDMONT REGION OF GEORGIA: IMPLICATIONS FOR  
FAWN PREDATION**

by

JOHN EDWARD HICKMAN

(Under the Direction of Karl V. Miller and Michael J. Chamberlain)

**ABSTRACT**

I used GPS collars to monitor movements, habitat use, and spatial distribution of 15 female coyotes (*Canis latrans*) in west-central Georgia during May-July 2012-2013, coinciding with the fawning season of white-tailed deer (*Odocoileus virginianus*). Mean home range size was 22.7 km<sup>2</sup> but ranged from 3.0-73.0 km<sup>2</sup>. I categorized coyotes into those with small home ranges (SHR) and large home ranges (LHR). Mean home range size was 7.4 km<sup>2</sup> for SHR coyotes (n=8) and 41.7 km<sup>2</sup> for LHR coyotes (n=5). Open areas were important at multiple scales of selection for SHR coyotes. Movements and space use varied among individuals. SHR individuals used relatively small areas intensively. Hence, they may have a greater impact on fawn predation, although their effect is likely patchy across the landscape. Future research should be focused on improving understanding of coyote spatial ecology and its implications for local fawn predation rates rather than coyote abundance.

**INDEX WORDS:** *Canis latrans*, compositional analysis, dynamic Brownian bridge, eastern coyote, fawn, Georgia, GPS, GSM, habitat use, home range, movements, *Odocoileus virginianus*, predation, white-tailed deer

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## DEDICATION

For my wife Whitney, you have made me into the person I am today. Without you, none of what I have achieved would be possible. Additionally, my parents, John and Patricia Hickman, who have always supported my dreams and aspirations, to them I am forever grateful.

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## CHAPTER 1

### INTRODUCTION AND LITERATURE REVIEW

#### INTRODUCTION

Native to the Great Plains and desert regions of the central and western U.S., the coyote's (*Canis latrans*) range has expanded through anthropogenic and natural means (Bekoff 1977, Hill et al. 1987). Coyote distribution expanded across the Mississippi River into the eastern United States in the early 1900s (Moore and Parker 1992, Parker 1995). By the 1980s, they occupied most of the southeastern U.S. (Hill et al. 1987). Hill et al. (1987) suggested coyote colonization of the Southeast was a direct result of humans translocating coyotes for sport hunting with hounds. However, others believe the range expansion was more natural, resulting from the extirpation of red wolves (*C. rufus*) and other top predators from the region (Thurber et al. 1992, Peterson 1995, Gompper 2002, Mech and Boitani 2003, Bozarth 2010).

The ecology of coyotes has been studied extensively throughout their native range (Bekoff 1977, Young et al. 2006). However, due to their recent arrival in the Southeast, little research has focused on the ecology of coyotes in this region. The Southeast has been without a large canid predator since the extirpation of red wolves, and many scientists are questioning the impacts of coyotes on other wildlife. For example, coyotes can impact white-tailed deer (*Odocoileus virginianus*) populations in some areas of the Southeast by lowering fawn recruitment (Saalfeld and Ditchkoff 2007, Howze et al. 2009, VanGilder et al. 2009). Further, recent evidence suggests that predation risk of fawns may be associated with habitat and coyote

distribution (i.e., residents vs. transients; Kelly et al. 2012, Kilgo et al. 2012, Gulsby 2014). Gulsby (2014) reported that fawn recruitment differed between 2 proximal, but differently managed sites in central Georgia with similar coyote abundance. He suggested that differences in habitat and prey availability between the sites likely affected how intensively coyotes used each site. Furthermore, Kilgo et al. (2014) removed coyotes during 3 successive years in western South Carolina and found little to no change in indices of coyote abundance among years, suggesting that coyote spatial distribution may also affect the efficacy of coyote removal efforts. Additionally, researchers in South Carolina found that female coyotes were responsible for most fawn deaths and suggested this may have resulted from increased nutritional needs during the gestation and pup-rearing season (Kilgo 2010).

Although significant evidence exists to infer that coyote spatial ecology affects fawn predation rates throughout the Southeast, information detailing how coyotes use space in the region is lacking. Therefore, I initiated a study to describe space use, habitat use, and movement patterns of female coyotes during the white-tailed deer fawning season to evaluate potential spatial patterns related to fawn predation risk.

## **LITERATURE REVIEW**

### *Impacts of Coyotes on White-tailed Deer Populations*

Coyotes can negatively affect ungulate populations through predation on neonates. This has been demonstrated throughout the coyote's native range for mule deer (*O. hemionus*), pronghorn (*Antilocapra americana*), elk (*Cervus elaphus Canadensis*) and white-tailed deer (Truett 1979, Barrett 1984, Gregg et al. 2001, Onorato et al. 2006, Turner et al. 2011). In the Southeastern United States, recent evidence of the impact of coyotes on white-tailed deer comes

from 3 lines of research: food habits studies based on scat analysis, coyote removal studies, and telemetry studies investigating cause-specific mortality of fawns.

Food habits studies have revealed spatio-temporal variability in diets (Bekoff 1977, Bowen 1982, Cypher et al. 1994). Soft mast species such as blackberry (*Rubus* spp.), plum (*Prunus* spp.), persimmon (*Diospyros virginiana*) and grapes (*Vitis* spp.) were commonly found in coyote diets during their respective fruiting seasons along with small mammals such as *Peromyscus* spp. (Schrecengost 2008, Howze et al. 2009, Kelly 2012), although this trend is not uniform throughout the Southeast (Hinton 2014). Most studies have documented high importance of white-tailed deer fawns in coyote diets during the fawning season (Berg and Chesness 1978, Wooding et al. 1984, Dibello et al. 1990, Wagner 1993) and, in some southeastern studies, fawns were among the most prevalent prey item (Blanton and Hill 1989, Chamberlain and Leopold 1999, Howze et al. 2009). Further, research conducted in central Georgia revealed that coyote diets may differ dramatically based on landscape-level habitat composition across relatively minor distances (Kelly 2012).

Across the U.S., variable rates of coyote-induced fawn mortality have been reported, including 28% in Oklahoma (Garner et al. 1976), 15% in Iowa (Huegel et al. 1985), 20% in southern Illinois (Nelson and Woolf 1987), 50% in south Texas (Cook et al. 1971), and 10% and 22% in Pennsylvania (Vreeland et al. 2004). However, predation rates in the Southeast are typically greater. For example, in western South Carolina 73% of fawns died prior to recruitment age (i.e. 6-8 months); coyotes were responsible for as much as 82% of this mortality (Kilgo et al. 2010). Likewise, Saalfeld et al. (2007) reported a predation rate of 28% in an exurban deer population in Alabama. It is unknown if high predation rates observed in the Southeast are a result of higher coyote densities, variations in habitats, or differences in space-

use among coyotes, making it imperative to further investigate and understand space-use and movement ecology of coyotes within the region.

Recent coyote removal studies indicate coyotes can significantly impact deer population recruitment rates. For example, recruitment rates increased 200% following an intensive coyote removal in Alabama (VanGilder et al. 2009). Similarly, recruitment increased two-fold following the removal of bobcats (*Lynx rufus*) and coyotes in southwestern Georgia (Howze et al. 2009), and 154% following removal in an Oklahoma study (Stout 1982). In a Texas study, net productivity of deer was 74% greater in predator removal (i.e. bobcats and coyotes) versus control areas (Beasom 1974). However, these results are not ubiquitous as Gulsby (2014) found variable results following coyote removal in central Georgia on 2 proximal sites with different landscape characteristics. Although fawn recruitment was inversely related to coyote abundance, pre-removal recruitment estimates differed between sites despite similar coyote abundance. This suggested that differences in habitat composition and movement ecology of coyotes likely played a significant role in mediating fawn predation rates (Gulsby 2014).

### *Spatial Ecology of Coyotes*

Understanding the spatial patterns of an animal is vital to understand its ecology and inform management decisions (Bekoff and Mech 1984). Information on home-range size, movement patterns, and habitat use aids in developing management techniques by identifying the requisite scale of management efforts. Improving knowledge of coyote space use in the Southeast may allow development of techniques to monitor localized coyote activity and inform managers about potential fawn predation risk. Reports of coyote home range sizes vary across the species' range, a fact often related to an interaction among season, sex, energy requirements, habitat composition, food distribution, physiographic characteristics, and spatial behaviors (i.e.,

resident or transient; Bekoff and Gese 2003). Although some studies have separated transient and resident animals into distinct classes, the methods of doing so are unclear, subjective, and vary among studies. Reported home range sizes of residents versus transients, respectively, were 12 km<sup>2</sup> and 57 km<sup>2</sup> in New Mexico (Howard and Delfrate 1991), 11 km<sup>2</sup> and 106 km<sup>2</sup> in southeastern Colorado (Gese et al. 1988), 16 km<sup>2</sup> and 313 km<sup>2</sup> in Vermont (Person and Hirth 1991) and 13.7 km<sup>2</sup> in Alberta (Bowen 1982).

Reports on coyote home range size in the Southeast are limited and results are variable. Average reported home range sizes varied from 10 km<sup>2</sup> in Georgia (Holzman et al. 1992), 15 km<sup>2</sup> in Mississippi (Chamberlain et al. 2000), 25 km<sup>2</sup> in Florida (Thorton et al. 2004), 27 km<sup>2</sup> in Alabama (Wooding et al. 1984) and 33 km<sup>2</sup> in Mississippi (Sumner et al. 1984). Individual variation among coyotes was also commonly observed. In western South Carolina, coyote home ranges varied from 4 km<sup>2</sup> to 148 km<sup>2</sup> (Schrecengost et al. 2009), and in south central Georgia home ranges varied from 7 km<sup>2</sup> to 28 km<sup>2</sup> (Holzman et al. 1992).

Because of the high degree of variability in home range size among individual coyotes, some researchers have suggested that 2 distinct types of coyotes maintain space on the landscape -- residents and transients. Resident coyotes exhibit high site-fidelity and maintain relatively small home ranges, whereas transients, which are typically non-breeders, exhibit low site fidelity and do not maintain consistent home ranges (Bowen 1978, Camenzind et al. 1978, Messier et al. 1982, Andelt 1985, Gese 1988). While some transient coyotes may eventually establish a permanent home range, others may temporarily confine their movements to a relatively small area and then resume transient behavior. These behaviors may be an attempt to locate new, unoccupied territories (Hinton and Chamberlain 2012). Unfortunately, studies often incorporate both classes of animals into home range analyses or do not report how classes were defined.



Understanding differences between resident and transient space use potentially has important implications for predation rates on white-tailed deer fawns. Breeding coyote pairs typically occupy mutually exclusive territories (Camenzind 1978, Bowen 1982, Andelt 1985) and transients typically avoid confrontation with residents. Thus, resident and transient food habits may differ as residents may occupy more optimal habitats. Further, residents may have a greater predation effect on a given site resulting from more intensive use of the area. In California, resident coyotes whose home ranges overlapped those of sheep were primarily responsible for lamb depredation (Sacks et al. 1999). Given these results, it is likely that resident coyotes have a disproportionate impact on white-tailed deer fawns in the Southeast, justifying further investigation of their space use.

#### *Coyote Habitat Use*

The widespread distribution of coyotes is evidence of their ability to adapt and thrive in a variety of habitats. However, coyotes likely use landscapes and habitats, even within localized regions (i.e. counties), differently. Therefore, understanding local-scale habitat selection by coyotes is imperative for understanding their space use in a given area (Kelly 2012, Gulsby 2014). Previous studies in the Southeast have used either Johnson's (1980) habitat selection orders (Holzman et al. 1992, Schrecengost et al. 2009), or orders loosely based on Johnson's levels of selection (Chamberlain et al. 2000, Thorton et al. 2004), to evaluate habitat selection by coyotes across spatial scales. The first and second scales compare (1) selection for habitat types within the home range relative to their availability within the study area and (2) selection for habitat types within the core area relative to their availability within the home range (Chamberlain et al. 2000). The third, or individual location, scale compares habitat selection at individual point locations versus their availability within the home range.

Within the Southeast, habitat selection is variable. In western South Carolina, coyotes selected home ranges with a greater proportion of early successional areas than available at the landscape level (1<sup>st</sup> order) across all 4 meteorological seasons (Schrecengost et al. 2009). However, in Mississippi and Florida coyotes exhibited no patterns of selection seasonally (Chamberlain et al. 2000, Thornton et al. 2004). Coyotes in south-central Georgia selected home ranges containing a greater proportion of open areas than available at the landscape level during winter (Holzman et al 1992), whereas coyotes in Mississippi selected home ranges containing a greater proportion of mature pine stands than available during the same season (Chamberlain et al. 2000).

Selection of habitats within core areas versus their availability within the home range (2<sup>nd</sup> order) also varies across reported studies in the Southeast. For example, coyotes selected early successional habitats over young pines in western South Carolina (Schrecengost et al. 2009), whereas coyotes in Mississippi selected all delineated habitats to establish core areas in proportion to their availability within the home range (Chamberlain et al. 2000). However, coyotes in Florida selected for coastal scrub habitat to establish core areas at a greater proportion than available within the home range (Thornton et al. 2004).

#### *GPS-based Movement Studies*

Few studies in the Southeast have examined the spatial ecology of coyotes (Sumner 1984, Holzman et al. 1992, Chamberlain et al. 2000, Thornton et al 2004, Schrecengost et al. 2009), and of these only 2, to our knowledge, have used GPS technology (Hinton and Chamberlain 2012, Hinton 2014). GPS technology allows for increased sampling frequencies (e.g., every 30 min), offering fine-scale data previously unattainable using radio telemetry. Global Systems of Communication (GSM) technology further improves the efficiency of data collection by offering

remote data retrieval. Using GSM, researchers can collect data from a computer anywhere, anytime, eliminating hours of field work as well as fuel and other costs typically associated with telemetry. GSM also reduces the loss of data associated with long-distance movements or transient behavior, which has been significant in previous research (e.g., Holzman et al. 1992, Chamberlain et al. 2000, Schrecengost et al. 2009). Finally, GSM allows researchers to monitor animals in nearly real-time which can be useful in identifying the onset of specific behaviors.

Although GSM offers advantages over traditional GPS telemetry, there are some disadvantages. For example, GSM can significantly reduce the battery life of collars. It also relies on a cellular signal; therefore cellular service, frequently unavailable in rural areas, must be available in the study area. However, GPS/GSM collars do incorporate VHF and non-volatile memory so if cellular service is unavailable, data are stored on the collar and can be tracked and/or retrieved via VHF.

## **OBJECTIVES AND HYPOTHESES**

Coyote predation on white-tailed deer fawns can significantly impact fawn recruitment in some areas of the Southeast, but predation rates apparently vary over relatively small spatial scales. Space use of coyotes, including habitat selection, intensity of use of areas, and resident versus transient behavior, likely influences this predator/prey dynamic. However, knowledge of coyote space use within the region is limited, and most previous reports are confounded by equivocal definitions of spatial classes of coyotes or technological limitations. Therefore, the primary objective of this research was to describe coyote space and habitat use in Georgia during the fawning season as a determinant to evaluate fawn predation risk. In addition, I used quantitative methods to clearly define coyotes as resident or transient animals. I hypothesized

that resident female coyotes would use their home ranges more intensively than transient coyotes, thus potentially increasing predation risk of white-tailed deer fawns.

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## CHAPTER 2

### HOME RANGE, HABITAT USE, AND MOVEMENT PATTERNS OF FEMALE COYOTES IN THE PIEDMONT REGION OF GEORGIA: IMPLICATIONS FOR FAWN PREDATION.<sup>1</sup>

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<sup>1</sup> Hickman J.H., W.D. Gulsby, K.V. Miller, M.J. Chamberlain. 2014. To be submitted to *Southeastern Association of Fish and Wildlife Agencies Proceeding, 2014.*

## ABSTRACT

Coyote (*Canis latrans*) depredation rates on white-tailed deer (*Odocoileus virginianus*) fawns are variable across the southeastern United States, perhaps due to varying dispersion of coyotes as related to social behavior and habitat preferences. As a means to evaluate fawn predation risk related to coyote distribution, we studied home range patterns and habitat use of 15 female coyotes during the 2012 and 2013 fawning periods. Seasonal home range sizes were highly variable but generally followed 2 patterns. Small home range coyotes (SHR; likely breeding females) had a mean home range size of 7.4 km<sup>2</sup> (range = 3.0-11.8 km<sup>2</sup>), whereas large home range coyotes (LHR; transients) had a mean home range size of 47.1 km<sup>2</sup> (range = 22.8-73.1 km<sup>2</sup>). We measured consistency of space use as a gauge for predation risk by examining revisitation rates of core areas. SHR coyotes used their home ranges more consistently and intensively than LHR coyotes. Additionally, compositional analysis for 8 SHR coyotes was conducted at the home range, core area, and individual location levels, which were separated into diurnal and nocturnal periods. No selection occurred at the home range level and pines were avoided at the core area level, with equal selection among other habitats. Coyotes avoided developed areas during the day and preferred open areas at night. I also assessed diel movements and found no significant differences between SHR and LHR coyotes. SHR females, particularly during gestation and provisioning, likely preyed disproportionately on fawns within their home ranges due to heightened energy requirements and area-use intensity. Therefore, it is important that future research concerning coyote fawn interactions focuses on indices of use rather than coyote abundance in an area.

INDEX WORDS: *Canis latrans*, compositional analysis, dynamic Brownian bridge, eastern coyote, fawn, Georgia, GPS, GSM, habitat use, home range, movements, *Odocoileus virginianus*, predation, white-tailed deer

## INTRODUCTION

Native to the Great Plains and desert regions of the central and western U.S., coyote (*Canis latrans*) range has expanded through both anthropogenic and natural means (Bekoff 1977, Hill et al. 1987). Coyote distribution expanded across the Mississippi River into the eastern United States in the early 1900s (Moore and Parker 1992, Parker 1995). By the 1980s, they occupied most of the southeastern U.S. (Hill et al. 1987). Hill et al. (1987) suggested coyote colonization of the Southeast was a direct result of humans translocating coyotes for sport hunting with hounds. However, others believe the range expansion was more natural, resulting from the extirpation of red wolves (*C. rufus*) and other top predators from the region (Thurber et al. 1992, Peterson 1995, Gompper 2002, Mech and Boitani 2003, Bozarth 2010).

Increasing concern surrounding the impacts of coyotes on white-tailed deer (*Odocoileus virginianus*) recruitment in the Southeast has prompted a series of studies of varying designs. Results from coyote food habits studies (Schrecengost et al. 2008, Kelly 2012), cause-specific fawn mortality studies (Saalfeld and Ditchkoff 2007, Kilgo et al. 2012, McCoy et al. 2013), and coyote removal studies (Howze et al. 2009, VanGilder et al. 2009, Gulsby et al. 2014) have all indicated coyotes consume significant numbers of fawns. However, the level of predation or impact on fawn recruitment varies significantly among studies. For example, coyotes were responsible for depredating 7% of radiocollared fawns on one South Carolina site (McCoy et al. 2013), and 62% on another (Kilgo et al. 2012). In addition, fawn-to-doe ratios increased 200% following predator removal on an Alabama site (VanGilder et al. 2009), whereas the fawn-to-doe ratio was 100% greater in a predator-removal zone versus an untreated area in South Georgia (Howze et al. 2009). Finally, pre-treatment recruitment rates on 2 Georgia sites separated by only 8 km differed by almost 0.3 fawns/doe (Gulsby 2014).

Although many hypotheses have been offered to explain differences in fawn predation among studies, recent evidence suggests that fawn predation risk may be associated with habitat characteristics and coyote distribution across the landscape (Kelly et al. 2012, Kilgo et al. 2012, Gulsby 2014). Coyotes prefer edges, early successional habitats, and agricultural/open areas (Holzman et al. 1992, Chamberlain et al. 2000, Kays et al. 2008, Schrecengost et al. 2009), which are often associated with increased prey abundance (Atkeson and Johnson 1979). Therefore, areas containing greater amounts of preferred habitats may support greater coyote abundance or concentrate coyote movements, leading to increased fawn predation (Gulsby 2014). However, information regarding coyote space use and distribution in southeastern U.S. ecosystems is significantly lacking. Average reported home range sizes of coyotes in the Southeast vary from 10 km<sup>2</sup> in Georgia (Holzman et al. 1992), 15 km<sup>2</sup> in Mississippi (Chamberlain et al. 2000), 25 km<sup>2</sup> in Florida (Thorton et al. 2004), and in Alabama and Mississippi, 27 km<sup>2</sup> (Wooding et al. 1984) and 33 km<sup>2</sup> (Sumner et al. 1984), respectively. Significant individual variation has also been reported with home range size varying from 4 km<sup>2</sup> to 14 km<sup>2</sup> in South Carolina (Schrecengost et al. 2009) and from 7 km<sup>2</sup> to 28 km<sup>2</sup> in Georgia (Holzman et al. 1992).

Coyote home range sizes may be related to an interaction among several factors including season, sex, seasonal energy requirements, habitat composition, food distribution, and physiographic characteristics (Bekoff and Gese 2003). Furthermore, some have separated individuals into 2 classes based on spatial behavior. Resident coyotes exhibit high site fidelity and maintain relatively small home ranges. In contrast, transients, which are typically non-breeders, exhibit low site fidelity and do not maintain consistent home ranges (Bowen 1978, Camenzind et al. 1978, Messier et al. 1982, Andelt 1985, Gese 1988).



Because residents intensively use smaller areas, sites with specific habitat or landscape characteristics attractive to these animals may experience disproportionate coyote predation on fawns. Conversely, the effects of transient coyotes on prey populations are likely more evenly distributed across the landscape. Although researchers have previously reported on the existence of 2 spatially distinct classes of coyotes in the Southeast, methods of quantitatively defining these 2 behaviors are scarce or ambiguous. Therefore, we investigated the spatial ecology of female coyotes during the fawning season with the objective of characterizing the spatial distribution and habitat selection of these animals during the season when fawns are most vulnerable to coyote predation. Our primary objective was to document the possibility of differential coyote predation risk for fawns across the landscape and characterize habitat selection of resident animals.

## STUDY AREA

The coyote capture area was 7,200 ha located in Harris County, Georgia within the Piedmont physiographic region (Figure 2.1). The entire study area was defined by combining the 95% minimum convex polygon (MCP) home ranges of 8 coyotes with well-defined home ranges and placing a 500-m buffer around the boundary of the resulting polygon. Topography was typical for the area, consisting primarily of gently rolling hills approximately 200 m above sea level. However, a prominent ridge with a maximum elevation of 323 m transected a portion of the study area. The area was mostly forested and contained both natural and planted pine (*Pinus taeda* and *P. palustris*) stands in upland areas. Remaining forest types included oak-hickory ridges and mixed hardwoods in bottomlands. Oak-hickory ridges primarily included white oak (*Quercus alba*), northern red oak (*Q. rubra*), southern red oak (*Q. falcata*), chestnut

oak (*Q. prinus*), pignut hickory (*Carya glabra*), and mockernut hickory (*Carya tomentosa*). Bottomland forests were mainly comprised of water oak (*Q. nigra*). Many wildlife openings of various sizes were interspersed throughout the area and were planted in agronomic crops including alfalfa (*Medicago sativa*), corn (*Zea mays*), soybeans (*Glycine max*), and various clover (*Trifolium* spp.) species.

Approximately 15% of the study area was intensively managed for white-tailed deer hunting and included low basal area loblolly pine stands burned on 3-year rotations. A recreational resort was also located within the area and included ornamental gardens, outdoor recreation areas (e.g., golf courses, fishing ponds, etc.), several homes, and a wildlife preserve. Most of the area surrounding the study site was rural except for a 526-ha subdivision located adjacent to the northern end.

## METHODS

### *Capture and Telemetry*

We captured female coyotes during January – April 2012 and 2013 using #1.75 and #2 offset-modified coil-spring traps (Minnesota Trapline Products, Pennock, MN) equipped with modifications to prevent injury to animals (i.e. padded jaws, swivels, springs, etc.). Coyotes were restrained using a 1.5-m catch pole, removed from the trap, and electrical tape was used to secure their hind legs and muzzle. We equipped female coyotes with Tellus Light global system of mobile communications (GSM; Followit AB, Lindesberg, Sweden) GPS collars. Animal handling procedures were approved by the University of Georgia Institutional Animal Care and Use Committee (#A2012 01-016-Y3-AO).

Collars were programmed to collect and store GPS locations (in the form of X, Y coordinates) on their nonvolatile memory. During 2012, collars collected 12 locations/day at equal intervals from deployment until April 30 and 36 locations/day from May 1 until collar failure. During 2013, collars were programmed to collect 6 locations/day from deployment until April 30 and 24 locations/day from May 1 until collar failure.

Data were downloaded using Followit's secure server. To decrease the probability of erroneous points in the datasets, we censored points representing non-fixes or impossible locations. After data censoring, we uploaded GPS fixes for each coyote into ArcMap 10 (Environmental Systems Research Institute, Inc., Redlands, CA) and projected data in Universal Transverse Mercator (UTM) North American Datum (NAD) 1983 Zone 16 North (meters).

#### *Home Range Estimation*

We estimated 95% home ranges and 50% core areas for 13 coyotes during May 1-July 4, 2012 and 2013 using a dynamic Brownian Bridge Movement Model (dBBMM) as described by Kranstauber et al. (2012) and implemented in Program R 3.01 (R Development Core Team 2013), using the statistical package "move" (Kranstauber and Smolla 2013). We used a margin size of 9 and window size of 31 as recommended by Kranstauber et al. (2012). We calculated location error by deploying 3 collars programmed to collect hourly positions for 24 hrs at georeferenced points within University of Georgia's Whitehall forest, which was comparable in habitat composition to the study area. Because most prior studies of coyote home range size used the MCP method to construct home ranges (Holzman 1992), we also calculated the 95% MCP home range of each individual using the Geospatial Modelling Environment (GME) version 0.7.2.0 (Beyer 2012).

### *Characterizing Spatial Distributions and Assessing Home Range Use Intensity*

To characterize resident and transient behaviors, we examined consistency of space-use for each coyote by calculating revisitation rates of core areas (50% UDs) produced by the dBBMM. We considered >1 48hr visit to a core area as a revisitation, suggesting coyotes were intensively and consistently using these areas.

We examined step lengths within coyote movement paths and created density maps of point locations to further evaluate how intensively coyotes used certain areas within their home range. We used the tool `movementpathmetrics` in the GME software to calculate step lengths for each coyote. To address issues with non-subsequent locations in the step length analysis, datasets were filtered to include only step lengths associated with time intervals of 1 and 2 hours. To create density maps of point locations, we overlaid a grid consisting of 1-ha cells on the study area using the `fishnet` tool in ArcMap 10.1 (Environmental Systems Research Institute, Inc., Redlands, CA). We then used the tool `countpntsinpolys` in GME to count the number of coyote point locations occurring within each 1-ha cell. We depicted results both as a temperature gradient map in ArcMap 10.1 and as a 3-dimensional figure in ArcScene 10.1 (Environmental Systems Research Institute, Inc., Redlands, CA).

### *Multi-scale Habitat Selection*

We developed a map of habitat types for our study area using the National Land Cover Database (NLCD) 2006 map. We reclassified the data into 5 habitat classes using ArcMap 10.1. We classified habitat types as developed, open, early successional, pine, and hardwood. Developed areas included constructed materials, unpaved roads, and impervious surfaces such as home sites and paved roads. Open habitats primarily consisted of maintained pastures, wildlife food plots, and agricultural fields. Early successional habitats consisted of scrub/shrub, < 5 year

old clear cuts, and overgrown pastures or old fields. Pine habitats consisted of upland pine stands >5-years old. Hardwoods consisted of mostly bottomland hardwoods with occasional upland hardwood ridges.

We used the command `isectpolyrst` in the GME to obtain the percentage of each habitat type within each home range and core area as well as throughout the study area. We then used compositional analysis (Aebischer et al. 1993) to identify habitat selection at 3 spatial scales as described by Chamberlain et al. (2003). The first order compared habitat composition within the home range versus the study area, the second order compared habitat composition within core (core) areas versus the home range, and the third order compared habitat composition at individual locations versus within the home range. We evaluated habitat selection at the third order during diurnal (07:00-19:00) and nocturnal (20:00-06:00) periods.

Because compositional analysis uses log-ratios, a use value of zero can be problematic as it increases the risk of a Type I error. Therefore, we substituted a value of 0.7% for areas with zero use as recommended by Bingham and Brennan (2004). We examined differences in habitat selection using the Wilkes lambda test. When significant differences between habitat use and availability existed, we used a ranking matrix of *t*-tests to assess the order of preference.

#### *Identifying Diel Movement Activity*

We used variance values produced by the dBBMM and step-lengths to quantify movement activity during 4 diel periods. We separated each 24-hr day into 4 periods: night, dawn, day, and dusk. Dawn and dusk (crepuscular periods) were 1 hour prior to sunrise and 1 hour after sunset, respectively. Night was the period between dusk and dawn, and day was the period between dawn and dusk. We compared variance values and step lengths during each period to examine differences in movement activity.

## RESULTS

We collared 20 female coyotes during January-April 2012 and 2013. However, one coyote was killed by a vehicle, another by a hunter, and collar malfunctions resulted in partial or no datasets for 5 additional coyotes. Therefore, we quantified habitat selection and constructed dBBMM home ranges and core areas for 13 female coyotes. We used partial datasets from 2 additional coyotes for the step length and MCP home range analyses, resulting in a sample size of 15 coyotes for these analyses.

### *Characterizing Spatial Behaviors and Movement Patterns*

We observed distinct differences in spatial behaviors among coyotes. Eight females (62%) revisited 100% of their core areas, whereas 5 (38%) revisited  $\leq 50\%$  of core areas over a 48-hour period (Figure 2.2). Interestingly, females with 100% revisitation rates of their core areas had smaller home ranges than those with lower core area revisitation rates (data presented below). As a result, we defined coyotes with 100% revisitation rates as small home range coyotes (SHR, likely residents;  $< 20\text{km}^2$ ) and coyotes with  $\leq 50\%$  revisitation rates as large home range (LHR, likely transients;  $>20\text{km}^2$ ). On average, SHR coyotes had fewer core areas ( $\bar{x} = 2$ ) than LHR coyotes ( $\bar{x} = 6$ ; Figure 2.3).

We found a high degree of individual variability in movement patterns among coyotes. The dBBMM variance and step length values were not related to diel period (Figure 2.4) or whether the coyote was a resident or transient (Figure 2.5). Further, mean daily step lengths did not differ between SHR and LHR coyotes (Figures 2.6, 2.7). Graphical representations of high-use areas within SHRs demonstrated variability even within this spatial class. Whereas some coyotes ( $n = 5$ ) almost exclusively used restricted areas within their home ranges, movements of others were more evenly distributed throughout their home range ( $n = 3$ ; Figure 2.2.8, 2.9).

### *Home Range Analysis*

Mean 95% dBBMM home range size was 22.7 km<sup>2</sup>, but varied widely among individuals (range = 3.0-73.0 km<sup>2</sup>). Overall mean 95% MCP home range was 103.1 km<sup>2</sup> and was similarly variable among individuals (range = 10.0-255.0 km<sup>2</sup>). Mean dBBMM home range size for SHR and LHR coyotes was 7.4 km<sup>2</sup> (range = 3.0-11.8 km<sup>2</sup>) and 47.1 km<sup>2</sup> (range = 22.8-73.0 km<sup>2</sup>), respectively. In contrast, mean MCP home range size for SHR and LHR coyotes was 15.8 km<sup>2</sup> (range = 10.01- 29.33) and 203.1 km<sup>2</sup> (range = 55.50-390), respectively (Table 1).

### *Multi-Scale Habitat Selection*

The composition of habitats within home ranges was similar to the availability of habitats across the study area (1<sup>st</sup> order of selection). However, the composition of habitats within core areas differed relative to the availability of habitats within the home range (2<sup>nd</sup> order of selection), with coyote selecting core areas with more open areas (Table 2.2). Coyotes used (3<sup>rd</sup> order of selection) all habitats within home ranges similarly during the day, except that they avoided developed areas. In contrast, coyotes disproportionately used open habitats at night.

## **DISCUSSION**

Although natural variation in coyote space use across their range is expected (Bekoff and Gese 2003), the lack of standardization among studies contributes to this reported variation. Small sample sizes, variable sampling methods (Laundre and Keller 1984), use of different home range estimators (Woodruff and Keller 1992), and perhaps more importantly inclusion of transient coyotes with large home ranges in calculations all contributed to the high degree of variability observed among studies. Classification of a resident coyote is intuitive, but classifying a transient is more ambiguous. As a result, we described a discrete, quantitative method that classified coyotes based on consistency of space use, rather than overall space use

(i.e. home range size). Five of 13 (38%) female coyotes in our study were classified as LHR coyotes, similar to a previous report in southern Texas (Windberg and Knowlton 1988). Although incomplete datasets for 2 additional females precluded our ability to estimate space use using the dBBMM, their 95% MCP home ranges were comparable to those of other LHR individuals. Therefore, nearly 50% of our coyotes were potentially transient individuals which is slightly higher than what has been reported elsewhere (Gese et al. 1988, Chamberlain et al. 2000, Hinton 2014). To understand differences in spatial distribution among coyotes, we urge standardization of methods for classifying spatially distinct behaviors in future research.

Comparison of the number of core areas, core area revisitation rates, and step lengths indicated that SHR coyotes used significantly smaller areas more intensively than LHR coyotes. Although intensive use of small areas likely increases coyote encounter rates with fawns, and thus predation risk, these intensively used areas were not evenly distributed across the landscape. Therefore, patchy distribution of high use areas likely results in a similar, patchy pattern with regards to predation risk of fawns across the landscape. In our study, SHR coyotes selected open habitats at the second and third order of selection, which is not surprising given that other studies have reported general preferences for open, treeless environments by coyotes across their range (Gosselink et al. 2003, Van Deelen and Gosselink 2006). Additionally, open habitats are preferred by a variety of coyote prey and therefore are highly attractive (Holzman et al. 1992, Chamberlain et al. 2000, Kays et al. 2008, Schrecengost et al. 2009).

Although coyotes exhibit similar habitat preferences within regions (Gese et al 1988), residents often occupy more productive habitats (Kamler 2000, Hinton 2014), and transients avoid encounters with residents by restricting their movements to areas between or on the margins of resident home ranges (Witham 1977, Hinton 2014). Because productive habitat types



are generally associated with greater deer densities, resident coyotes likely have a disproportionate effect on fawn recruitment in these areas. For example, on 2 sites in central Georgia, fawns occurred in a greater percentage of coyote scats on the site with a greater proportion of habitat preferred by both coyotes and deer (Kelly 2012). Despite greater deer abundance on the site and similar coyote abundance between sites, recruitment was lower on the site with more deer and preferred habitat, suggesting that coyotes may have used the site more intensively during the fawning season (Gulsby 2014).

Our results regarding coyote space use may also hold important implications for predation management through coyote removal. Because transients cover large areas over relatively short time intervals, these animals may serve as population founders in areas vacated by coyotes following removal efforts. Thus, in areas where transient coyotes are abundant removal efforts may yield marginal or temporary results. For example, in South Carolina annual coyote removal rates remained constant among 3 sites for 3 years (Kilgo et al. 2014) and in central Georgia coyote abundance decreased following the first year of removal, but increased to nearly pretreatment levels after year 2 (Gulsby 2014). These results demonstrate how quickly coyotes, perhaps transients, can occupy vacant areas.

The scattered distribution of transient coyotes is likely an adaptation for coyote populations to persist where they are heavily exploited. In other words, transient behaviors increase the probability of quickly locating and occupying areas containing preferred habitat where resident animals are removed. Transient home range patterns in our study were similar to those reported in North Carolina where coyotes established biding areas which are temporary localized movements analogous to home ranges (Hinton et al. 2012). A 3-year study in North Carolina revealed 88% of transient coyotes eventually established permanent home ranges in or

near their biding areas, suggesting this was a strategy used to familiarize themselves of areas they roam. Further, these biding areas may also be a result of extended foraging needs for traversing long distances (Hinton 2014).

Our results indicate that wildlife managers should consider coyote spatial ecology as an important indicator of local fawn predation risk, rather than coyote abundance. Resident animals used smaller areas more intensively, but the distribution of intensively used areas was patchy, even within home ranges, and likely resulted in variable predation risk of fawns across the landscape. Additionally, because transient coyotes serve as a source population, removal efforts in areas of highly productive habitats may yield marginal, temporary results. Although we acknowledge that our study was limited in sample size and duration, the variability in intensity of use patterns, even among resident animals, offers a strong hypothesis to explain differences in fawn predation across small spatial scales.

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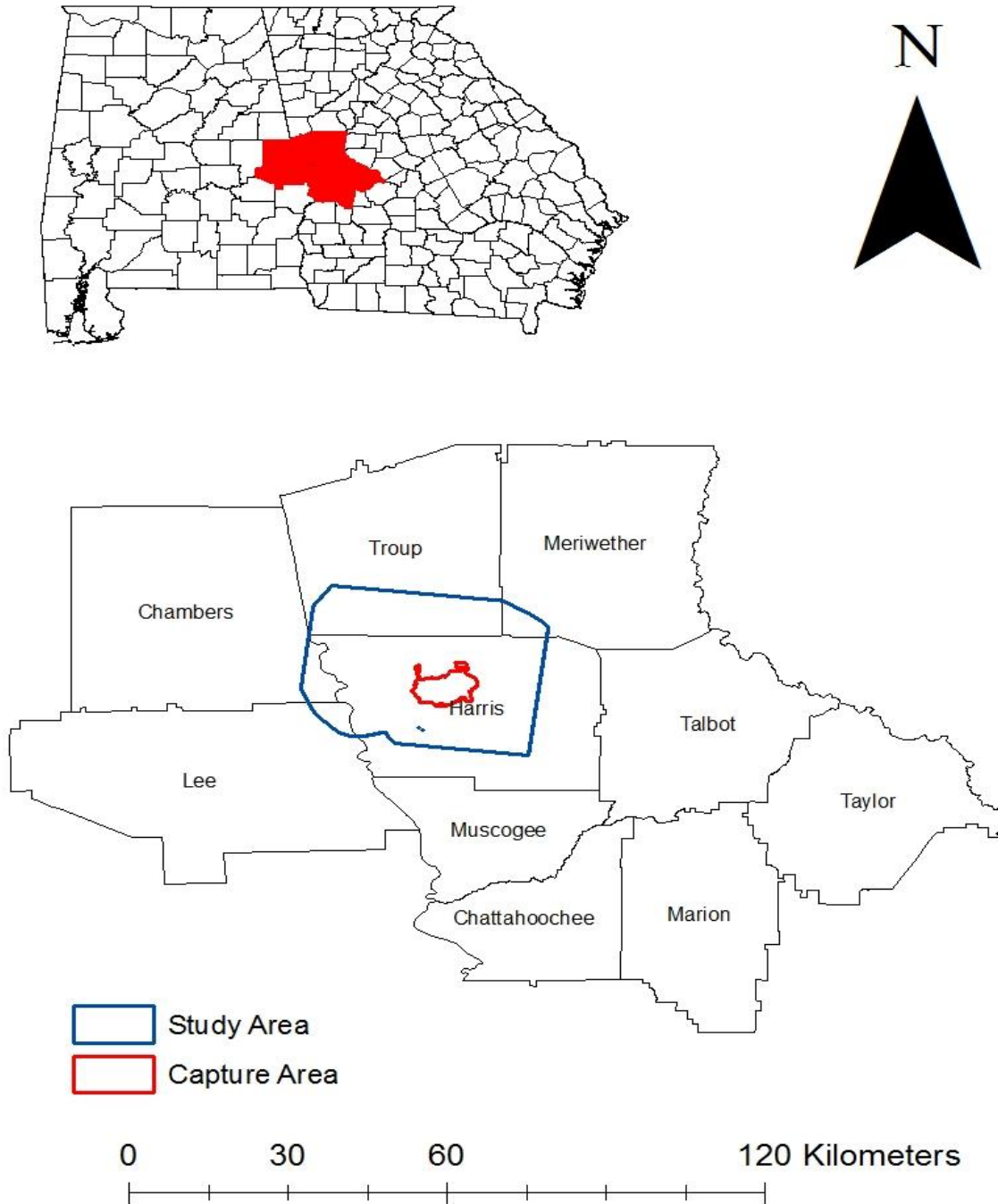
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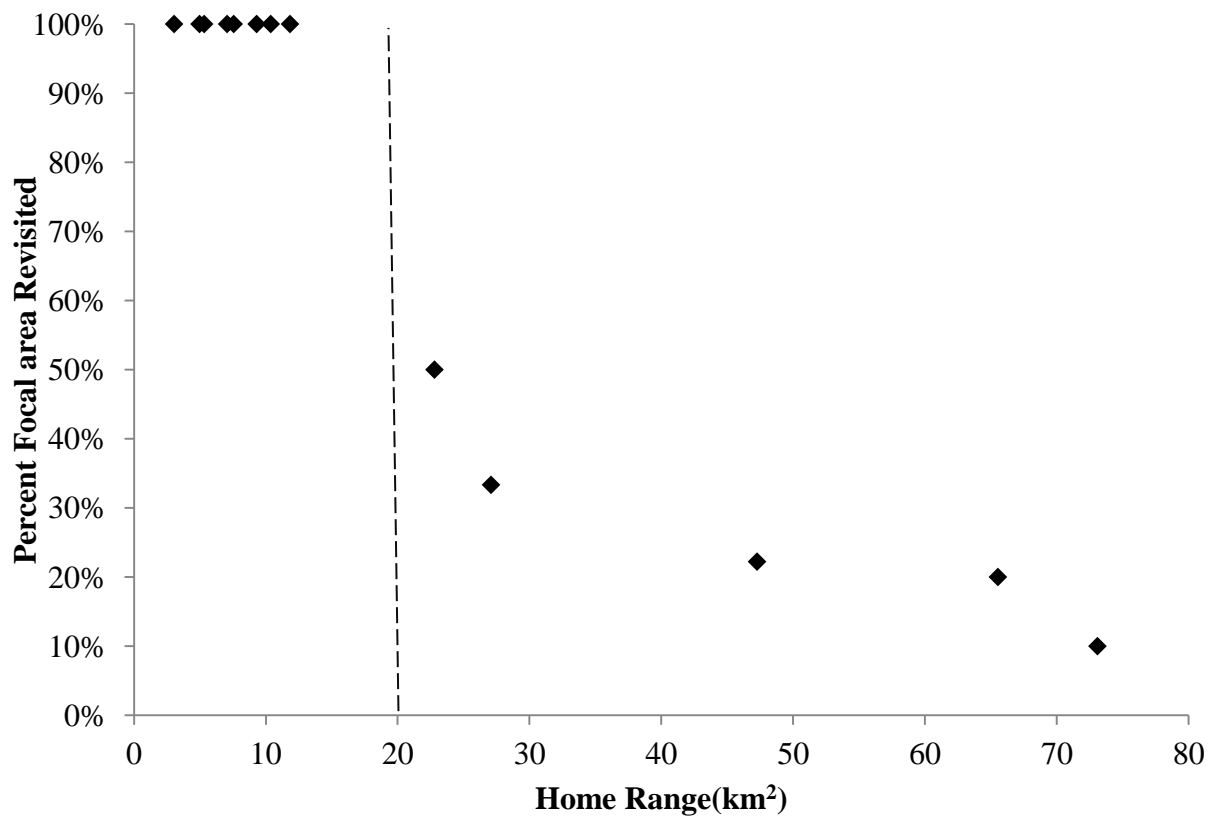
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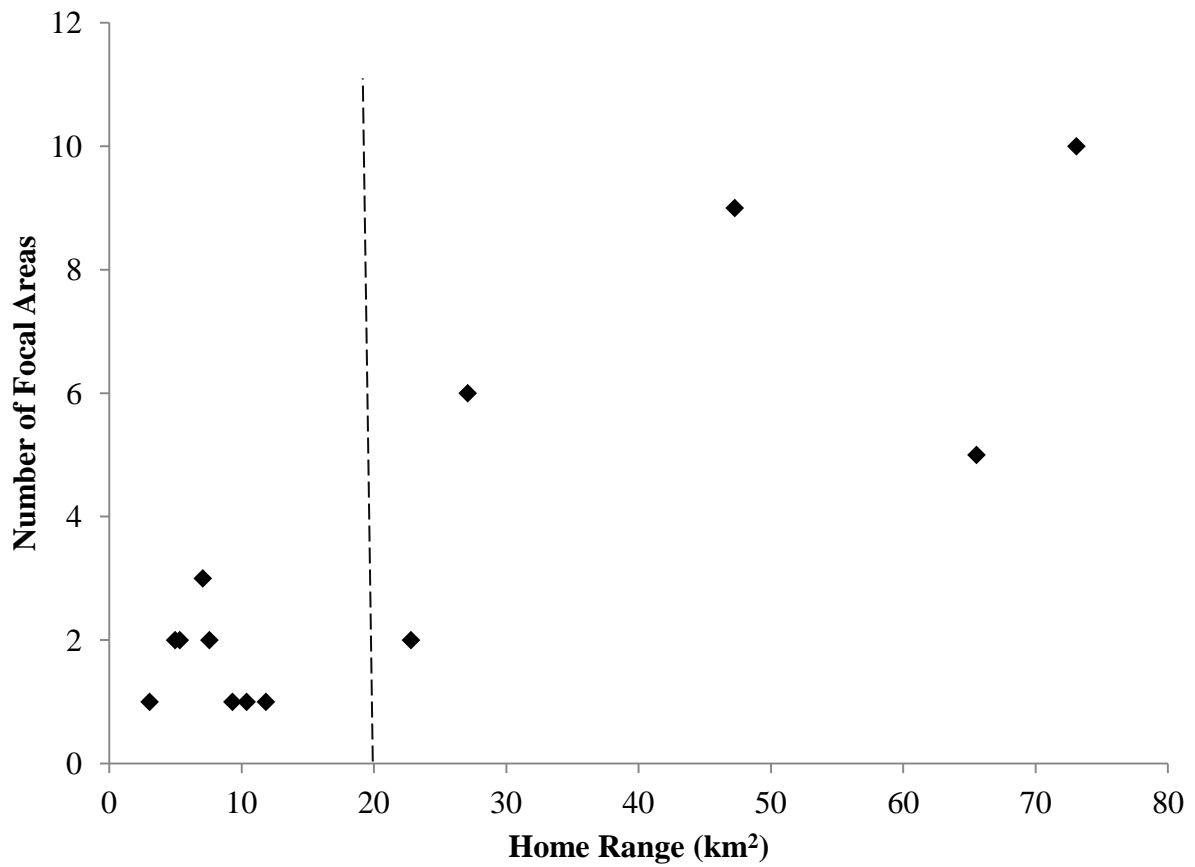


**Figure 2.1:** Map depicting the capture and study area for 20 female coyotes fit with GPS/GSM collars in west-central Georgia during May-July 2012 and 2013. The capture area consisted of private landholdings and the study area was determined by creating a polygon around 95% MCP home ranges of study animals.

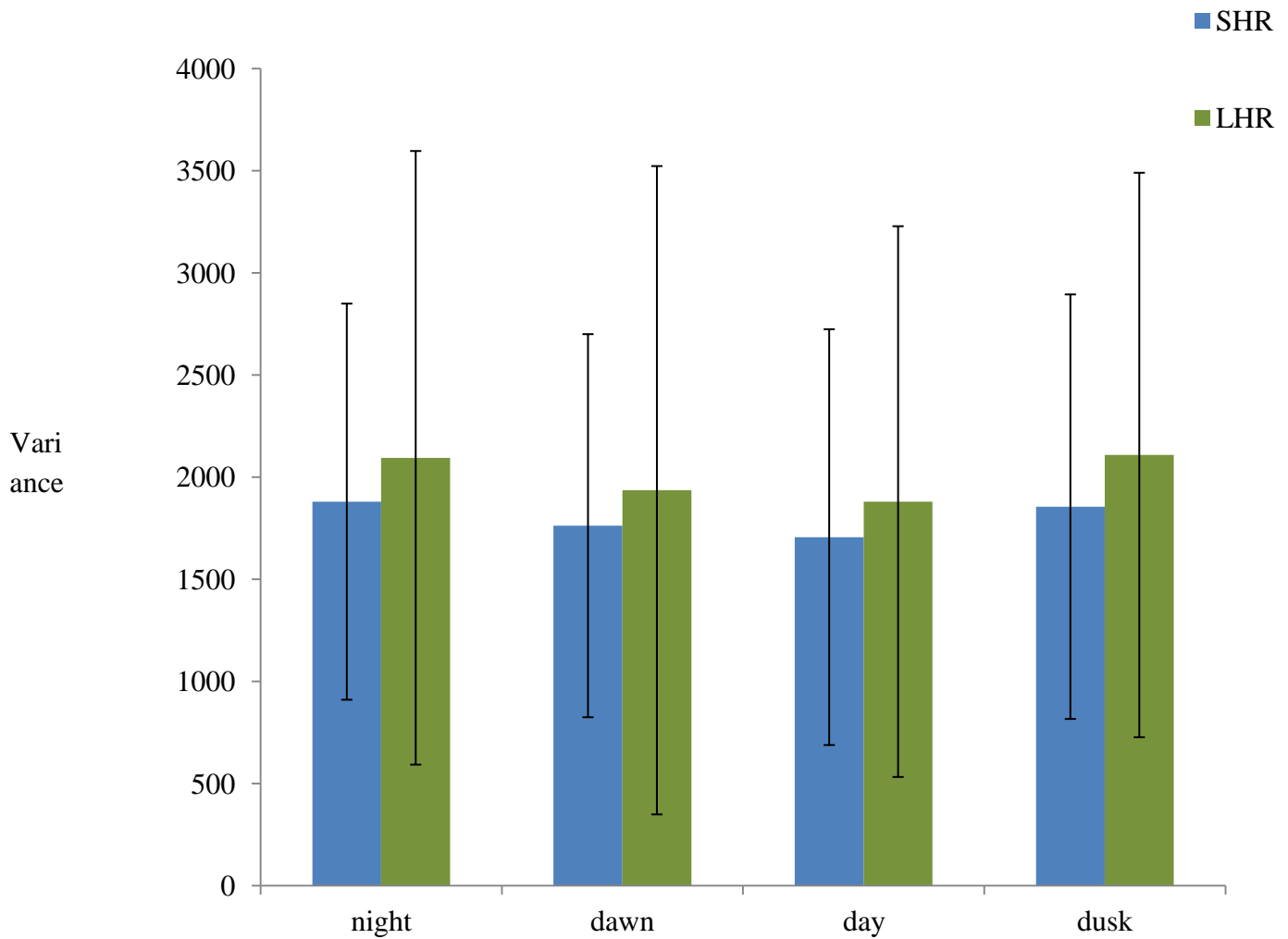




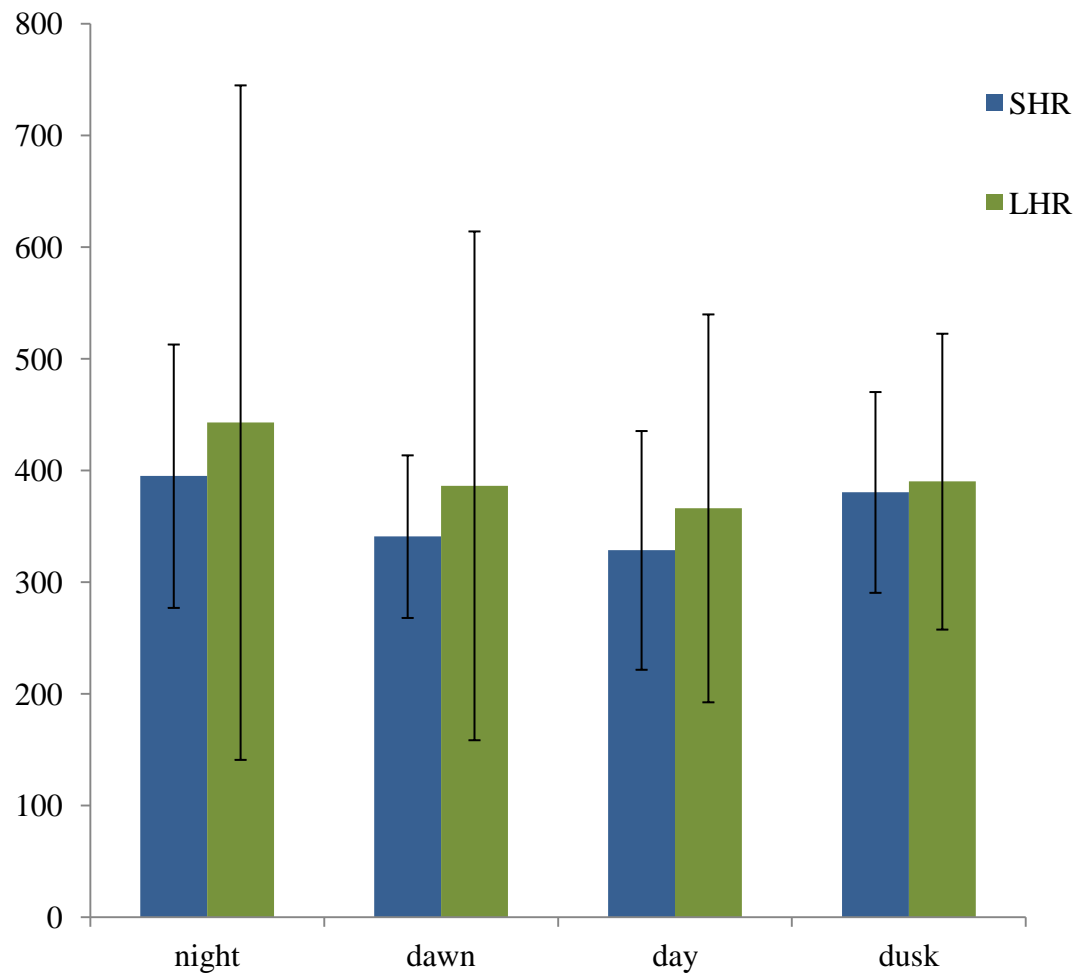
**Figure 2.2:** The percentage of female coyote focal areas (50% dBMM core areas) revisited by individual coyotes within a 48-hr period during May-July 2012 and 2013 in west-central Georgia. Small home range females (likely breeding residents) revisited 100% of their focal areas while Large home range females (likely transients) revisited  $\leq 50\%$  of their focal areas.



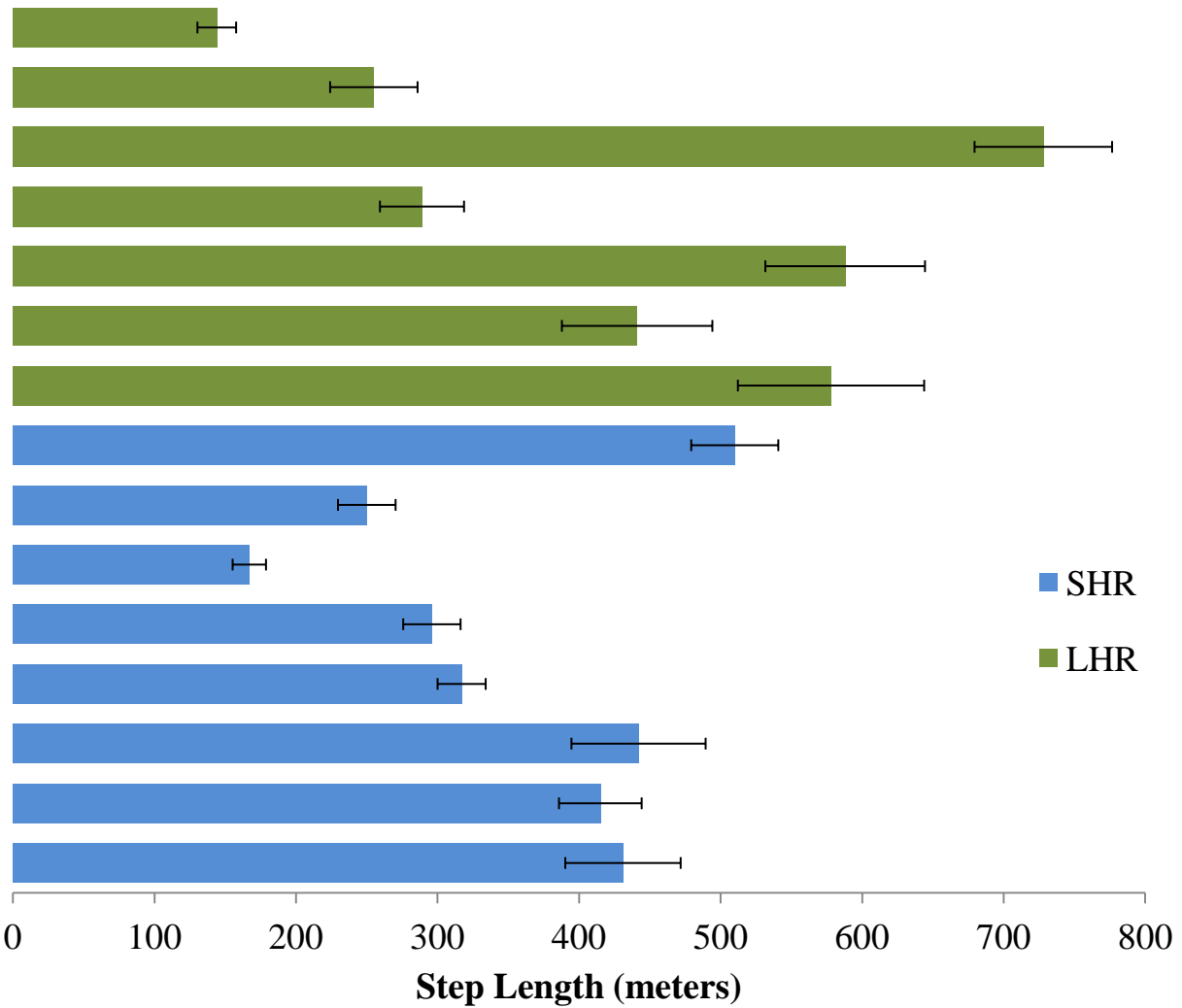
**Figure 2.3:** Relationship between home range size (95% dBBMM) and the number of focal areas (50% dBBMM) for 13 female coyotes in west-central Georgia during April-July 2012 and 2013. Home range size was a good indicator of the number of focal areas for each individual indicating that individuals with smaller home ranges use smaller areas more intensively.



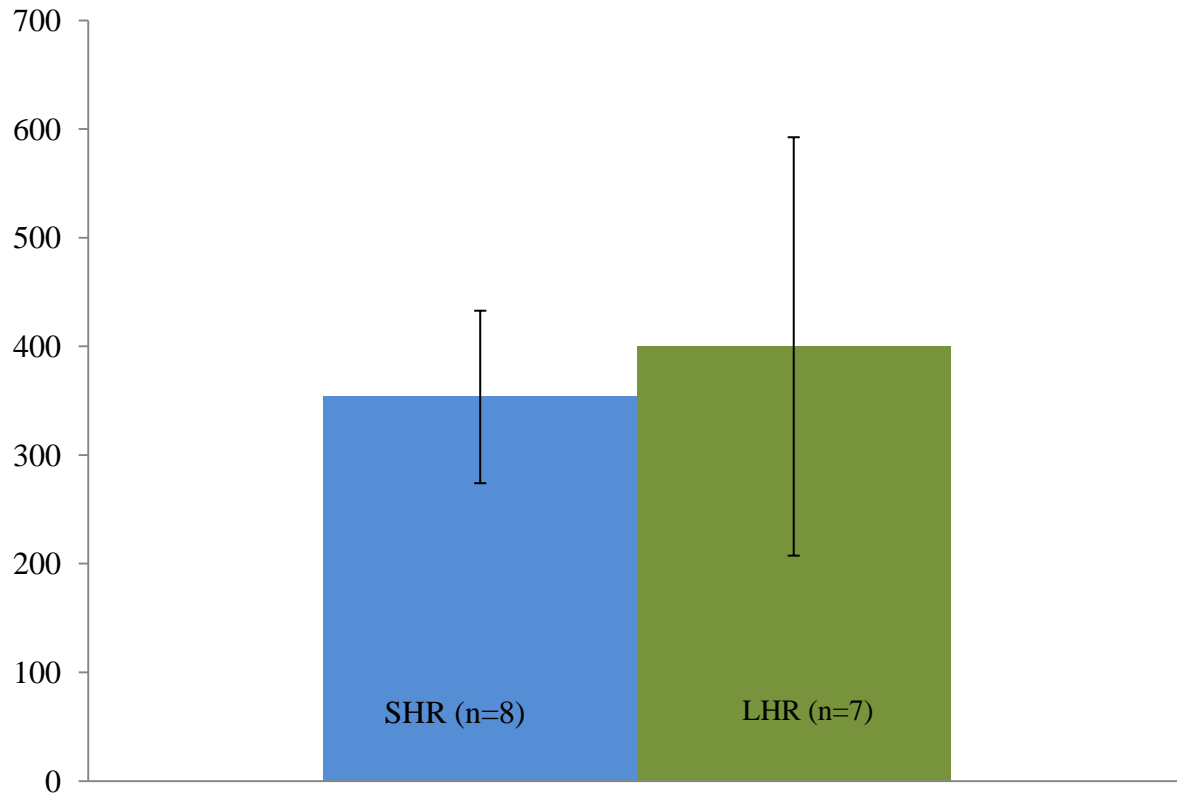
**2.4:** Movement variance values for small home range (SHR;  $n = 8$ ) and large home range (LHR;  $n = 5$ ) coyotes in west-central Georgia during May-July 2012 and 2013. We classified SHR and LHR coyotes by revisitation rates of the 50% utilization distribution produced by a dynamic Brownian Bridge Movement model. Movement variance was similar among diel periods and between spatial classes.



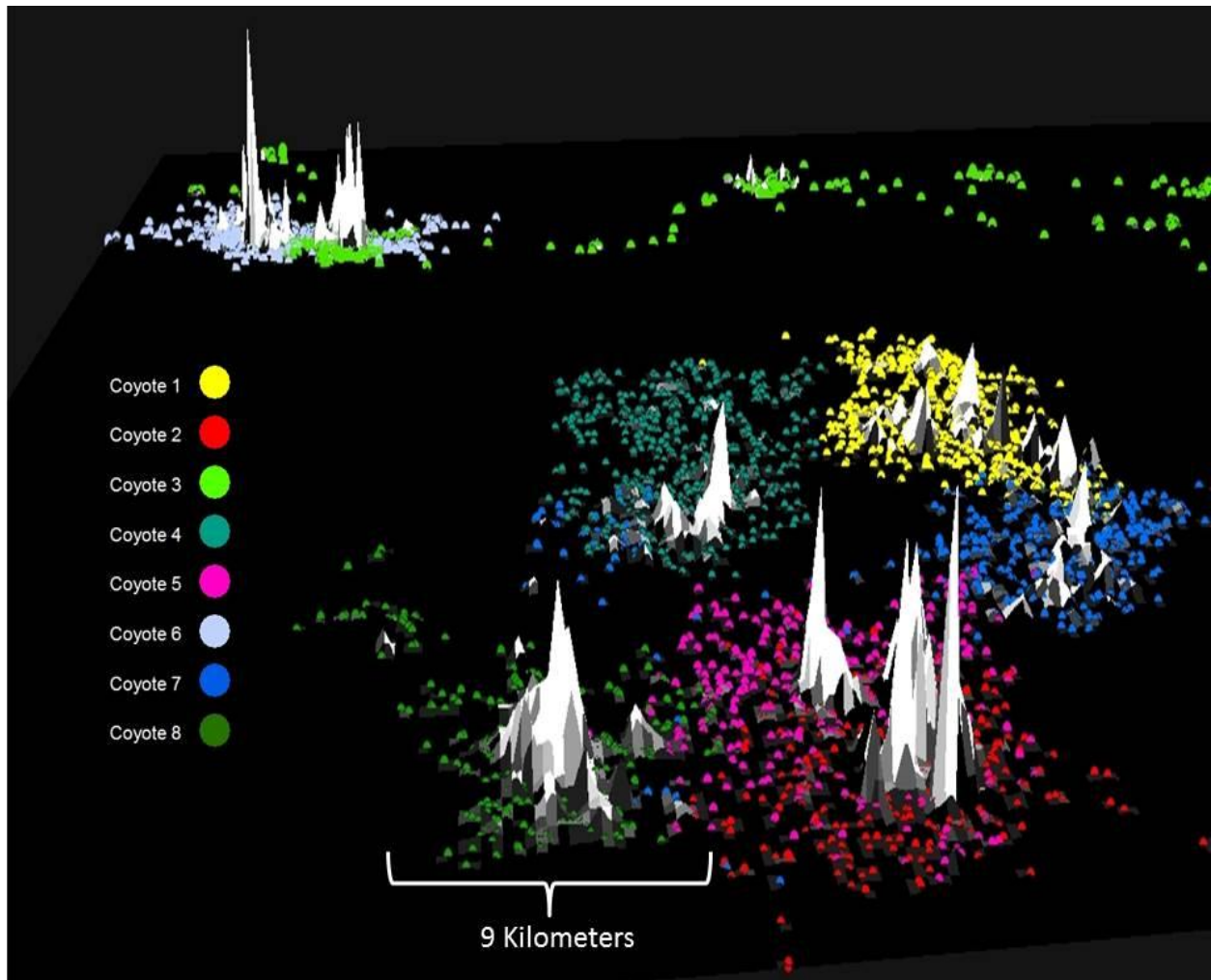
**Figure 2.5:** Step length values (meters) for small home range (SHR; n = 8) and large home range (LHR; n = 5) coyotes in west-central Georgia during May-July 2012 and 2013. We classified SHR and LHR coyotes by revisitation rates of the 50% utilization distribution produced by a dynamic Brownian Bridge Movement model. Step Length was similar among diel periods and between spatial classes



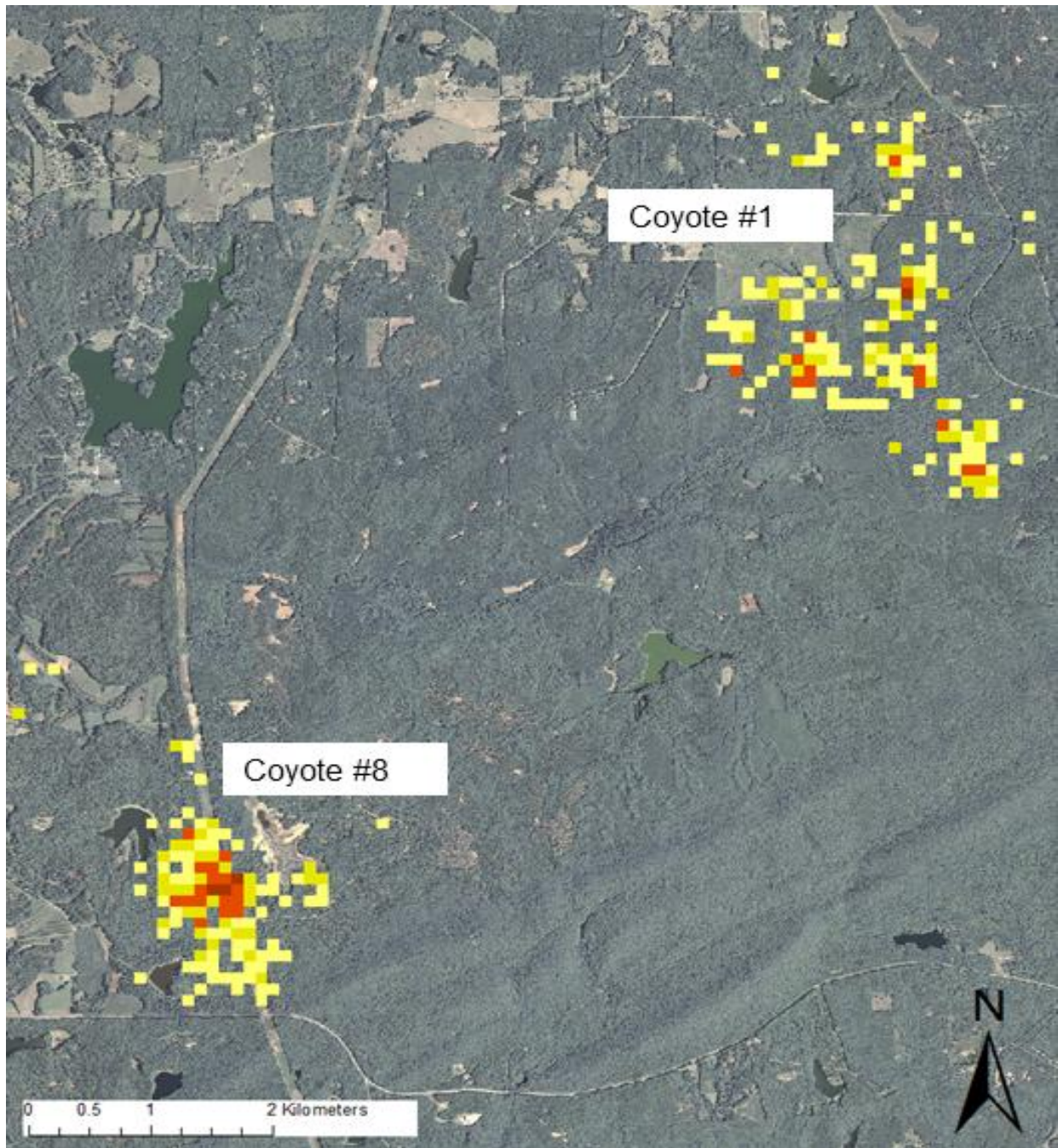
**Figure 2.6:** Average daily step lengths (meters) of 15 female coyotes in west-central Georgia during May-July 2012 and 2013. We classified small home range (SHR) and large home range (LHR) coyotes by revisitation rates of the 50% utilization distribution produced by a dynamic Brownian Bridge Movement model. SHR coyotes are likely resident coyotes while large home range LHR is likely transients. Error bars represent 95% confidence limits.



**Figure 2.7:** Mean daily step length values among small home range (SHR;  $n = 8$ ) and large home range (LHR;  $n = 7$ ) coyotes in west-central Georgia during May-July 2012 and 2013. We classified SHR and LHR coyotes by revisitation rates of the 50% utilization distribution produced by a dynamic Brownian Bridge Movement model. Mean daily step length was similar between spatial classes.



**Figure 2.8:** Illustration of home range use intensity among 8 SHR female coyotes in west-central Georgia during May-July 2012 and 2013. We classified SHR by revisitation rates of the 50% utilization distribution produced by a dynamic Brownian Bridge Movement model.. Peaks represent high use, or the density of locations, within a SHR coyote’s home range.



**Figure 2.9:** A comparison of 2 home range use patterns between two female coyotes in Harris County, Ga during May-June 2012 and 2013. Coyote #8 had a small, intensively used area within her home range while Coyote #1 utilized her home range more evenly with intensively used areas dispersed. Darker colors depict greater use.



**Table 2.1:** Dynamic Brownian Bridge Movement Model (dBBMM) 95% and 50% utilization distributions and 95% Minimum Convex Polygons for small home-ranged (SHR) and large home-ranged (LHR) coyotes in west-central Georgia during May-June, 2012 and 2013, respectively. Coyote 14 and 15 did not have sufficient data to conduct a dBBMM analysis, therefore we reported only MCP for these individuals.

Coyote ID	95% MCP (km <sup>2</sup> )	dBBMM	
		95% (km <sup>2</sup> )	50% (km <sup>2</sup> )
<b>SHR</b>			
1	14.97	7.06	1.26
2	13.13	5.32	0.40
3	17.19	9.30	0.53
4	13.79	11.83	1.35
5	12.79	7.56	0.65
6	14.85	4.97	0.60
7	29.33	10.37	1.60
8	10.01	3.04	0.36
<b>Mean</b>	15.76	7.43	0.84
<b>LHR</b>			
9	227.13	73.08	2.71
10	208.29	27.08	0.58
11	55.50	22.79	1.28
12	254.97	65.53	4.14
13	117.82	47.26	3.84
14	167.94	--	--
15	390.00	--	--
<b>Mean</b>	203.09	47.14	2.51

**Table 2.2:** Results depicting multi-scale habitat selection using compositional analysis across 8 small home range coyotes in west-central Georgia during May-June, 2012 and 2013, respectively. First order is selection of home range habitats in proportion to their availability within the study area, The second order is selection of core area habitats in proportion to their availability within the home range. The third order is selection of diurnal and nocturnal habitats to availability within the home range. Rankings are on a scale from 1 (most preferred) – 5 (least preferred) and values with the same letter are not significant at  $p < 0.05$ .

	First order	Second Order	Third order	
			day	night
Developed <sup>1</sup>	4 <sup>a,b,c</sup>	4 <sup>c</sup>	5 <sup>c</sup>	5 <sup>b</sup>
Open <sup>2</sup>	5 <sup>c</sup>	1 <sup>a</sup>	1 <sup>a</sup>	1 <sup>a</sup>
Early Successional <sup>3</sup>	2 <sup>a,b,c</sup>	2 <sup>a,c</sup>	3 <sup>a,b</sup>	3 <sup>b</sup>
Hardwood <sup>4</sup>	1 <sup>a,b,c</sup>	3 <sup>b</sup>	2 <sup>a</sup>	2 <sup>b</sup>
Pine <sup>5</sup>	3 <sup>a,b</sup>	5 <sup>a,b,c</sup>	4 <sup>b</sup>	4 <sup>b</sup>

1 - Constructed materials and impervious surfaces such as home sites and roads.

2 - Maintained pastures and agricultural fields as well as few areas having rocky outcrops.

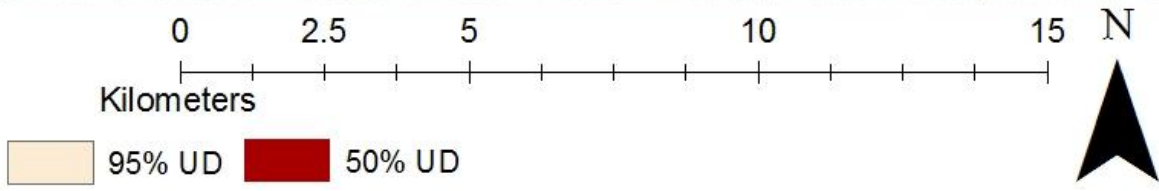
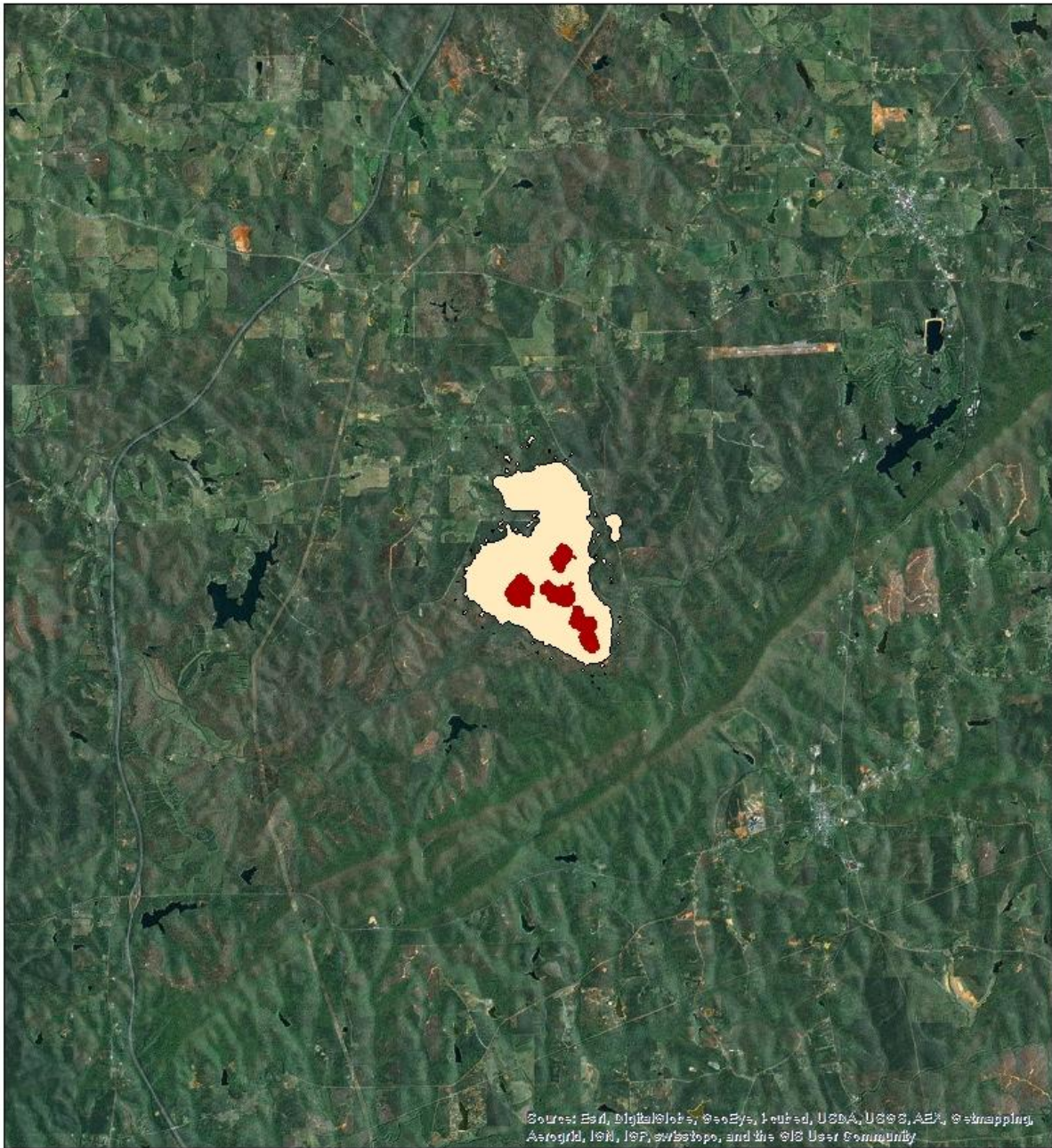
3 - Scrub/shrub, < 5 year old clear cuts, and overgrown pastures or old fields.

4 - Deciduous species such as White Oak (*Quercus alba*), norther red oak (*Quercus rubra*), southern red oak (*Quercus falcate*), water oak (*Quercus nigra*), and hickory (*Carya spp.*) as well as some pine species such as loblolly (*Pinus taeda*) interspersed.

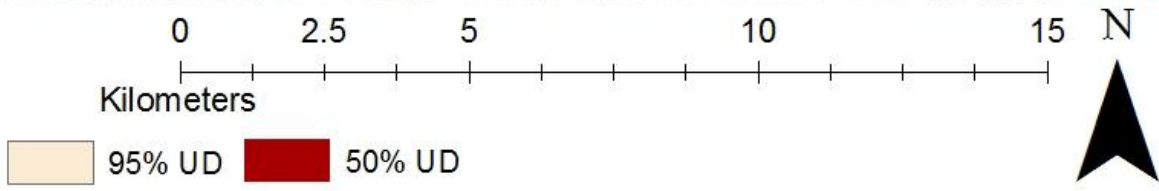
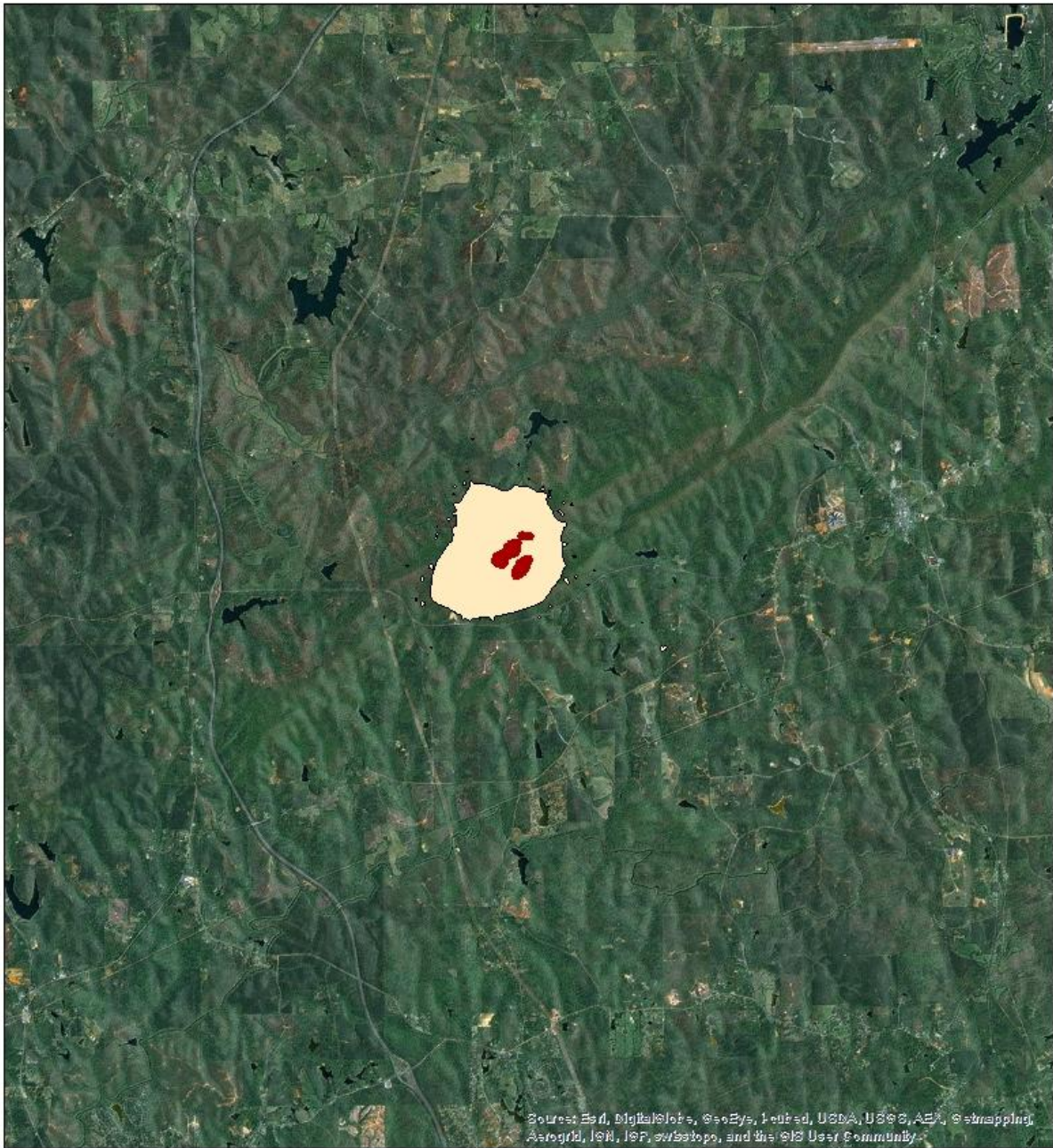
5 - Upland pine species >5yr such as loblolly (*Pinus taeda*) and Longleaf (*Pinus palustris*).

APPENDIX:  
COYOTE HOME RANGE MAPS

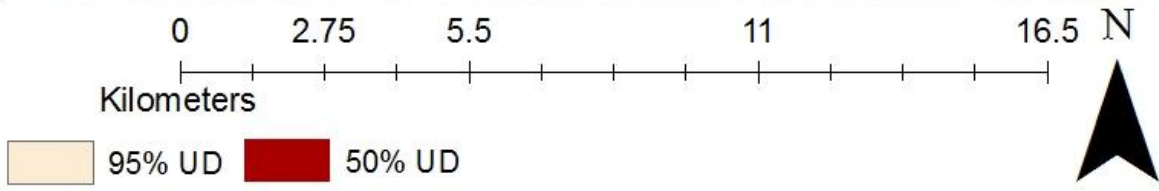
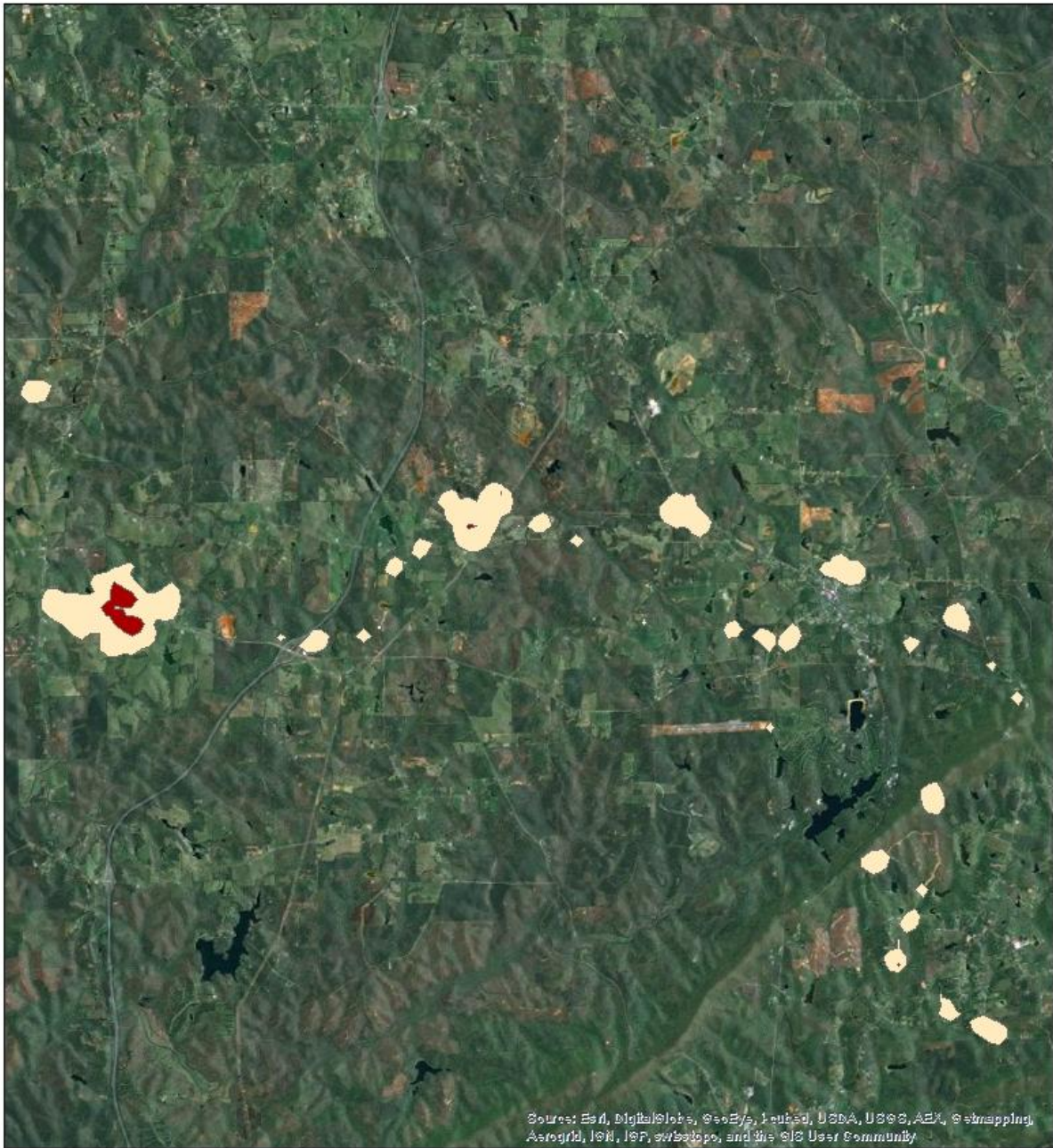
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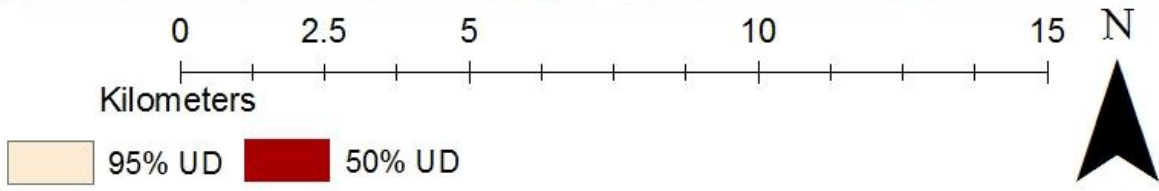
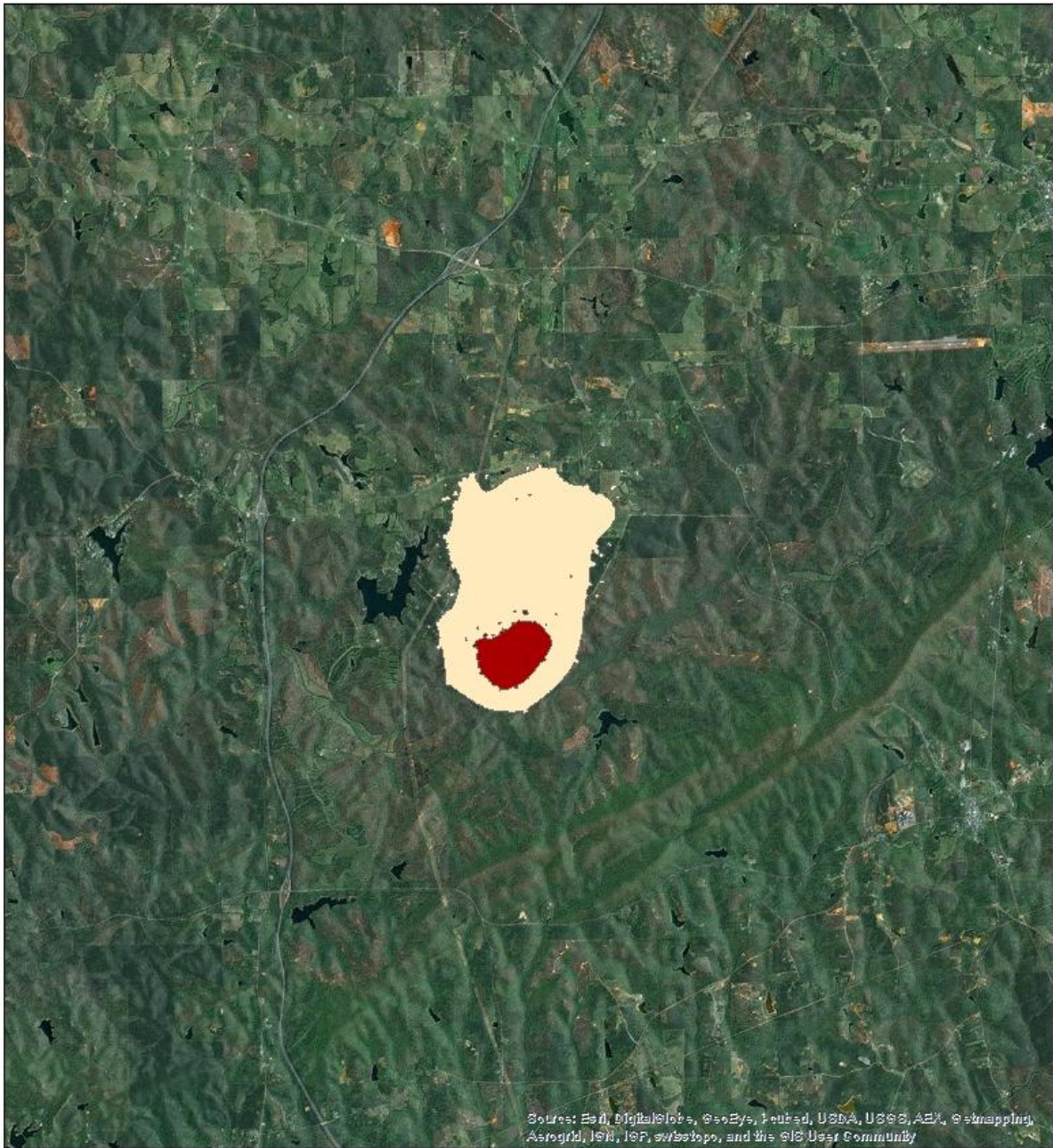
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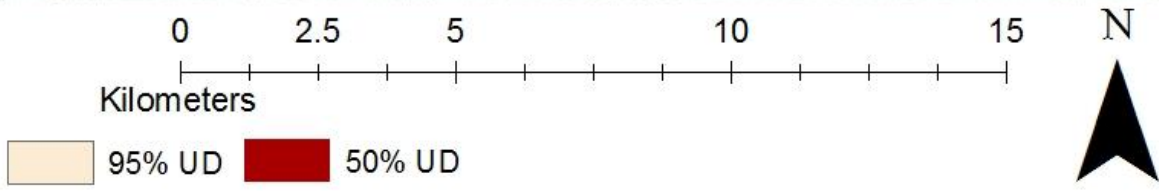
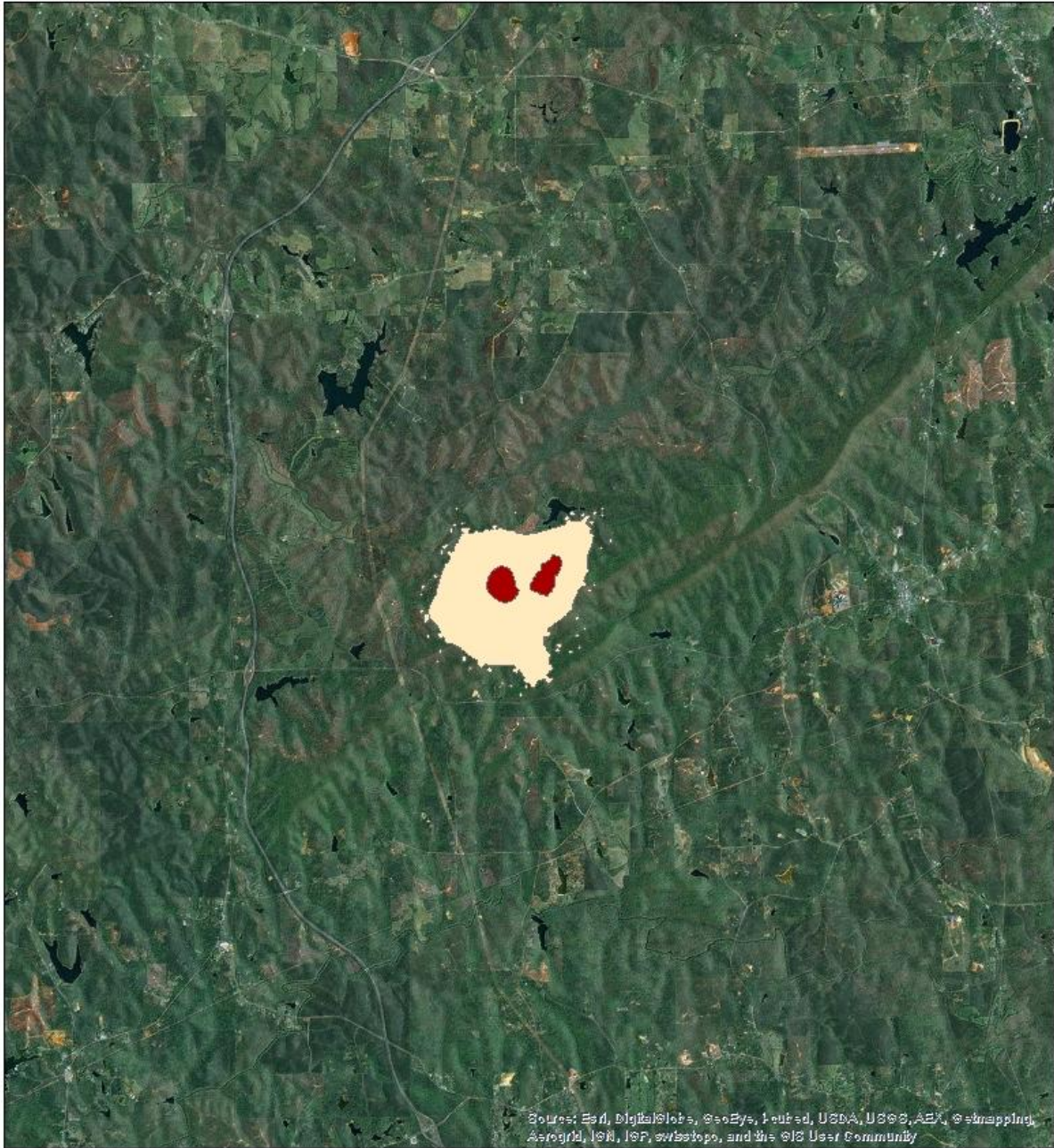
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# Coyote 4

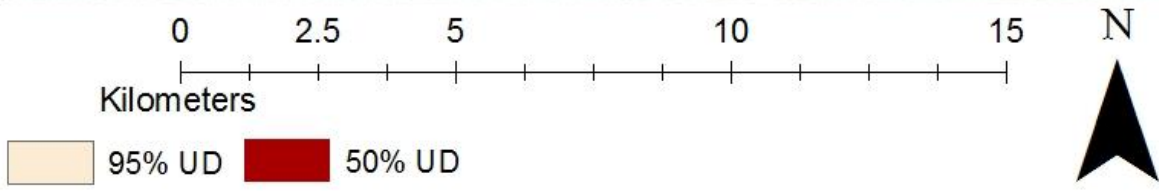
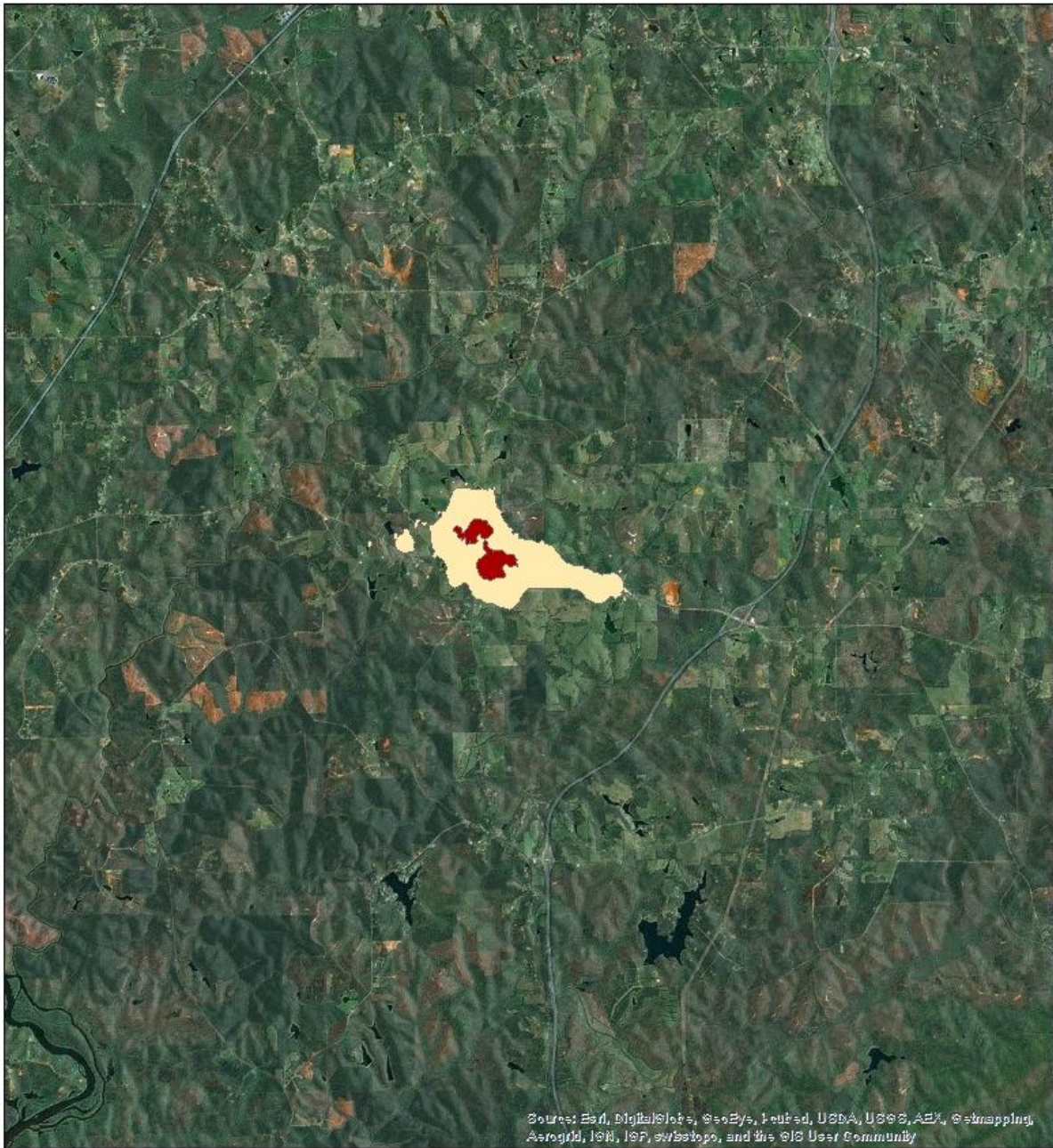


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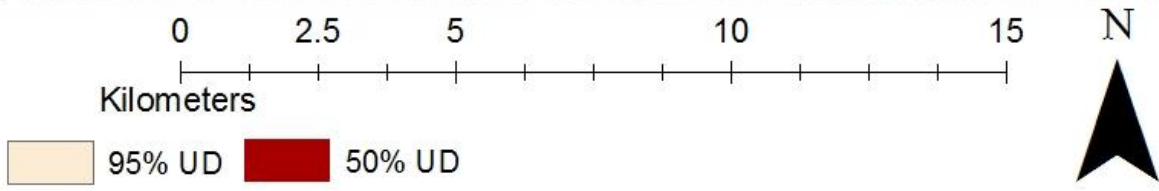
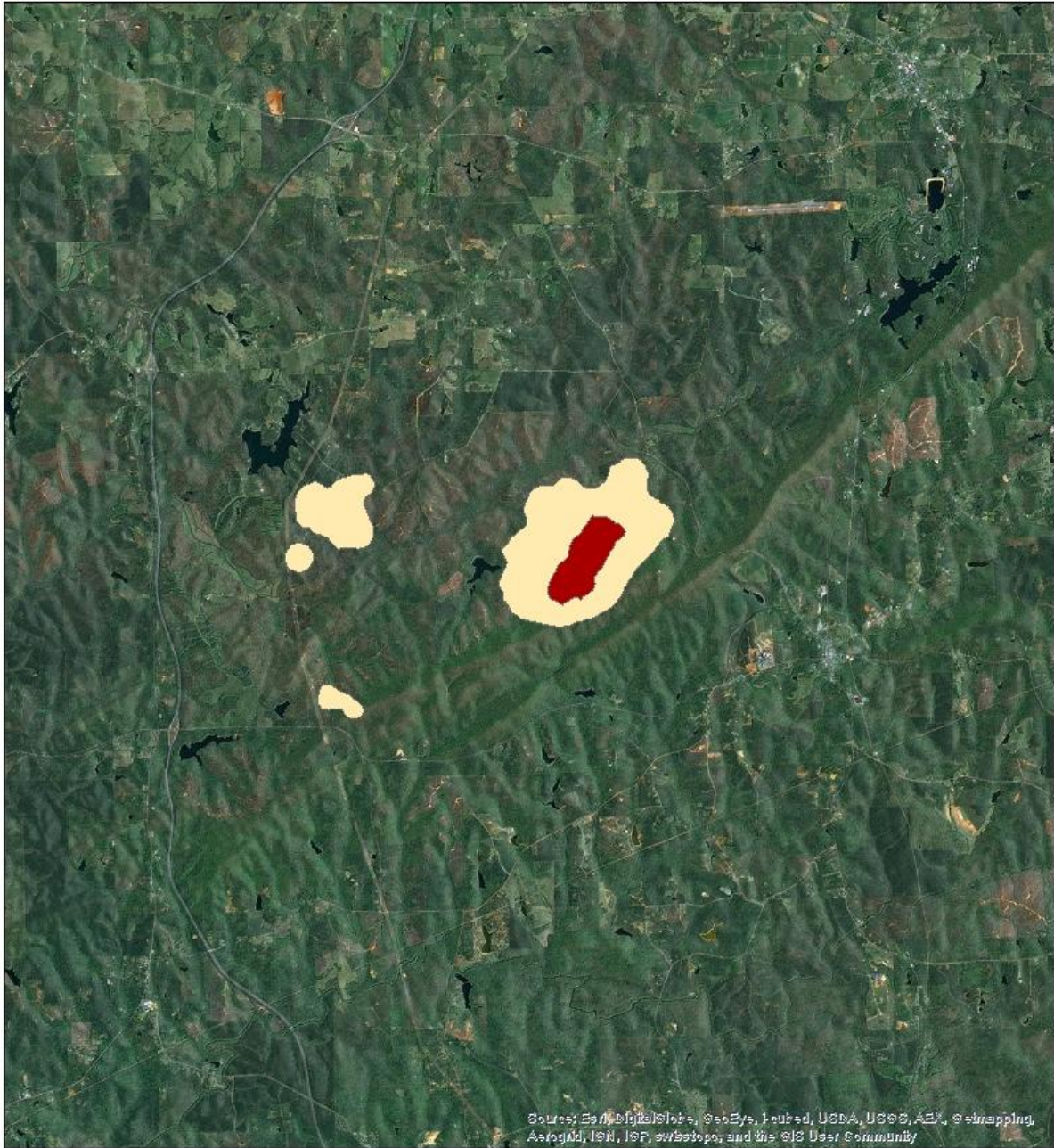


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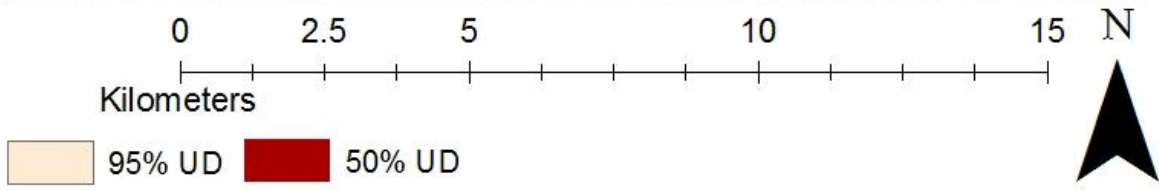
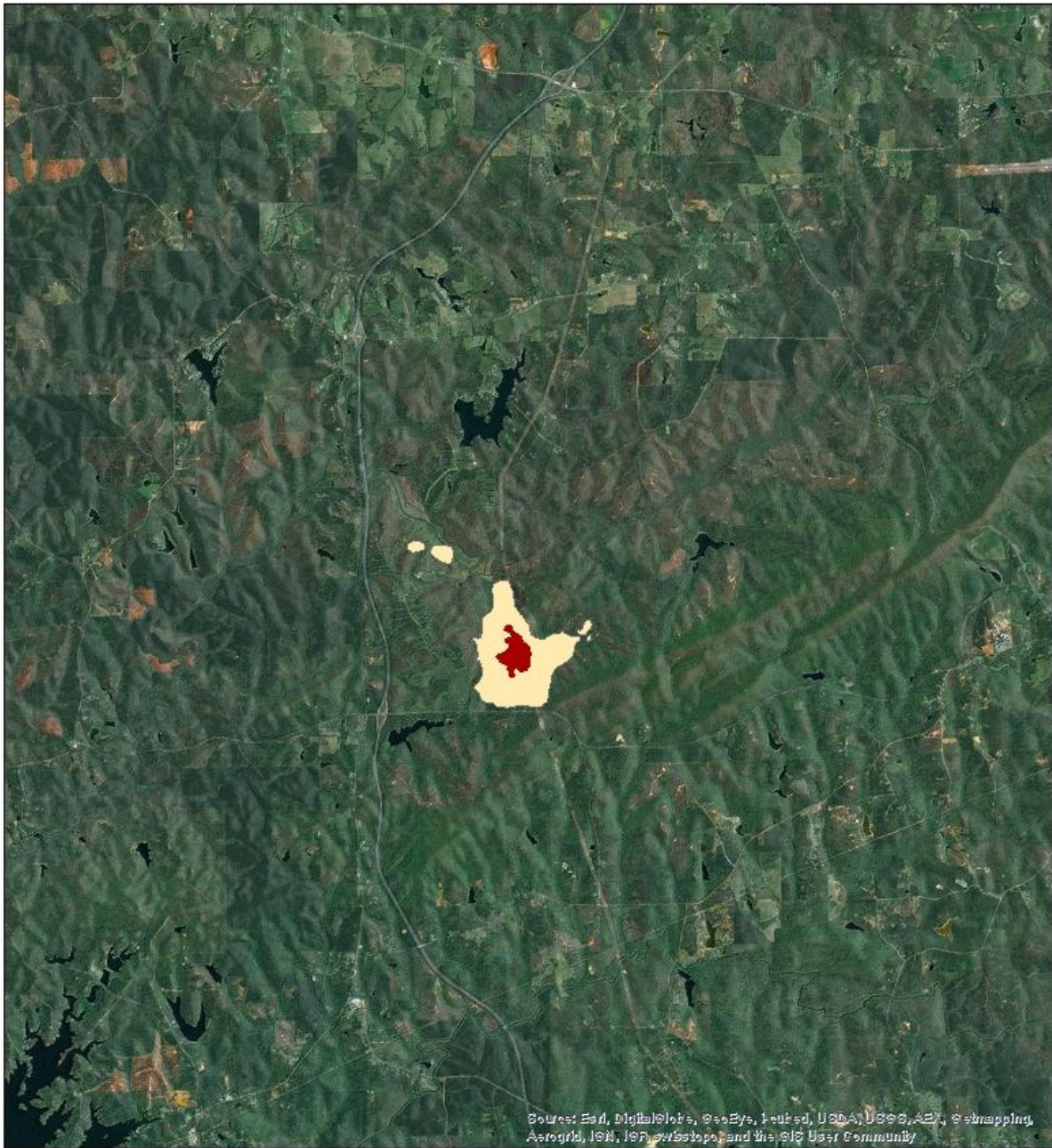


95% UD 50% UD

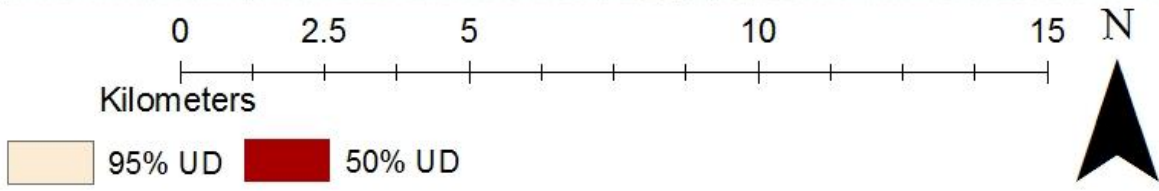
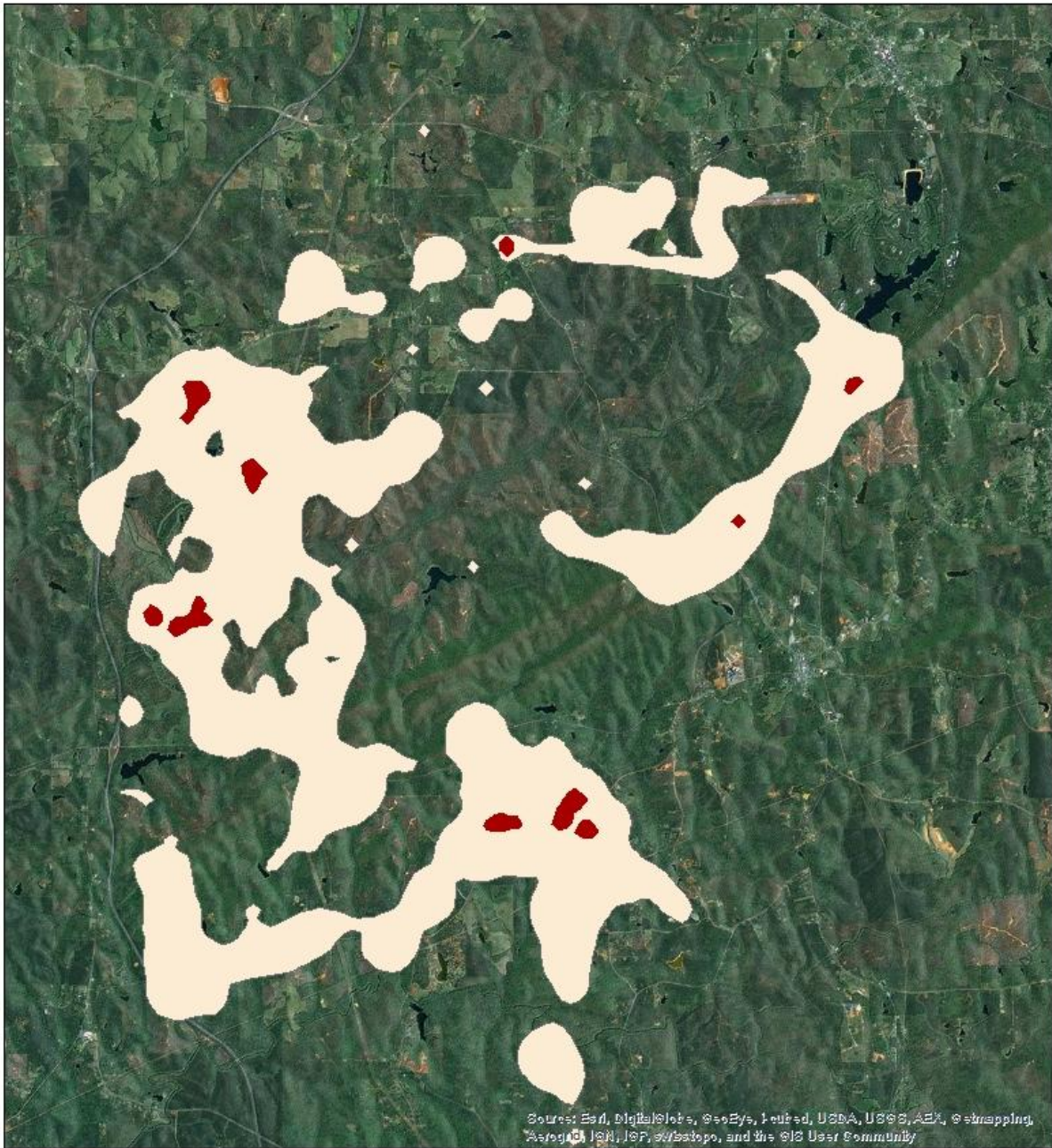
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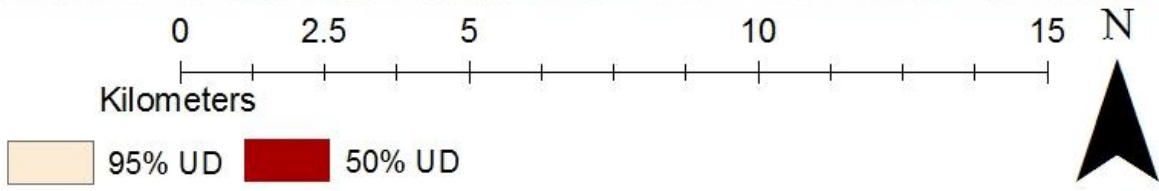
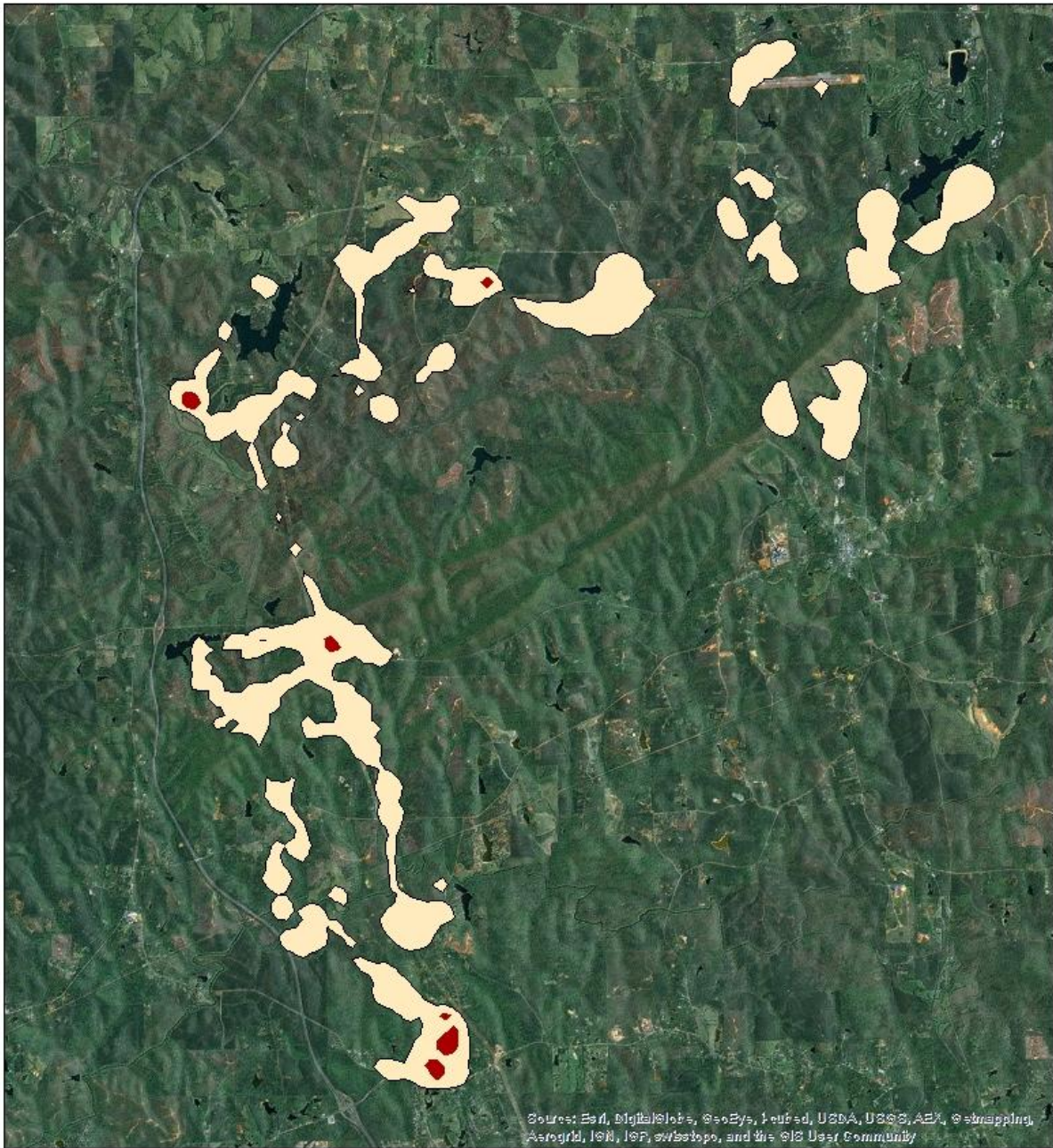
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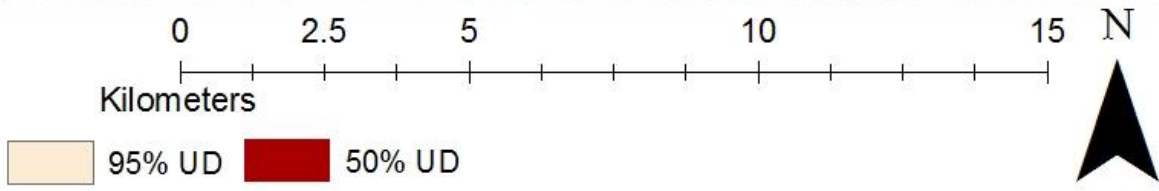
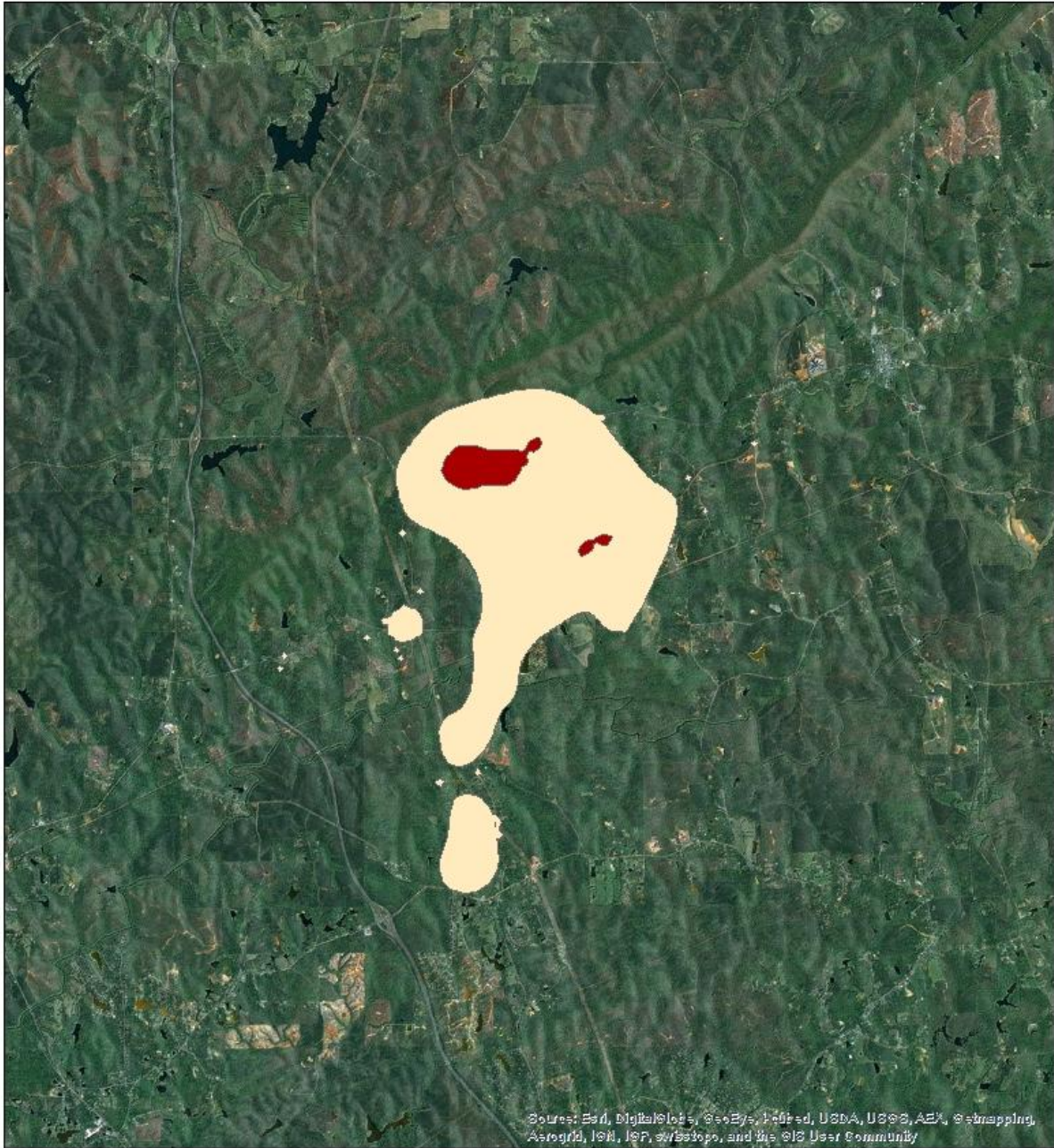
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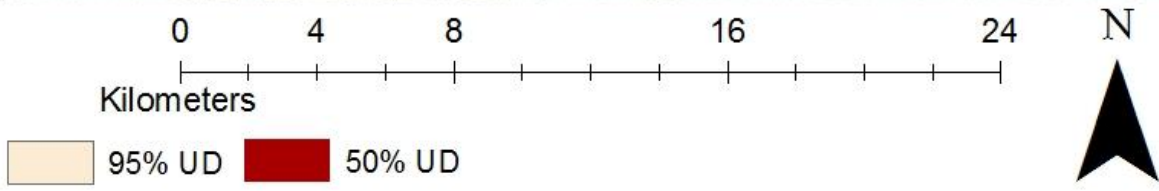
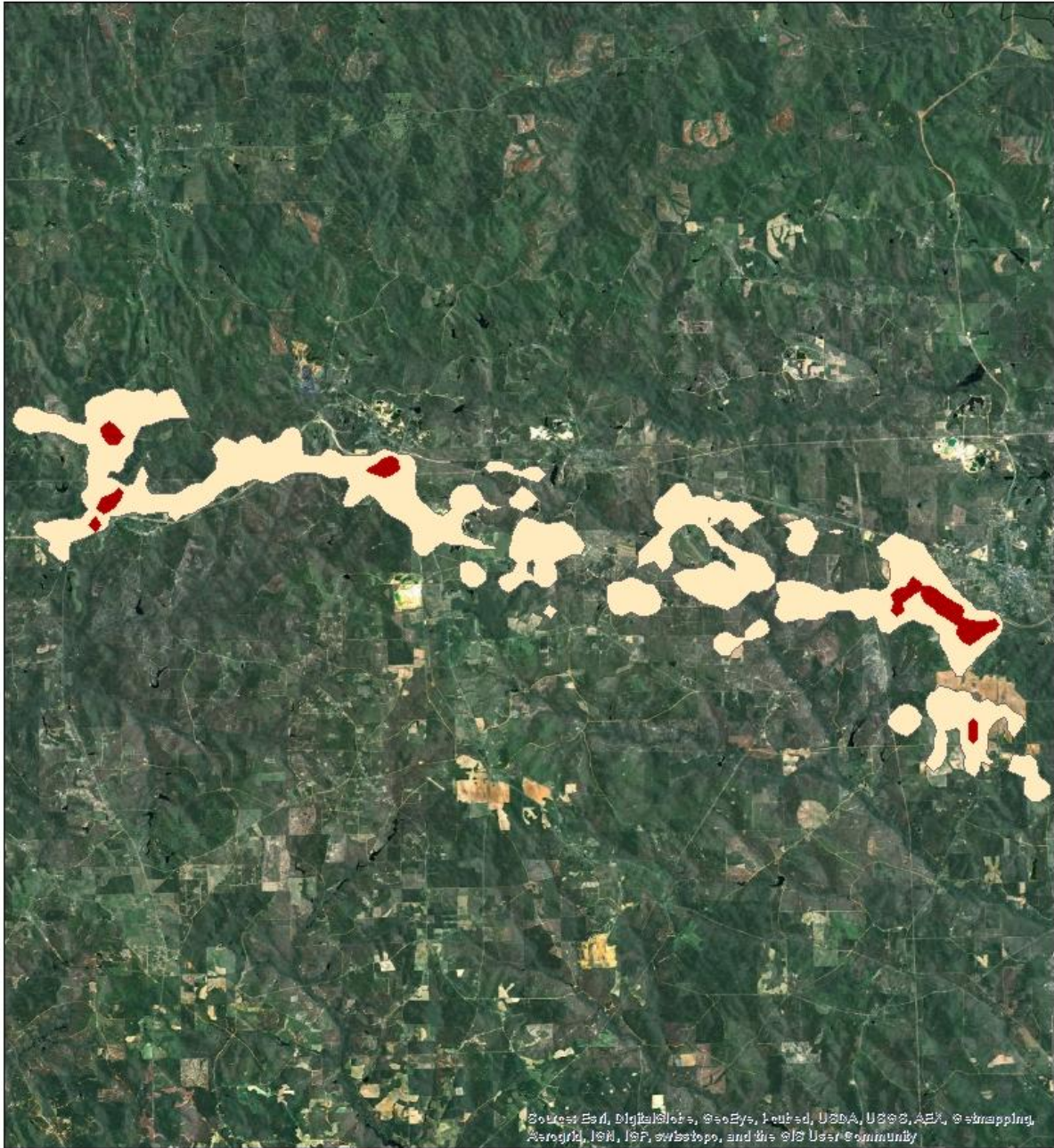
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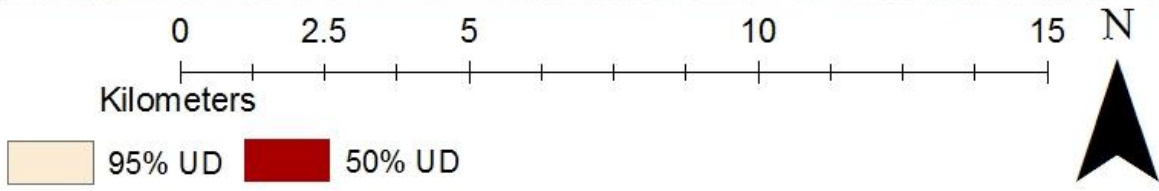
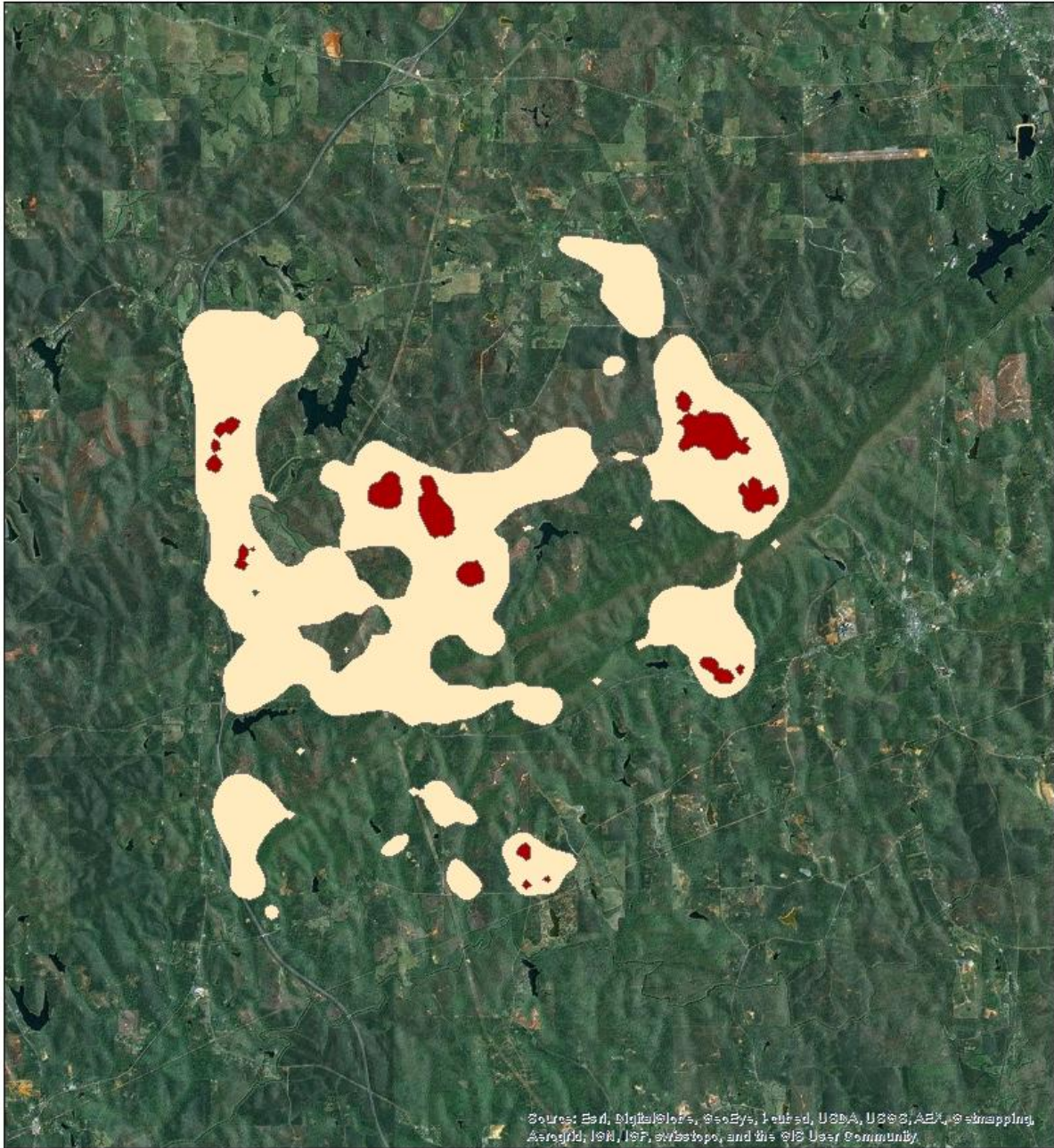
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# Coyote 12

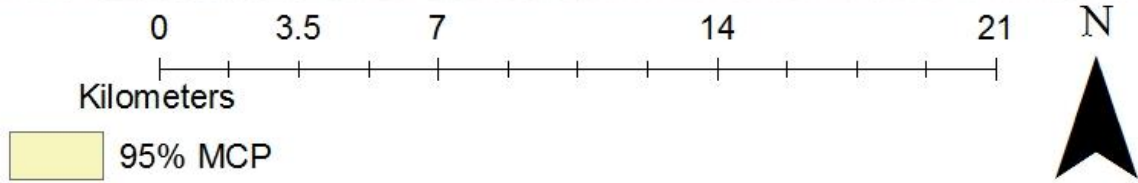


# Coyote 13





# Coyote 14



# Coyote 15

