SPACE USE AND PREDICTIVE HABITAT MODELS FOR AMERICAN BLACK BEARS (*URSUS AMERICANUS*) IN CENTRAL GEORGIA, USA

by

KIERSTEN LEAH COOK

(Under the direction of Michael J. Conroy)

ABSTRACT

American black bears (*Ursus americanus*) occupy 5% of their historic range in Georgia. Extensive development will likely occur in the central Georgia bear range. I predicted bear habitat and analyzed bear home range and movement dynamics in central Georgia to assist management and conservation planning. Models predicted annual home range presence in areas of low road density, while habitat diversity was potentially important. Bears crossed high-traffic highways mainly during activity center shifts, which predominated during fall. Hard mast was absent from scat and some males used agricultural areas in fall and winter. Results suggest bears occupy home ranges where road densities are low, cross high-traffic highways mainly during fall and exploit agriculture and common areas, information that can focus conservation actions. An evaluation of uplands and swamps that provide fall hard mast is needed. Landowners, especially in areas of low road density, and local governments are important bear management partners.

INDEX WORDS: American black bear, *Ursus americanus*, central Georgia population, habitat, habitat modeling, road crossing, home range, movement dynamics, Markov Chain Monte Carlo, Bayesian hierarchical modeling, logistic regression

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DEDICATION

Ocmulgee

A Poem by Horace M. Dubose,
a speaker at the Ocmulgee Chautauqua 1898

Where the lazy fern leaves float
On the fragrant vernal air,
And the gushing sunbeams gloat
o'er the fringing "maiden hair";
By the little breezes stirred,
By the ancient forest cheerer,
Murmurous in the silence there,
Flows the Ocmulgee.

Dreamy spaces stretch away
Through the woodland, dusky, cool
Where the dancing naiads play
At the marge of many a pool,
Overbrimming in the shade,
Dripping through the reedy glades,
Mimic rivers running full
To the Ocmulgee.

Farm and orchard edging down,
Meadows green with browsing kine,
Lodges that the high cliffs crown,
Hamlets in the broader shine,
Cities by the laving tide,
Watch the waters onward glide;
Watch the Ocmulgee.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

American black bears (*Ursus americanus*; hereafter, 'black bears') occupy approximately 62% of their historic range in the United States (Pelton and Van Manen 1994). Population declines were most dramatic in the midwestern and southeastern USA likely from over-harvest, habitat loss (Maehr 1984) and other factors correlated with increases in human density (Jones et al. 1998, Pelton et al. 1999). In the Southeast Coastal Plain bears have been extirpated from approximately 90% of their former distribution and their populations remain fragmented (Wooding et al. 1994, Clark et al. 2005). Current estimates based on expert opinion indicate that bear population ranges from 1994 to 2005 have likely remained static in Georgia and South Carolina, expanded in North Carolina and have declined by over 50% in Alabama (100 km^2), Mississippi (159 km^2) and Louisiana (2,921 km^2) (Wooding et al. 1994, Clark et al. 2005). Population sizes in Alabama and Mississippi have been estimated at < 50 bears (Pelton et al. 1999).

Three black bear populations remain in and around public lands or leased Wildlife Management Areas in the north, central and southern parts of Georgia (Figure 1.1). The central Georgia bear population (CGP) occupies a range in the Upper Coastal Plain, comprised of mostly private land, potentially 1,200 km^2 in size. This area is less than one fifth the size of those ranges occupied by the populations in the north Georgia mountains and Okefenokee in southern Georgia (Carlock et al. 1999). The majority of this population is considered to inhabit forested land in and around 186 km^2 that comprised the Ocmulgee and Oaky Woods Wildlife

Management Areas (WMAs), where the only breeding has been recorded (Clark et al. 2005). Recently almost 145 km^2 of these WMAs were sold to timber companies and developers. Currently 74 km^2 within the CGP range is publicly owned in dispersed large tracts. In 1985 Grahl (1985) estimated the population size within the original WMA extent to be approximately 64 (±18) bears. The population over the CGP range is likely to be larger than this, and quantitative research on population size and dynamics has been undertaken.

The CGP may be isolated from other black bear populations based on a lack of bear reports from surrounding counties (Georgia Dept. Nat. Res. Unpublished data), public forestland where wildlife are monitored (C. Johnson, Chattahoochee-Oconee Forest Supervisor, US Forest Service, pers. comm 2002) and the findings of preliminary genetic analyses (Miller 1995, Miller et al. 1998). The CGP exists along the "boundary zone" between the *U. a. luteolus*, *U. a. floridanus* and *U. a. americanus* subspecies (Miller et al. 1998). Genetic evidence suggested that the CGP is part of the *U. a. americanus* subspecies, the most common in eastern North America, but that it shows almost equal relatedness to the *U. a. floridanus* population of the Okefenokee Swamp in Georgia (Median band-sharing value (S) = 0.485) as with the *U. a. americanus* population in South Carolina (S = 0.45) (Miller 1995). Significant signs of genetic isolation exist as the CGP was found to have the second highest within population genetic similarity (MBS=0.82) of the all populations in the Southeast Coastal Plain (Miller 1995). Miller (1995) recommended that the CGP be considered for listing as a distinct population segment under the Endangered Species Act.

Multi-lane interstate highways dissect the CGP population range. Interstates have been demonstrated to reduce movement (Brody and Pelton 1989, Beringer et al. 1990, McCowen et al. 2004) and genetic exchange among black bear populations (Thompson et. 2005, Dixon et al.

2006). Small, isolated populations are more prone to extinction due to stochastic environmental or anthropogenic disturbance (MacArthur and Wilson 1967, Allendorf 1983). An example of extreme decline in a black bear population due to isolation mechanisms exists currently in an area of half the size of the CGP range in Florida (Maehr et al. 2003). The status of the CGP is not well known and the desire for extended bear hunting and conservation exists in the region. Due to these factors, the diversity of land tenure and potential effects of development and infrastructure within the CGP range, the assessment of potential habitat, spatial dynamics, and diet are needed in order to manage for the persistence of this black bear population. A reintroduction of bears in the region of the Altamaha River will be evaluated in the near future by wildlife managers and our study will provide initial information regarding predicted female home range habitat in central and southeastern Georgia for that study.

Black bear populations require habitat-specific and landscape-scale habitat management due to the high energy requirements of bears and temporally available food sources, obtained by foraging in a variety of vegetation types over large, dynamic home ranges (Schoen 1990, Schooley et al. 1994, Carr et al. 2002, Jones and Pelton 2003, Mitchell and Powell 2003). Furthermore, the high mobility needed to forage and mate can make bears susceptible to mortality associated with roads and human activity (Brody and Michael R. Pelton 1989, Powell et al. 1996, Oka et al. 2004). Black bear populations persist in areas that contain seasonally available, high nutrient foods, den habitats that meet thermodynamic needs, and which are sufficiently remote to protect them from over-exploitation (Pelton 1990, Sargeant and Ruff 2001). Food abundance directly affects reproductive success through its effects on pre- and post-natal nutrition and through indirect effects on adult mortality. Females tend not to produce , or have fewer young in years of low mast production (Costello et al. 2003, McGlaughlin et al. 1994, Rogers 1987, Dobey et al. 2005) and cubs may not survive in these years (Rogers 1987, Elowe and Dodge 1989, Eiler and Pelton 1989). Mast abundance has been tied to shifts in bear home range placement and overlap (Garshelis and Pelton 1981, Kasbohm et al. 1998, Schooley et al. 1994), regional and seasonal home range size (Dobey et al. 2005, Kasbohm et al. 1998, Powell et al. 1997, Jones and Pelton 2003, Hellgren et al. 2005, Olfenbuttel 2005) movement of bears into human dominated areas (Rogers 1976, Samson and Hout 1998) and culling of bears which wander more and into residential areas (Oka et al. 2004). Average annual home range size for female bears in southeast Georgia in the Okefenokee Swamp, where habitats are interspersed with open water and bears and their foods exhibit low densities, have been estimated to be as large as 57.9 km^2 for females with cubs of the year (COY) and 95.8 km^2 for solitary females. Home range sizes for solitary and female with COY in the adjacent Osceola National Forest in Florida, where habitats are contiguous and bears have access to agriculture, were less than half the size of solitary and females with COY in the Okefenokee (Dobey et al. 2005). Habitats deficient in critical food may likewise affect productivity and survival by causing decreased birth rates and increased movement induced mortality from roads and bear-human interaction. CGP bears have been reported to travel into the highly developed surrounding towns and into the city of Macon (C. Johnson, Chattahoochee-Oconee Forest Supervisor, US Forest Service, pers. comm 2002, Georgia Dept. Nat. Res. Unpublished data).

Habitat and population research in the southeastern USA suggests that hard and soft mast species, high in calories and abundance, which may be constrained by social factors, are important to maintenance of bear populations. Upland oak-hickory (*Quercus spp. – Carya spp.*) and mixed hardwood-pine (*Pinus*) forests that contain acorn hard-mast appear to be selected over pine forests by female black bears (Clark 1993, Clark et al. 1994). Acorn mast failure has been tied to female productivity (Rogers 1976, Clark 2004) and increased harvest of apparently more mobile females (Noyce and Garshelis 1996, Costello et al. 2003). Hardwood forest plantations were shown to be most productive for fall acorn hard mast and spring and summer soft mast species such as (in order of ripening): serviceberry (*Amelanchier* spp.), black berries (*Rubus* spp.), blueberries (*Vaccinium* spp.), cherry (*Prunus* spp.), pokeweed (*Phytolacca* spp.), wild grape (*Vitis* spp.), devil's walking stick (*Aralia* spp.), greenbrier (*Smilax* spp.) (Clapp 1990). Regenerating pine plantations were shown to have the second highest productivity for these species followed by mature pine stands in the aforementioned study. Early succession habitats such as clear cuts provide high densities of berries and may be exploited by congregated bears that display little aggressive behavior (Powell et al. 1997, Rogers 1987). However, females may rely on these and other open and highly productive habitats but may use these areas infrequently due to avoidance of males or humans (Clark et al. 1994, Beckmann and Berger 2003, Jones and Pelton 2003, Mitchell and Powell 2003). The only study that measured mast productivity and habitat use reported that female black bear habitat use frequency was correlated with hard and soft mast productivity except in early succession pine plantations where productivity was high but use was low, presumably from avoidance of males (Clark et al. 1994). Mature pine stands provide an important source of blueberries and squawroot and other spring foods, which grow in acidic soil types early in the year. Generally cypress-tupelo swamp (*Taxodium spp. – Nyssa spp.*), a prominent landscape component in the southeastern USA and central Georgia, provides few food sources to black bears (Hersey et al. 2005), among which are usually a variety of oak species and sweetbay (*Magnolia* spp.) (Allen 1997).

Predicting black bear habitat

A suite of promising techniques can be employed to predict species resource use and occurrence in relation to habitat factors (Strickland and McDonald 2006). With the advancement of Geographical Information Systems (GIS) many species conservation efforts have employed predictive habitat mapping of empirically-based habitat models in their attempts to aid planning for habitat conservation (Coops and Catling 2002). Although it is ideal to evaluate habitat selection parameters in relation to population demographic analyses (eg. Oakleaf et al. 2006, Fahrig and G. Merriam 1985) predictive habitat models based on radio- telemetry can be an important first step to informing habitat conservation (Mitchell and Powell 2003) and further research. Research pertaining to multi-scale habitat selection commonly describes relative habitat importance by ranking habitat use within different scales using multivariate approaches (Aebischer et al. 1993, Johnson 1980) or employs separate regression-based analyses of habitat at different scales which do not fully account for the hierarchical structure of the data (Thomas and Taylor 2006). Information regarding location-level (within-home-range) and home-range-level (within-study-area) habitat have been shown to be important to black bears (Carr et al. 2002, Dobey et al. 2005, Tankersley 1996) and other wildlife (Chamberlain et al. 2003, Mosnier et al. 2003, Thomas and Taylor 2006). However, hierarchical models that account for this multi-level habitat response have not been employed in predictive habitat modeling (Thomas and Taylor 2006). Bayesian hierarchical models are useful for hierarchical predictive analyses that model multivariate species-habitat relationships because such models are robust to deviations from multivariate normality and from assumptions concerning the covariance structure among model levels (Thomas et al. 2006, Link et al. 2002). Data and parameters are modeled as random variables under the Bayesian paradigm and the distribution for model selection criteria can be calculated. As such, an additional benefit to using a Bayesian hierarchical analysis is that sampling and model selection uncertainty can be explicitly modeled and evaluated due to the nature of Bayes theorem, and incorporated directly into cost-benefit analyses for land conservation.

Incorporating Uncertainty with Bayesian Analysis, Markov Chain Monte Carlo (MCMC) and Model Selection

Under Bayes' paradigm inference is expressed in terms of probability about the parameter θ conditioned on the data, comprised for example by a vector $\underline{x}$ of habitat variables. Bayes' Theorem for a habitat use model specifies

$$p(\theta \mid \underline{x}) = \frac{p(\underline{x} \mid \theta) p(\theta)}{\int p(\underline{x} \mid \theta) p(\theta) d(\theta)} \tag{1}$$

the posterior probability of observing θ given a vector of habitat data $\underline{x}$ is equal to the product of the likelihood $P(\underline{x}|\theta)$ and the unconditional prior probability of observing θ, $p(\theta)$ as a ratio of the independent probability of the data within the entire population, termed the normalizing constant in the denominator. The normalizing constant is usually intractable because we do not have complete information and since it is independent, it is possible to drop this term, making the probabilities relative instead of absolute.

$$p(\theta \mid \underline{x}) \propto p(\underline{x} \mid \theta) p(\theta) \tag{2}$$

Posterior distribution forms can be readily sampled via MCMC with the Metropolis Hastings algorithm. A first order Markov Chain of ordered random variables X

$$\{X_s : s \in S\} \tag{3}$$

exhibits properties that allow sampling of the posterior form by exploring its state space *S*, through a stochastic process of 'mild dependency', whereby each state X_s is dependent only on the previous state

$$\Pr(X_{s+1} = x_{s+1} \mid X_t = x_t)\,. \tag{4}$$

Transition between states is regulated via the Metropolis Hastings algorithm, which evaluates transition probabilities via a ratio of the likelihoods of proposed parameter values $q_s(\theta' \mid \theta)\pi(\theta)$ and accepted parameter values, $q_s(\theta \mid \theta')\pi(\theta')$

$$a(\theta', \theta) = \frac{q_s(\theta' \mid \theta)\pi(\theta)}{q_s(\theta \mid \theta')\pi(\theta')}\,; \tag{5}$$

a process termed rejection sampling. Rejection sampling allows for the illumination of the state space and hence the posterior distribution in that every transition is not guaranteed but constrained by the likelihood. As the number of Metropolis Hastings iterations increases the Markov chain converges to an ergodic state or stationary distribution at which point descriptive statistics $\hat{p}(\theta)$ can be derived as follows

$$\hat{p}(\theta) = \frac{1}{n}\sum_{j=i+1}^{i+n} p(\theta_j) \approx p(\theta)\,. \tag{6}$$

Parameter estimates can be updated with additional datasets through the use of an informative prior value in equation 2, and relative posterior model support can be adjusted over time which in turn allows for adaptive decision making (Conroy et al. 2002, Conroy et al. 2005).

Our understanding of ecological processes is almost always incomplete, especially for observational studies, thus model selection based in information theory is essential to account for model misspecification (Akaike 1973), (Akaike 1983). Model selection also avoids the need to conduct exhaustive stepwise analyses in search of statistically significant non-correlated variables as is a common approach in habitat modeling (Rexstad et al. 1988). Model hypotheses under the model selection paradigm should consist of ecologically defensible hypotheses and thus avoid the inclusion of solely statistically significant variables which may or not be of direct ecological importance (Burnham and Anderson 2002).

Justification

Black bear populations in the north and south of Georgia and in many states appear to be increasing (Pelton et al. 1999). Therefore, it may seem premature to begin planning for conservation measures to protect and enhance bear population viability in Georgia. However, human populations will continue to expand, at times rapidly and unpredictably. Georgia's human population, in the Atlanta region, is currently the fourth fastest growing region in the US (US Census Beaurau 2004). Central Georgia experienced an 18% rate of population growth from 1990 to 2000 and human densities in half of the counties within the CGP exceed 150 people per square mile, a threshold above which forest management opportunities cease to exist (USDA Forest Service 2002). Additionally, little information exists concerning the population status of the CGP, which exists mostly on public land. Incomplete planning for future conservation strategies, which leads to an inability to implement conservation measures in a timely manner, is believed to be one of the greatest threats to bear populations (Peyton et al. 1999). Therefore, data gathered for more immediate bear management purposes as reported in this work, can be used for future conservation planning.

Objectives

Objectives of this research on black bears in central Georgia are: 1) to describe the spatial dynamics and movement of bears in relation to human landscape features, 2) to model habitat use for presence-only radiotelemetry data while incorporating telemetry and model selection uncertainties and to validate and map these models, and 3) to gather information on bear diet to enhance space use and habitat analyses.

In order to gain information on CGP bear space use and habitat I posed the following questions.

a) How do bears distribute themselves in the landscape and with regard to each other?
b) How do bears respond to roads and other land uses and do patterns of potential bear-human interactions exist?
c) What food sources are exploited by the CGP?
d) What landscape and habitat variables can predict the presence of black bears in central Georgia?
e) Where does potential habitat exist in central Georgia, along the Altamaha River and leading to southeast Georgia?
f) Where might bear habitat management and conservation actions be targeted?

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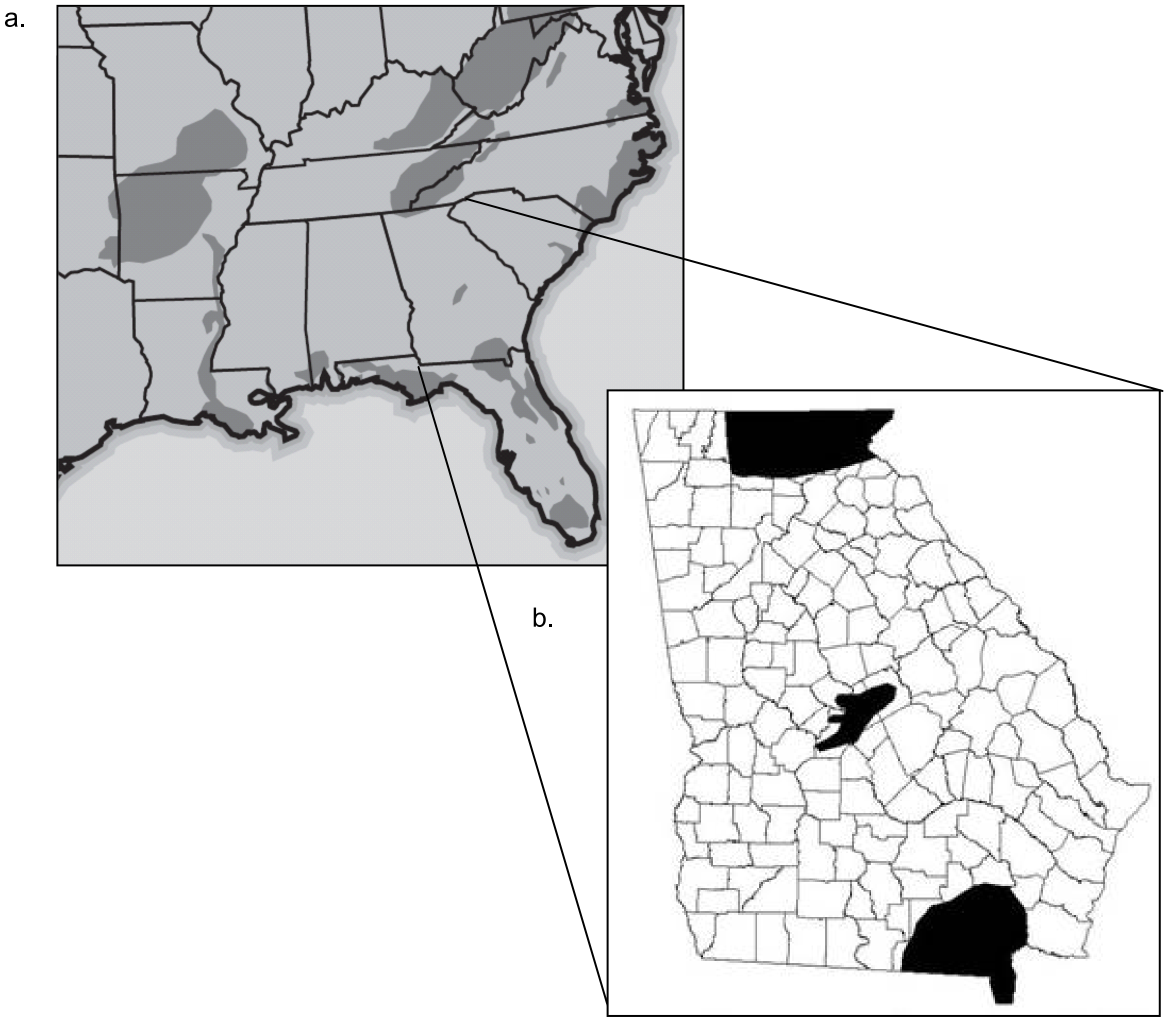

Figure 1.1. a) Distribution of American black bears in the southeastern USA (Pelton et al. 1999), b) Distribution of black bears in Georgia, estimated by frequency of sightings (Carlock et al. 1999). The Central Georgia population ranges over the counties of Houston, Bibb, Pulaski, Bleckley, Twiggs, and Wilkinson. No information exists concerning bear reproduction in the most northeast part of the range in Wilkinson County.

CHAPTER 2

HOME RANGE DYNAMICS, MOVEMENT AND DIET BY BLACK BEARS IN CENTRAL GEORGIA[1]

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Abstract: The central Georgia American black bear (*Ursus americanus*) population (CGP), 1 of 3 bear populations known in Georgia, exists primarily on private land adjacent to the cities of Macon and Warner Robbins. Information regarding home ranges, movement and diet of the CGP were required to inform bear management in the region where land tenure is changing and significant development is planned. Annual home ranges were distributed along the forested Ocmulgee River corridor and tributaries, bordered by agriculture, urban areas, and interstate highways. The mean 95% fixed kernel annual home range size of adult female CGP bears was 14.7 km^2 (95%CI: 9.8 – 19.6 km^2) and was 195.3 km^2 (95%CI: 49.51 – 352.02 km^2) for adult males; which is comparable to other findings from the southeastern USA. Seasonal home range sizes, measured over periods determined by scat analysis, were similar. Male home range sizes for all seasons were larger than those of females (F(1, 51) = 98.9, $\bar{x}_{\text{log diff}} = 1.8$, 95% CI: 1.12 – 2.48). Changes in dominant foods did correspond with shifts in centers of activity for male bears, suggesting that scat information approximated meaningful changes in resource availability. There was a lack of hard mast in scats and 5 of 12 males moved to agricultural areas during the late fall and early winter for 1.5 to 4 months, suggesting high calorie late-fall and winter food sources may have been limited. A location density analysis showed that multiple bears used disperse common areas. Female home ranges were contained almost completely within Wildlife Management Areas where common areas overlapped those of males. These common areas, although their location may change in future years, may be important places to work with landowners regarding bear management. Bears tended to cross high traffic volume highways (>3,000 cars per day) more during shifts in centers of activity and excursions, which were twice as frequent in fall. There was essentially no relationship between a highway crossing and traffic volume and bears crossed highways in proportion to home range highway density.

This suggests temporal avoidance of crossing high-traffic highways by bears but that state highways in the study area, under current conditions, do not pose as barriers. Wild-caught bears were not observed to cross interstate highways and were not observed to venture into high-density residential areas. Two females were captured in and returned to residential areas, suggesting some bears rely on resources in close proximity to people within the CGP range. The emigration path of a female translocated to the study area from Atlanta followed a consistent NE bearing over > 100 miles. Her path did not relate to any particular landscape features but corresponded to the solar declination of sunrise, suggesting that bears can migrate through the landscape from central Georgia NE toward South Carolina. Overall, our results demonstrate that most bears likely avoid high-traffic volume highways and high-density residential areas. Research on reducing mortality due to car collisions and other factors associated with human presence in bear habitat will be vital to management and conservation as people encroach into bear habitat. Areas frequented by multiple bears and agricultural areas adjacent to Wildlife Management Areas can be targeted to identify opportunities for education of and cooperation with landowners, whose actions are of key important to CGP management and conservation in a landscape undergoing increased development.

Key words: American black bear, *Ursus americanus*, home range, movement dynamics, diet, highway response, navigation

Introduction

Understanding regional space use dynamics of wildlife is important to inform management and conservation actions. This is especially true for populations that inhabit areas with significant land use where protected area borders (Woodroffe and Ginsberg 1998) or highly fragmented habitat (Maehr et al. 2003) may act as population sinks. Wildlife spatial dynamics are also shown to be critical to resolving wildlife-human conflicts from vehicle collisions to cattle disease outbreaks (Donnelly et al. 2003, Woodroffe et al. 2005). American black bears (*Ursus americanus*; hereafter, 'black bears') are territorial and have dynamic movement patterns in large home ranges that expose them to mortality risk from human interactions such as vehicle collisions. The potential for negative bear - human interactions, and home range size appear to decrease when sufficient natural resources are available (Rogers 1976, Lindzey 1977, Lindzey et al. 1986, Obbard 2003, Oka et al. 2004). Thus, bear home range and movement dynamics may provide some information on resource conditions and potential human-interaction areas for management consideration.

Black bears adapt their activity and space use to natural and human induced environmental changes, which also affect territoriality. Across the geographic range, black bear home range size is moderately correlated with plant productivity, decreasing slightly in more southerly latitudes of the US (Gompper and Gittleman, 1991) and male bear home ranges are many orders of magnitude greater than those of females (Pelton 1982, Powell et al. 1997). Female space use depends in part on male defense of the most productive habitats (Jonkel and Cowan 1971, Beckman and Berger 2003), and avoidance of aggressive males due to the threat of infanticide (Garshelis and Pelton 1981, Rogers 1987 a, Powell et al. 1997). Home range size is most directly related to habitat condition for female bears, while male bear home range size also depends on access to mates (Kovach & Powell, 2003). Within the population range, home ranges vary in size in relation to the spatial and temporal availability of plant food and mating resources (Rogers 1987 a, Powell et al. 1997, Koehler & Pierce 2003, Dobey et al. 2005). Spatial dynamics have been shown to be affected by roads and particularly highways (Brody and Pelton 1989, Beringer 1990, Percy 2003, McCowen et al. 2004, McCoy 2005). Annual spatial dynamics have been tied to fluctuations in mast productivity (Garshelis and Pelton 1981, Rogers 1987 a, Clark et al. 1994, Dobey et al. 2005, Schooley et al. 1994), agricultural production, (Beausoleil, 1999) and urbanization (Beckmann & Berger 2003, Lyons et al. 2005, MacKenzie 2003). Home range expansion (Dobey et al. 2005) and low home range overlap (Garshelis and Pelton 1981) generally occur in years of poor mast yield and regions with low plant productivity (Powell et al. 1997). Small home range size and low territoriality have been reported for black bears in agricultural areas with high forest fragmentation where agricultural crops provide abundant food (Beausoleil, 1999).

Home ranges in the southeastern USA (Table 2.1.) follow the above trends and tend to be large in regions with dispersed or limited foods such as the Okefenokee Swamp (Dobey et al. 2005). Home ranges can be small and overlapping in areas with typically high food abundance such as that found in the Oak-hickory forests of the Great Smokey Mountains (Garshelis and Pelton 1981, Horner and Powell 1990, Powell et al. 1997) or upland pine habitats adjacent to agricultural foods (Dobey et al. 2005) (Table 2.1). Seasonal home ranges and 50% kernel home range core areas in the southeastern USA also tend to have an inverse relationship to abundance of particular seasonal food types especially for females (Kasbohm et al. 1998). However, seasonal and annual home range size trends do not necessarily coincide due to the temporal abundance and nutritional importance of foods. Seasonal ranges and core areas tend to exhibit a positive correlation suggesting that core areas are tied to seasonal resource availability (Powell et al. 1997).

Black bears are opportunistic foragers that favor foods which are abundant and high in carbohydrates (Kimball et al. 1998), the seasonal availability of which partially drives space use (Clark et al. 1994, Powell et al. 1997). Generally in spring, black bears enter the negative foraging period during which they loose weight (Beeman and Pelton 1977). Spring diets in the Southeast and Interior Highlands, as studied by scat analysis, consist of green plant matter, ants (*Formicidae*), other insects and scarce spring foods such as squaw root (*Conophilis spp.*) and blueberries (*Vaccimium spp.*) (Beeman and Pelton 1977, Clapp 1990, Powell et al. 1997, Landers et al. 1979). In summer, berries and other soft mast such as black berries (*Rubus spp.*), wild plums (*Prunus spp.*) and grapes (*Vitis spp.*) become available and allow for significant weight gain. Fall diets are comprised of hard mast such as acorns and available soft mast, which have equal and high energetic content and are necessary for reproduction and survival (Clapp 1990, Inman et al. 2002, Maehr and Brady 1984, Powell et al. 1997). Corn and other crops are exploited in agricultural landscapes (Landers et al. 1979, Benson and Chamberlain 2006). Mammals, including deer are documented as a rare food source (Powell 1997). However fawns are a common food source in forested landscapes but not in landscapes dominated by agriculture (Vreeland, 2004). Abundance of high nutrient fall food sources are essential to female reproduction (Rogers 1987 a, Elowe and Dodge 1989, Costello et al. 2003, Clark 2004, Dobey et al. 2005).

Den availability can be critical to cub survival and black bear reproductive rate depending on weather driven conditions. Bears using ground dens without sufficient cover tend to exhibit decreased survival and productivity (Johnson and Pelton 1981) due to exposure and flooding. Black bears in the southeastern USA select den sites primarily in large trees (White et a. 2001), or in rock crevices (Clark et al. 1998) when they are available; ground dens dug under slash and downed trees are used in areas of timber harvest (White et al. 2001). Denning chronology in the south differs dramatically from northern latitudes in that males do not den for extended periods due to the extended growing season. Most males are inactive only during extreme weather in the winter (Oli et al. 1997). Females without COY tend to exhibit the same winter activity patterns as males, while females with cubs generally den from December to the end of April (Willey et al. 1996).

Road access to bear habitat and permeability of highways are other important factors to black bear survival. Information on road effects is important to bear management and conservation, due to the abundance of roads in most regions (Clark 1991, Brody and Pelton 1989, Dixon et al. 2006). In Florida over 100 bears are killed every year in traffic collisions (Simek et al. 2005). Road collisions are estimated to take around five percent of the CGP each year (Carlock et al. 1999). Illegal hunting success can increase with road access (Trombulak and Frissell 2000) and bears may avoid traveling near remote and paved roads presumably to avoid being shot (Brody and Pelton 1989, Clark 1991). Evidence suggests that bears cross heavily trafficked roads less frequently, may shift their home ranges to avoid intolerable road densities or may be obligated to cross roads more frequently than they would normally prefer, to access necessary food resources (Brody and Pelton 1989, Berringer et al. 1990, McCowen *et al.* 2004, Simek et al., 2004).

Objectives and Hypotheses

This research is the first study on the spatial dynamics and diet of black bears in central Georgia and was conducted to inform CGP management. Black bear populations remain on 7 –

10% of their historic distribution in the southeastern USA (Maehr 1984, Clark et al 2005) and the CGP is 1 of 3 remaining populations in Georgia (Carlock, 1992). Given the added pressures of a steadily increasing human population and vertical integration by timber companies, driving rapid changes in regional land use, we formed the following research objectives.

1) To evaluate annual and seasonal home range size, home range overlap in relation to sex and season
2) To examine bear movement in relation to highways and other human land use.
3) To enhance analyses by describing CGP bear diet and denning

We made the following predictions about CGP black bear behavior:

a) Bears will distribute themselves along the river corridor and home range core areas will lie primarily within Wildlife Management Areas (WMAs) (> 50% overlap).
b) Annual and seasonal home ranges will be larger for males than females. Overlap among male home ranges will be greater than female range overlap.
c) Bears will venture into agricultural areas during periods of low food availability but bears will not venture into highly populated residential areas.
d) Bears will cross high traffic volume highways less than low traffic volume highways and will do so more during shifts in centers of activity.
e) Bear scats will consist of more vegetation during spring, soft mast during summer and hard mast during fall. Seasonal changes in major food items will coincide with changes in centers of activity.

Additionally we wish to present descriptive results for a small but relevant data set collected on 2 females captured and living in urban areas and for the emigration of one female after translocation to the study area from Atlanta.

Specifically we predict:

1) Females will attempt to return to their previous range or a residential environment.
2) Emigrating females will use connected forest to travel across the landscape and will travel during dark hours of the day.
3) Seasonal and annual home ranges will be smaller for urban-captured females as compared to wild-caught females.
4) High-traffic highway crossings will occur during centers of activity shifts or excursions.

Methods

Study Area

The CGP range, estimated by bear sightings and captures, occurs over approximately 1,200 km^2 (298,751 acres) south and east of Macon, Georgia along and extending from the Ocmulgee River (Figure 2.1). This area includes portions of Bibb, Houston, Pulaski, Twiggs, Laurens and Wilkinson Counties. Average total annual precipitation (1966-2003) for the region is 118.1 cm per yr, average maximum and minimum temperature is 24.8 ^{o}C and 11.4 ^{o}C respectively (Georgia Automated Environmental Network 2006). The region experienced a drought from 1999 to 2002 and recovered the year our study began. The lowest oak mast production in 15 years was measured in 2003 in north Georgia (Georgia Department of Natural Resources 2007).

The landscape of this region contains the second largest wild-land urban interface in Georgia (Radeloff et al. 2005). The western edge of the black bear range borders the cities of Macon and Warner Robins and the towns of Bonaire and Perry. The Ocmulgee River runs from Macon directly south, bisecting the study area. Three multi-lane highways run through the study area. The CGP exists on all but 16,000 Ac. of private land. The privately owned Oaky Woods and Ocmulgee Wildlife Management Areas totaled 51,000 Acres during the study and comprise the only upland forests in the CGP range that are uninhabited by people. These WMAs were managed for even-age commercial pine and hardwood timber harvest until 2004. Specifically, timber stand types in 1999 were comprised of 45% planted pine of more than 5 years of age, 20% of planted pine less than 5 years of age, 30% bottomland hardwoods, and 5% upland pine-hardwood forest (Carlock et al. 1999). Recently the majority of the WMAs were sold to a variety of companies that will manage for timber, but that may also develop up to 50% of the WMA land over time for residential housing and other development (Macon Telegraph 2006).

The region lies along the Fall Line between the Piedmont and the Upper Coastal Plain physiographic regions and the vegetation types in this area are characteristic of both. Forest types fall under the general categories of upland hardwood forests, mixed pine – hardwood forests, bottomland hardwood forest, cypress-gum swamp, and loblolly-shortleaf pine plantations containing clear-cuts, which are the most common landcover type (Carlock et al. 1999). There is limited quantitative information pertaining to the plant communities of the Ocmulgee River. A report to the National Park Service pertaining to the vegetation of the Ocmulgee National Monument site, along the river near Macon describes the above land cover types (Froeschaer 1989). A list of the dominant plant species, which comprise the upland hardwood, mixed pine – hardwood, bottomland hardwood plant communities and pine plantations along the Ocmulgee River of central Georgia, are listed in Appendix A. The previous botanical study is consistent with what was observed on the study site during fieldwork. Mesocarnivores and other large mammal species that were observed on the study site were raccoon (*Procyon lotor*), red fox (*Vulpes vulpes*), grey fox (*Urocyon cinereoargenteus*), bobcat (*Lynx rufus*), coyote (*Canis latrans*), and feral hogs (*Sus scrofa*).

Bear capture techniques

Trapping was conducted from March 14 through August 30 of 2003. Georgia Department of Natural Resources wildlife biologists conducted trapping, tranquilizing and handling of black bears. Twenty-four Fremont foot trap snares (Fremont 1986) were placed in small clearings along logging roads and beside clear-cuts within the WMAs. Trap spacing allowed for four sets of traps per average likely female home range (15 km^2), a general practice in bear trapping (Dobey 2002, Vaughn Pers. Comm 2003). Trap grids were moved after 10 bears were caught, no less than 4 of which were female. However, individual traps that did not show any sign of bear activity after 5 days were moved. Traps were baited with corn hanging from a punctured plastic bag doused with grape Koolaid ®, 16 oz. plastic bottles were hung at traps that contained volatile anise oil. Traps were checked daily from sunrise to 1100. Culvert traps were used to trap nuisance bears within residential areas and these bears were released on Oaky Woods WMA.

Bears were immobilized with a 2:1 mixture of ketamine hydrochloride (Ketaset) and xylazine hydrochloride (Rompun) at a dosage of 4.4 mg/kg of Ketaset and 2.2 mg/kg of Rompun, for estimated body weights. Drugs were administered with a dart gun and additionally with a jab stick if bears remained alert. Moisture drops were applied to bear’s eyes and cloth placed over the eyes to prevent stimulus and irritation from dirt. Bears were weighed with a calibrated spring scale in a mesh net. Females were examined for signs of estrus and nursing if cubs were not present (LeCount 1986). A first premolar tooth was pulled for aging (Willey 1974) and determination of litter frequency for females by cementum annuli analysis of the first premolar tooth (Willey, 1974). A permanent identification code was tattooed inside the upper lip of the bear using animal tattoo ink. Flat metal cattle ear tags with the same code were pierced through the bear's ears. Male bears received tags in the right ear and females in the left. Colored streamers were also pierced through bears ears for sighting ID. Bears were collared with VHF (very high frequency), nylon, colored, MOD 500 radio collars with unique radio frequencies, mortality signal and motion sensors and four male bears received GPS collars (Advanced Telemetry Systems, Asanti MN) with unique signals and a mortality switch. These collars were equipped with a leather spacer to enable breakaway of the collar after approximately one year (Hellgren et al. 1988). Body temperature, pulse, respiration and mucus color were monitored throughout bear processing. Bears were observed until they revived and were able to walk away steadily when disturbed.

Radio-telemetry

Location data were collected by ground radiotelemetry from May 1, 2003 to August 30, 2004 using a 3- element yagi antenna (Advanced Telemetry Systems, Isanti, MN). Only locations collected after one week from capture were used in habitat and home range analyses to allow bears to resume normal behavior after capture and collaring. Telemetry was conducted by vehicle and initial bear signals were obtained by constantly scanning all signals with the receiver and a whip antenna (Advanced Telemetry Systems Asanti, MN).

We attempted to obtain 3 to 4 locations per week on each bear, with more frequent locations for females because they were likely to move shorter distances on average and select habitat at a finer temporal scale. An equal number of locations were generally obtained over the 24-hour diel period and during each season that bears were tracked. We attempted to obtain at least 40 locations per bear per season to estimate accurate seasonal home ranges (Belant and Follmann 2002), however this was not always possible. We considered observations of female location intervals greater than 16 hours as independent because an average female black bear can traverse a home range in 16 hours (Clark 1991) and males were located every other day.

Locations were estimated using the loudest signal method triangulation technique by acquiring the azimuths of the edges of the signal and calculating the midpoint (Springer 1979). Receiver and transmitter locations were recorder in UTM Universal Transverse Mercator using a Garmin GPS 12 (Garmin Ltd., Olathe KS). Attempts were made to decrease location error by obtaining 2 azimuths as close to a 90^o angle intersection as possible at no less that 60^o and no more than 120^o (White and Garrott 1990). Location attempts were made as close to the bear as possible and usually within 1 km, until two or more bearings were taken within 15 minutes of one another.

Home range analysis

We used the Home Range Extension program (Rogers and Carr 1998) to define the 95% and 50% fixed kernel home ranges and core areas due to its superior performance for black bear home range estimation (Olfenbuttel 2005). We adjusted the generic LSCV smoothing factor by increments until there were no buffered isolated single locations included within the 95% fixed kernel and the 50% home range core did not incorporate areas devoid of locations. This later situation may occur when animals use habitat that surrounds an area that is not used and can bias kernel estimates. We estimated Minimum Convex Polygon home ranges with the Animal Movements Extension (Hooge 1999). Home range is defined for the purposes of our research as “that area traversed by the individual in its normal activities of food gathering, mating, and caring for young,” following Burt (1943). We determined sufficient sample size for annual home range estimation using a bootstrap analysis of 100 simulation runs for the MCP home range size plotted against the number of locations used for estimation, beginning with 5 locations and incremented by 1 location. If an asymptote resulted from plotting the number of locations against MCP size then we classified the home range as annual for the purposes of MCP and 95% fixed kernel estimation. We analyzed home range and core overlap area by calculating the area of overlap between adjacent bears (Poole 1995). ArcView 3.2 (ESRI 1998) and ArcGIS 9.1 (ESRI 2001) were used for spatial analyses.

Movement dynamics

We determined areas used by multiple bears with the point density function in Spatial Analyst, ArcGIS 9.1 (ESRI 2001), to convert the each bear's location set to a point density layer and summed location density over multiple bears. We used a window area within which to calculate location density, of a diameter equal to the average male and female daily travel distance of 1.9 km and 1.150 km respectively. The point density layers were then standardized by division of all bear location density layers by the lowest maximum location density. This ensured that the density of locations of multiple bears was not biased by the number of locations for each bear. We used the map calculator, to sum the standardized bear location density layers to pinpoint areas where the most bears were observed most frequently.

We analyzed movement dynamics by the vector dispersal technique (Kenward 2001). Via this method, we classified excursions and shifts in centers of activity as a set of locations that are outside of a 95% confidence interval of sequential movement distance, for a set of locations. The term, 'dispersal' is commonly defined in ecology as a permanent movement from the birth area to the place where mating would occur (Howard 1960). For the purposes of this study this definition does not apply and we used the vector dispersal technique to classify shifts in centers of activity. Centers of activity are a common way of defining changes in animal movement patterns and we follow the definition of Hayne (1949) that centers of activity are, "a twodimensional average of a group of points." The arithmetic center for 3 or more locations (x, y coordinates) is plotted and the 95% CI is buffered around this point. The arithmetic center for the following 3 or more locations is plotted and the vector that connects the 2 centers is plotted. If the perpendicular lines from this vector to the following 3 or more locations are outside the 95% confidence interval then a dispersal event has occurred. If a dispersal event has not occurred then the sample of locations is increased by 1 and the confidence interval is recalculated, and the analysis proceeds. For the purposes of this study we used 6 locations as the criteria to classify a shift in the center of activity, hereafter termed, "an activity center shift" (ACS). Bears often made excursions that consisted of < 6 locations after which the bear returned to the previous range for at least 6 locations. We classified excursions as those locations outside the confidence interval circle, calculated for all locations before an activity shift or if 3 locations along the vector between arithmetic centers were outside of the confidence interval. These later excursive locations were considered outliers and were not included in confidence intervals for determining activity shifts. Bear movement distances were calculated as the straight-line distance between sequential locations. All spatial analyses were conducted using ArcView 3.2 (ESRI 1998) and ARCGIS 9.1 (ESRI 2001).

Diet analysis

Bear scat was collected at bear trap sites and during telemetry research from May 2003 to January 2004 and from April 2004 to December 2004. Bear scat was also collected at some hair and camera trap sites from November 2003 to February 2004 and from April 2004 to October 2004. Scat analysis was achieved by the aggregate percentage by volume method (Martin et al. 1946). Food items were reported by proportion of volume in all scat by season.

Denning

Bears were considered to be denning after three locations, no more than one day apart, were recorded within a distance less than the 95%CI about the mean telemetry error. Denning was considered temporary if directional movements were observed in a 4-week period.

Statistical analyses

Home range analyses

All statistical analyses were conducted in R (R 2006) unless otherwise stated. We used a linear regression analysis to determine the degree of relationship between male and female weight, age and annual 95% fixed kernel home range size for log-transformed data. Analyses were separate for males and females because the relationship between home range size, weight and age has been shown to differ; males have a unimodal relationship, while that of females was shown to be linear (Coley 1995). Three models included an age by weight interaction by home range size, age by home range size and weight by home range size and AIC was used to select the best approximating model for males and females (Akaike, 1973). We analyzed the difference in log-transformed annual home range size between males and females with a Wilcoxon rank sum test and the difference in log-transformed seasonal home range sizes between the sexes with an ANOVA. For analysis of seasonal home range differences we also ran a random effects model to evaluate a random bear effect.

Season determination by scat analysis

We determined cut-off dates for seasonal home range analysis by analysis of changes in bear scat contents using a Markov Chain Monte Carlo simulation of a change point model in PyMC (Fonnesbeck 2005), information on local plant phenology, den duration and extreme bear movements. We analyzed change points for the proportion of major food items (>13% volume) from a dataset for each major food item that consisted of % volume on each sampling day. Each major food item dataset began at the date when scat items appeared and extended to the beginning of the date of occurrence for the next major food item, or began at the end of the previous season and extended to the date when items were no longer detected. The MCMC change point analysis consisted of 80,000 iterations of the Metropolis Hastings Algorithm, a thin of 10 values and a burn-in period of 30,000 iterations. We used the mean dates from the posterior distribution output by the MCMC change point analysis to delineate changes in the proportion of major food types and delineate dates for spring to summer and summer to fall. Plant phenology literature for the region was used to validate changes in bear food items and den duration was used to delineate changes form fall to winter and winter to spring; periods when scat was lacking. For those bears that made dispersal movements between seasons of a distance greater than the 95% CI for movement distance (measured over the entire tracking period), we adjusted the seasonal home range dates to omit these outlying locations.

Movement dynamics

An analysis of seasonal changes in centers of activity was done by conducting a cluster analysis of the number of days to all such shifts for all bears. This was done in R with the Partitioning Around Mediods function, a technique that is more robust than k means clustering (Kaufman and Russeeuw 1990) and the number of clusters used was 5; the number of seasons that were spanned by the data. We compared cluster medians to change points found from scat analysis.

Bear response to highways

We evaluated the relationship between highway crossing frequency and traffic volume with a 2-way non-parametric ANOVA (Gotelli and Ellison 2004). We determined the strength of the relationship by the 95% confidence interval on the slope parameter. We measured the highway crossing frequency as a Highway Crossing Index (HCI), which was the number of highway crossings divided by the total number of bear locations. Traffic volume classes were rounded up and equated to 1, 2, 3, 4, and 5 cars per minute from daily traffic-volume data (GA Dept. Transportation 2004). We determined if the correlation between the HCI and highway density (km / km^2) within the home range differed by traffic volume level. Highway crossings by bears were determined at the intersection of the bear movement vector and the highway.

Results

We obtained 33 captures of 31 bears (20 males, 10 females, 1unknown) from April 2 to August 28, 2003 on and adjacent to the WMAs over a total of 1,413 trap days. The 2 recaptures were male and female adults. Two females were observed with one cub each. Captures were comprised of 26 adult bears (17M:9F), 1 male juvenile and 3 cubs (2M, 1 unknown). Mean weight for adult, wild-caught females was 55.88 kg (SE = 3.13, n=8) and adult, wild-caught male mean weight was 99.43 kg (SE = 8.85, n=16). Mean ages were 7.67 yr (SE = 1.2) and 4.97 yr. (SE = 0.56) for females and males respectively. Nine female and 17 male, wild-caught, bears were radio-collared. Two females captured as nuisance bears in the town of Warner Robbins, and 1 female captured in Atlanta were also radio-tracked. The female captured in Atlanta originated from Gatlinburg Tennessee and had been released at the GA state line to remedy a nuisance situation. Four of the 17 males were fitted with GPS collars and the remainder of radio collars was VHF. Two GPS collars would not remote-release and we could not obtain GPS data for these males. We did not include the VHF locations from 2 of the GPS collared males due to location bias caused by VHF signal malfunction from a broken collar antenna and because the other bear was frequently inaudible and was hit by a car, but not killed, in the middle of the field season.

We collected 3,185 locations on 9 wild-caught females, 3 nuisance females, and 14 wild-caught males that were tracked for periods ranging from 4 to 14 months. We obtained an average of 3.09 locations per female per week during the non-denning period and 2.55 locations per female per week during denning season. We located male bears a mean of 2.36 times per week during non-winter seasons and 2.73 times per week on average during the winter.

Season Delineation and Diet

Blackberries (*Rubus* spp.) and wild plums (*Prunus* spp.) were the major food items detected during the spring and summer. Major food items were determined as those >13% volume which was sufficient occurrence for convergence for the change point analysis. Data were pooled for blackberries because MCMC change point dates of June 7 (22 samples since the first spring scat) were equal for each season and this was the date used for the beginning of summer (95% HPD Interval = 22, 22 sample days, MC error = 0.000, 95% HPD rate parameter = 79.6 - 86.1, 35.9 - 41.1, MC error rate parameter = 0.024, 0.019). The change point date for wild plum between spring and summer was 6/19, 21 sample days from the start of spring scat collection (95% HPD Interval = 16, 21, q50 = 21, MC error 0.033; 95% HPD rate parameter = 0.0 – 5.78, 27.0 – 32.6, MC error rate parameter = 0.034, 0.021). The midpoint date between 6/19 and 6/7, 6/13, was used as the date for the start of summer. September 1 was used as the beginning of fall because scat volume was dominated by persimmon (*Phytolica Americana*) after August 31 ($\bar{x}$ = 99.4, 95% CI: 98.4 – 100%). Regional phonological data shows September 1 as the maturation date for acorns (Duncan 1950, Radford et al. 1968, Little 1976, Mellinger 1984, Duncan and Duncan 1988, Jones and Coile 1988). Winter began for male home range and movement analysis on January 1, when the first male began to den. The spring season for 2004 for males and females that denned for < 1 month was determined as the date when the last male finished denning and began on April 1. Spring began for females after their average movement distance suggested they had finished denning.

Plant material dominated bear scat volume (Figure 2.2). Spring diets consisted predominantly of blackberries (46.5%), followed by wild plums (13.4%), grasses (13%) and 6.3% squawroot (*Conophilis spp.*). The remaining 13 items, each < 5% volume, comprised 21% of scat contents. Summer diets had similar blackberry content; however the next most abundant food was pokeberry (*Phytoacca rigida*) (19.6%), and wild grape (11.9%) with only 6.0% wild plum and 0.2% grass volume. The remaining 19 summer foods comprised 20.4% of scat volume. Fall diets were dominated by persimmon (69%) and 17% pokeberry and were the least diverse with 14% additional foods of 5 types. Acorns (*Quercus* spp.) were detected in only 2 bear scats during fall.

Annual and seasonal home ranges

Home ranges were generally distributed along the forested Ocmulgee River and tributaries with all but one home range occurring within 16 km from the river (Figure . 2.3). Male annual home ranges were larger than those of females ($\bar{x}_{\text{log diff}} = 2.16$, 95% CI: 1.38 -3.19) (Table 2.2). Male seasonal home ranges were larger than those of females but there were no differences within sex among seasonal home range sizes, and there was no interaction between sex and season (F_{sex} (2, 51) = 98.9, $\bar{x}_{\text{log diff}} = 1.8$, 95% CI: 1.12 – 2.48) (Figure .2.4). There was no support for a random bear effect in the model of seasonal differences in home range size. Male home range cores were larger than those of females ($\bar{x}_{\text{log diff}} = 1.84$, 95% CI: 1.2 – 3.23). The proportion of the male annual home range size, comprised by the 50% fixed kernel core home range size was 20.7% on average (95% CI: 16.3 – 25.1%). The female home range core was on average 24.1 % of the annual home range (95% CI: 18.8 – 29.5%). Older bears generally had larger home ranges. Female age and weight (Table 2.3) were weakly correlated (R^2=0.474, β_{weight} = 1.99, 95% CI: 3.74, n = 9). Female annual home range size increased in relation to age (AICc w_i=0.991, R^2 = 0.932, β_{age} = 1.16, 95% CI: 0.560, n = 8) (Figure . 2.5. a.). Male age and weight (Table 2.4) were weakly correlated based on log-transformed data (R^2= 0.416, β_{weight} = 0.972, 95% CI: 1.54, n = 11). Male weight had a weak, positive relationship to annual home range size (AICc w_i= 0.622, R^2 = 0.478, β_{age} = 1.81, 95% CI: 2.84, n = 11) as did age (AICc w_i=0.367, R^2 = 0.425, β_{age} = 1.21, 95% CI: 2.12, n = 9) (Figure . 2.5. b.).

All female home ranges were contained within male home ranges (Table 2.5). There was little overlap among females home range cores and annual home ranges respectively. Average overlap for the 95% fixed kernel home range between individual females and males was higher than overlap among females for home range cores and annual home ranges. Overlap among males was higher than overlap among females.

Annual 50% home range core area overlap with the WMAs was high for females and relatively low for males. Ninety-seven percent of female home range cores were within the Oaky Woods WMA (n = 4) and 74%were within the Ocmulgee WMA 2003 boundary (which is lowered to 50% for the 2007 Ocmulgee WMA boundary). Male 50% annual home range core overlap with Oaky Woods WMA was low at 10% and 26.5% for the Ocmulgee WMA 2003 boundary (17% Ocmulgee WMA 2005 boundary). Areas with a high density of overlapping male locations coincided with areas of high female location density overlap, mainly in the Oaky Woods WMA. Areas used by multiple males were also associated with areas characterized by the presence of wildlife feed plots and stations on hunting club lands, a forest fragment in agricultural field and an orchard on a private farm. Multiple females used common areas generally within the WMA boundaries and directly adjacent to the WMAs (Figure . 2.6).

Movement, Denning and Highway Crossing

Vector dispersal analysis revealed that male bears frequently shifted their center of activity (12 of 13 males) (Figure 2.7), whereas 3 out of 8 females did so. The number of ACS and excursions that occurred in the summer was half that of the fall, for bears tracked in both seasons. Frequency of winter ACS were equal to fall, however activity center areas were 2.2 km^2 on average (95%CI: 0.48 – 3.9 km^2), much smaller than non-winter activity center areas ($\bar{x}$ = 83.2, 95%CI: 30.2 – 136.2 km^2). Twenty percent of ACS were directly preceded or followed by an excursion to or from the next activity center and 41% of excursions were visits to a previous range. Cluster analysis for male ACS revealed cluster medians at the following dates: 8/24, 11/12, 2/3, and 3/31 which correspond to: dates for changes in major scat contents from summer to fall (8/24), and the end of fall and beginning of denning season (11/12, 2/3) and to the end of denning season (3/31). There was do discernable change in male ACS from spring to summer, however. Two females shifted their activity centers during the fall and at the end of spring, and one other female took 4 excursions from mid-fall to the end of April. Each female ACS was preceded and followed by excursions between the respective activity centers. Respective maximum and minimum daily movement distances were 2.76 km (95%CI: 2.11 – 3.41 km, n = 8) and 0.22 km (95%CI: 0.12 – 3.24 km) for females, and 7.78 km (95%CI: 4.46 – 11.1 km, n = 10) and 0.126 km (95%CI: 0.0657 – 0.187 km) for males. Female mean daily movement distance was 1.14 km (95%CI: 0.841 – 1.14 km) and male mean daily movement was slightly higher at 1.86 km (95%CI: 1.44 – 2.28 km).

Wild-caught bears were not located in high-density residential areas (as classified by the Georgia GAP vegetation map). Two male bears were often located in rural low-density residential areas. One male traveled from his home range along a creek that bordered a high-density residential area for a brief period during the spring. Two residents of this area reported common sightings of a female with cubs along this creek. None of the wild-caught bears was detected to cross over the highways into the town of Bonaire, which had a volume of 8810 cars per day (Georgia Department of Transportation 2004). During the late fall and winter, from late November to the end of March, 5 of 13 males shifted their home ranges to agricultural areas for 1.5, 2, 3 and 4 months.

Five males and 2 females crossed state highways and tended to cross high traffic volume (HTV) highways (>3300 cars per day) when making ACS. Only 1 male crossed high-traffic highways during normal movements and 70% of HTV highway crossings by this bear were during activity shifts. One of 2 females crossed HTV highways only during the 1 ACS made. The other female crossed HTV highways during 73% of 7 ACS and excursions. Bears whose 50% kernel home range core bordered the intersection of hwy 87 (2740 cars per day) and hwy. 96 (7000 cars per day) crossed hwy. 87 more by a ratio of 2.35:1 (40 vs. 17 crossings). Bears may cross high traffic volume highways less often than low traffic volume highways, however the Friedman's test coefficient of variation was high and the correlation was weak (DF = 5, CV = 70.7, $R^2 = 0.157$). There was a slight negative relationship between the highway crossing index and traffic volume (θ_{cpm}) and a positive relationship between highway density within the home range (θ_{rdens}) and highway crossing (DF = 36, $\theta_{cpm} = -0.013$, 95%CI: -0.023 - -0.0031; $\theta_{rdens} = 0.203$, 95%CI: 0.032 – 0.374) (Figure 2.8).

With the exception of one crossing and return by a female, bears were not observed to cross the Ocmulgee River north of hwy 96 to the Warner Robins side of the river, where development is greater and the air force base operates. Male bears frequently crossed the river on the south side of the highway between Oaky Woods and Ocmulgee WMAs. 59 crossings of the river above Hawkinsville to hwy 96 by males were observed.

During the winter males and females restricted movements and appeared to den either throughout the winter or periodically. Males denned periodically for 1 week and up to 1 month from the end of January to the end of March 2004 (Figure 2.6). Males denned on average 19 days (95% CI: 11.2 – 26.8) at a stretch. Movements between periodic dens were less than 1.5 km. Seven females denned for 1 month or more from January 1 to the end of April. One of 2 females with cubs in 2003 did not den and the other denned for the shortest denning period of 1 month in February. The mean number of days that females were detected to be denned was 60.4, 95% CI: 34.4 – 86.4. Three females had just 1 den and 3 used 2 different dens. Six of 8 females were observed at dens and all were ground dens in pine plantations, within the 95% kernel home range.

Urban-capture Bears

The 2 females captured in Warner Robins, both left Oaky Woods WMA within 4 days and traveled to residential areas where they eventually remained within home ranges. One female traveled from Oaky Woods WMA along the same general route 3 times to Perry Georgia where she set up a home range. Her summer home range was comprised of a cypress gum swamp between a residential area and a state highway. The other traveled north to an area 2.5 km southeast of her capture location where she remained within a home range in Bonaire, on a cypress gum swamp, within a golf course residential community. Both urban-capture females only crossed high-traffic volume roads during excursions and activity center shifts although one was observed to do so by traveling along creeks under roads and an interstate. One bear shifted her home range during the fall to an area 9km north that contained extensive upland hardwoods and returned for the winter to the previous home range.

The 95% fixed kernel home range sizes for these were 4.05 and 15.07 km^2, with MCP home ranges of 37.8 and 14.56 km^2 and 50% fixed kernel home range core sizes of 0.612 and 2.58 km^2 respectively. The home range of the female that had a home range outside and adjacent to a residential area was within the range of sizes for wild-caught bear, whereas the female the had a home range size of the female within a residential areas was smaller than the range of wild-caught females.

The female bear captured in Atlanta, Georgia and released on Oaky Woods WMA, dispersed from the CGP range 2 days after release. She maintained a mean travel bearing of 51.7^o (95% CI: 32.7 – 70.7^o) over a straight-line distance of 108 km from July 3 to July 24 (7 tracking days), after which her signal was lost. After leaving the WMAs, she maintained the northeast trajectory and did not follow streams, topography or any land feature or vegetation type. Her trajectory matched the bearing of a state highway and major county roads, however these roads were 2 km and 1 km from her path respectively (Figure 2.9).

Discussion

Our study area offered a unique opportunity to observe bear home range distribution and movement in a forested river corridor surrounded by towns and agriculture. The 95% fixed kernel bear home ranges were distributed along the forested river corridor and tributaries bordered by interstates, urban and residential areas and land dominated by agriculture. While the bears tracked did not represent a random sample because trapping only occurred within the relatively remote WMAs and surrounding continuous forest, males traveled long distances outside of the WMAs and thus allowed us to observe space use in the surrounding landscape. Trapping area affected our observed distribution of female home ranges in the landscape, which were more than 10 times smaller than the WMAs, contained the trap of capture and which were contained almost entirely within the 2004 WMA borders.

Results of our research for home range size were similar to many other Southeast US black bear studies. Annual home range size for CGP females were comparable (Table 2.2), except to Florida bear populations in the Okefenokee, Osceola National Forest and Big Cypress Swamp (Table 2.1) for which confidence intervals lied above those found in our study. This finding suggests that productivity of bear foods may have been higher in the CGP than in those areas of Florida dominated by cypress and wet pine flatwoods. Relatively high productivity observed in early successional habitats (Lindzey and Meslow 1986), in regions with high precipitation (Koehler and Pierce 2003) and in regions with more dense food resources (Dobey et al. 2005), or during years of high food availability (Powell et al. 1997), correlates with smaller female home range size. Average annual home range size for female bears in the Okefenokee Swamp, where bear foods are interspersed with open water, were 4.6 times larger (95% CI: 3.6 – 8.3) for females than those of females in the North Georgia Mountains. Home range sizes for females in the region of the Osceola National Forest, adjacent to the Okefenokee, in Florida, where bears have access to agriculture, were 1.84 times less (95% CI: 1.46 – 3.3) than females in the Okefenokee Swamp. These differences were reported to be likely due to habitat productivity (Dobey et al. 2005) although home range size can vary by year. The CGP male home range sizes were most comparable to those of the White River National Wildlife Refuge (WRNWR) and the Ocala National Forest (ONF). The ecological system within which the CGP lies is also most comparable to the WRNWR and the ONF, which lays in the mid-range of productivity, compared to those of the mountains and cypress swamps of the Southeast. However, male home range size is only proximally tied to productivity (Gomper and Gittleman 1991) and is more closely related to access to females (Kovach and Powell 2003). The relatively large mean CGP breeding season male home range size suggests that females may have been widely distributed in the landscape. Male body size has been related to female encounter rates although home range size was lower for large males than medium sized males (Kovach and Powell 2003). Home range size for the largest males had an inverse relationship to habitat diversity and was smaller than that of medium size males at the WRNWR in Arkansas (Smith and Pelton 1990). The two heaviest males in our study had the largest breeding season home range sizes, which may be explained by a wide distribution of females in our study area since the largest males are thought to access the most females and yet maintain relatively low home range sizes in other studies. We do not have definite information about the continuity of female home ranges across the landscape however, since our trapping effort was concentrated within the WMAs, but our data suggest the largest males may have traveled considerable distances to access females.

The percent of the annual home range that was comprised by the 50% annual home range core in our study was 20% to 24% for female and male bears. In a long-term study of spatial dynamics of bears in NC, the home range core comprised 22% of the annual home range (Powell et al. 1997). This suggests that the home range core is most closely tied to resource productivity. Female annual home ranges and core areas were almost completely contained within the Oaky Woods WMA and core areas overlapped only 50% of the current 2007 Ocmulgee WMA boundary. Male annual home range core areas lied primarily outside the WMAs. Therefore under current WMA boundaries and for the bears we followed, the total extent of productive female habitat is potentially provided within the area of Oaky Woods WMA and only half of the productive female habitat is contained in Ocmulgee WMA. Bears may come into increased contact with people and the associated risk of mortality from roads and poaching, in search of productive habitat outside WMA boundaries. Additionally older females that usually have greater reproductive success (Powell et al. 1997) had larger home ranges in our study suggesting they may be at greater risk from mortality due to increased travel across the landscape.

Bear scat contents and movements in the fall suggested a potential low abundance of fall hard mast foods. Although, we did not have any scat data for November, acorns are typically available beginning in September and lasting through the winter, into the spring (Duncan and Duncan 1988, Clapp 1990) and thus we would have detected acorns if they were present. The lowest mast abundance in 15 years occurred in the Georgia mountains (Georgia DNR 2007) during our study. It is unclear what this means for our study area and we do not have information on the mast yield or consumption of water tupelo (*Nyssa aquatica*) present along the Ocmulgee River. The majority of scat was collected from upland habitats and we detected no water tupelo in scats. There is a possibility that should be investigated that water tupelo is not exploited as a food source by bears. It is not reported as a bear food item, produces 7 times less mast volume (Stiles 1980) and cypress-tuplelo was found to contain few hard or soft mast producing species in the Mobile- Tensaw Delta (Hersey et al. 2005). Bears may have consumed more vertebrates as a source of fall nutrition. We also found evidence for a bias due to the effect of digestibility and mass on % volume. Vertebrates comprised < 3% scat volume but were detected in more than trace amounts in 25% of the number of scats containing soft mast seeds. Bears have been shown to be seed dispersers for many soft mast species that they select and few if any soft mast seeds are completely digested (Auger et al. 2002) and thus may dominate scat contents.

Bear home ranges and movement dynamics suggest that bears increased efforts to find foods in the fall. There was no clear difference in male or female seasonal home range size, however, fall female home range size variation and mean size were high. Five of 8 females expanded their annual home range borders by 4 to 38 km^2 and 2 made excursions, exhibited changes in ACS and crossed HTV highways during the fall, indicating an increase in efforts to find food. In addition, territoriality among females was high since home range core areas did not overlap more than 3% and on average 77% of each annual range was not observed to be shared with another female. Males also exhibited an increase in ACS between summer and fall. During years of poor fall hard mast yield, adaptive exploitation of soft mast abundance and non-natural food sources can be critical to black bear reproduction (Rogers 1987 a, Eiler 1989, Kasbohm 1996). These factors can affect home range dynamics (Kasbohm et al. 1998, Dobey et al. 2005) and may correspond to an increase in excursions to areas with alternative fall foods (Kasbohm et al. 1994). It appears there were sufficient food sources during our study, however, to allow for reproduction.

Bears appeared to use the same widely dispersed areas across the landscape (Figure 2.6). Dominant land use types for these areas were hunting clubs with feeding stations and plots, a forest fragment in an agricultural field, and an orchard on a private farm. Males that were located on hunting club land were sometimes located near or observed at wildlife feeders or winter wheat food plots. A hunting club where bears were located presented over 100 photos taken over 2 years of bears feeding at wildlife feeders. Feeding stations (Fersterer et al. 2001), early successional habitats with abundant berries (Rogers 1987 a) and agriculture (Beausoleil

1999) have been shown to attract and to concentrate bears. Bears are known to share and use areas more intensely that contain high-density food resources such as clear cuts (Rogers 1987 a, Sampson and Huot 2001) and garbage dumps (Pelchat and Ruff 1982,). We found that females were present in many of the common areas used by multiple males and so access to females may have been a resource that was sought.

This study was enhanced by analysis of scat contents to inform home range and movement analysis. The correspondence of male ACS with shifts in major fall food items suggests that changes in major food items were correlated with movement dynamics, despite the lack of difference in male seasonal range sizes. Median dates from cluster analysis of ACS did coincide with change point dates from scat analyses for the summer to fall, fall to winter denning season and the spring of 2004. There was an additional median ACS cluster date during mid-November when males moved to agricultural areas and 2 that had used hunting lease areas left these lands when hunting season feeding is illegal, supporting the hypothesis and speculation of apparent food availability declines in late fall after persimmon was no longer available. This suggests that home range size analysis alone may be insufficient for inference about spatial dynamics for CGP black bears. Bear crossings of HTV highways corresponded to ACS and thus roads appear to be tolerated by bears while also presenting an obstacle to obtaining resources.

There were marked differences and similarities between scat analysis results from our study and those over the Southeast US and Interior Highlands. Bears are shown to exploit high nutrient, abundant foods as they become available and major changes in diet occur between seasons (Landers et al. 1979, Clapp 1990, Kimball et al. 1998). In the Interior Highlands of Arkansas, a region with some similar habitat to the CGP scat contents were most similar to those found in our study. Spring foods were limited and included ants ,insect larvae, blueberries

(*Vaccinium* spp.), grasses, forbs and buds in Arkansas (Clapp 1990). We detected these foods with the exception of blueberries, which were found in only one scat, although they were observed regularly in pine plantations. Blueberries had the shortest availability period of any of the bear foods in Arkansas (Clapp 1990) and thus we may not have collected scat at a fine enough time scale to observe foods that had limited availability. Another important spring food in the Appalachian Mountains, squawroot (*Conopholis americana*) (Powell et al. 1997), may have had limited availability to bears in the CGP. We found squawroot in only one scat, although high squawroot abundance was observed during a visit with a landowner to an area, which had abundant squawroot, and bear scat sign containing it. Therefore squawroot may be a localized and important spring food source for CGP bears. We did not collect scat in early spring when bears are known to feed mostly on vegetation and on hard and soft mast left from the previous fall (Carlock et al. 1983). Blackberries were dominant from mid to late spring in the study area, likely a product of the longer growing season. Dominance of blackberries continued in summer toward the end of which wild grapes and pokeberry were more frequent in scat. A variety of berries and fruits were reported in high volume in summer scat in Arkansas such as blackberry (Rubus spp.), blueberry (Vaccinium spp.), Cherry (Prunus spp.) and wild grape (Vitis spp.) (Clapp 1990). While in the north Georgia mountains American cancer root (*Conopholis Americana*) dominated summer scats (Carlock et al. 1983). Acorns and nuts dominated scats in fall and early winter in Arkansas and other regions of the southeastern USA (Eagle and Pelton 1980, Pelton 1982, Carlock et al. 1983, Clapp 1990), but were virtually absent from scats in our study area. However, persimmon in addition to late fall foods such as pokeberry may have been a sufficient replacement for necessary nutrition as evidenced by reproduction of females. Other studies have reported consumption of persimmon, but not its dominance in fall foods (Clapp 1990, Clark 1987). Therefore, this may have indicated a lack of fall hard mast. Black bears are known to switch to soft mast food sources during years of poor mast yield (Kasbohm et al. 1995).

Denning trends were similar to those documented in other regions of the southeastern USA (Oli et al. 1997) where food is available throughout the prolonged growing season. During the breeding season there was extensive overlap of male and female home ranges. However, during the denning season, only 2 female denning areas overlapped with male winter ranges, which were east and southeast of female denning areas. Should habitat decrease or fragmentation increase it may follow that male and female winter ranges and denning areas become more condensed. Most of the female dens were found on the ground and males were active throughout the winter. In Florida those females that lived and denned in a suburban area on the edge of the ONF exhibited anthropogenic and infanticide induced cub mortality rates which suggested a lower chance of persistence without access to a source population (Garrison 2004). Also in one of the most fragmented black bear populations in the USA that in the Chasowitzka National Forest in West Florida, has not exhibited recruitment in over 8 years, which is hypothesized to be due to high infanticide due to high bear encounter rates (Maehr et al. 2003). Therefore spatial dynamics and denning locations of CGP males and females should be monitored occasionally.

Highway avoidance was documented to some extent for males in our study, but it appears that current state highway traffic volume is below a threshold of definitive avoidance by males or females. However Interstates may pose an obstacle, since wild-capture bears were not observed to cross them. In Florida traffic volume of 15,000-16,500 cars per day was shown to act as a barrier to bear movement (McCown et al. 2004), and a highway bisected genetically 2 distinct populations (Dixon et al. 2006). The highest traffic volume on state highways in our study area was 7,675 – 8,810 cars per day. Overall the HCI increased with highway density (Figure 2.8), and there was only a slightly negative relationship to traffic volume. This could be a result of the small sample of bears we followed or due to the lack of a traffic volume threshold. Thus an effect of traffic volume on crossing frequency should not be discounted completely. Crossing frequency for highways with 2 cars per minute (cpm) was higher than that for highways with 3, 4 and 5 cpm and crossing frequency for highways with 1 cpm was the lowest; a potential arbitrary effect due to the distribution of highways in the study area. Males also showed a tendency to cross high traffic volume highways (>3,000 cars per day) during ACS only, which demonstrates a degree of avoidance. Fall was the season when more traffic induced mortality occurred for females in NC (Warburton et al. 1993) and all bears in FL (Simek et al. 2005). In our study the 2 females that crossed a highway did so in the fall when they expanded their home ranges which suggests that fall road kills may be an important factor to female mortality in the CGP.

The release of urban-captured females on our study area allowed us to observe bear travel behavior through a landscape with significant land use and fragmentation. Information on bear dispersal is very rare in the literature and aids in habitat corridor planning, a management concern for the CGP. Bear 15 emigrated across the landscape for over 100 miles that she had not previously explored at a consistent bearing of 51^{o}, similar to that derived from the solar declination for sunrise at that time of year in central Georgia of 67^{o}. This suggests that she used path integration, the ability to orient by general locomotion direction, to navigate in addition to the general direction of sunrise. Navigation mechanisms are not known for black bears. Black bears have been reported to disperse for distances of up to 80 km and during these events use ridgelines and remain within forest (Lee and Vaughan 2003). Male black bears have emigrated for distances of up to 507 km in as little as 1 month and over a consistent westerly bearing (Startman et al. 2001), which supports the use of path integration and the sun. Bears that were translocated can successfully home from distances as far as 229 km (Rogers 1987 b) and polar bears exhibit long distance circannual migration to and from the same seasonal ranges (Mauritzen et al. 2001). Bears have poor eyesight and thus navigation by stars may be unlikely. Bear 18 may have used landscape features in order to navigate or as cover. She was located along creeks during travel events. However, she was tracked continuously on only one occasion during a long-range movement and at that time she used a narrow fence line of trees beside a poultry factory to make her way partially across the landscape. Bear 15 also used fragmented forest, thus it appears that bears in the CGP range may be tolerant of disturbed habitat while traveling.

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Table 2.1. Annual home range sizes (km^2) for adult black bears (*Ursus americanus*) in the southeastern USA.

Habitat	Study Area	Sex	Estimator (software)	Mean Home Range Size in km^2 (SE) & (Range)	n	Mean age	n	Mean Weight (kg)	n	Author(s)
Mountainous terrain, Mountainous terrain, mixed pine-hardwood forest, oak forest	Smoky Mnt. Nat'l Park (NC)	F	MCP (by hand)	8 (2 – 23)	23					Garshelis & Pelton 1981
		M		21 (13 – 28)	8					
	Pisgah Bear Sanctuary (NC)	F	95% kernel (simulation)	16.9 (11.7)	38			39 - 61	40	Powell et al. 1997
		M		44.1 (27.6)	43			52 - 176	33	
	North Georgia Mountains	F	MCP	12	38					Carlock et al. 1983
		M		75	20					

Table 2.1. Continued.

Habitat	Study Area	Sex	Estimator (software)	Mean Home Range Size (SE) & (Range)	n	Mean age	n	Mean Weight (kg)	n	Author(s)
Forested wetlands	White River NWR (AR)	F	MCP (TELEM)	12 (7 – 22)	6	4 - 12				Smith and Pelton 1989
		M		116 (39 – 266)	6	5 – 9				
Forested wetland, oak, pine, pine flatwoods, suburban, sand pine	Ocala NF, (FL)$_e$	F	MCP (TELEM)	25 (4)	7					Wooding and Hardinsky 1994
		M		135 (16.8)	7					
	Ocala NF, (FL)$_e$	F	95% fixed kernel, (AME)	20.48 (17.04 – 26.25)	23	4.8	40	146.2(lbs)	40	McCown et al. 2004
		M		94.3 (87.29-159.89)	7	4.4	86	224.4	86	

Table 2.1. Continued.

Habitat	Study Area	Sex	Estimator (software)	Mean Home Range Size (SE) & (Range)	n	Mean age	n	Mean Weight (kg)	n	Author(s)
Cypress swamps, forested wetlands, pine, open wetlands	Okefenokee NWR (GA)e	F	95% fixed kernel, (AME)	55.9 (6.96)	69	4.5 (0.33) 1 - 10	49	53.3 (2)	32	Dobey et al. 2005
		M		336.7 (95.6)	7	3.3 (0.25) 1 - 10	75	103.3 (5.62)	28	
Cypress swamps, forested wetlands, pine, hunting clubs, pine flatwoods, mixed pine-hardwoods	Osceola NF (FL)e	F		30.3 (4.0)	53	3.4 (0.45) 1 - 10	30	64.6 (4.67)	10	Dobey et al. 2005
		M		Nd		3.2 (0.36) 1 - 13	48	138.5 (6.82)	14	

Table 2.1. Continued.

Habitat	Study Area	Sex	Estimator (software)	Mean Home Range Size (SE) & (Range)	n	Mean age	n	Mean Weight (kg)	n	Author(s)
Cypress swamp, forested wetland, hardwood hammocks, pine flatwoods, open wetlands	Big Cypress Nat'l Preserve	F	MCP	57.1	19	4.1				Land 1994
		M		303.2	32	4.4				

* AME - Animal Movements Extension (Hooge et al. 1999), (e) = exploited population, hunting allowed

Table 2.2. Annual and seasonal home range sizes (km^2) for adult American black bears in central Georgia, USA, from May 2003 to August 2004. Estimates are based on a 95% fixed kernel unless stated otherwise.

	Annual	Annual 50% fixed kernel	Annual (100% MCP)	Spring	Summer	Fall	Winter
Females (n)	14.7 (7)	3.2 (7)	21.4 (7), 12.3 (5)*	7.5 (8)	7.1 (8)	14.7 (9)	
95%CI	9.8 – 19.6	2.15 – 4.28	3.27 – 39.5, 8.46 – 16.1*	2.3 – 12.7	2.2 – 12.0	5.1 – 24.3	
Males (n)	195.3, (10) 138.9* (8)	39.3, 23.1* (10)	200.8 (10), 162.4* (8)	40.7 (10), 35.1* (8)	56.1(12), 48.0* (10)	89.9, 77.6* (9)	35.9, 35.7*(9)
95%CI	49.5 – 352.0, 76.9 - 313.7*	16.4 - 62.2, 11.5 – 82.1*	106.5 – 294.9, 68.1 – 223.1*	-3.2 – 84.6, 25.5 – 48.8*	12.2 – 100, 25.1 – 94.77*	36.6 – 143.2, 38.6 – 143.7*	-5.1 – 76.9, 15.2 – 82.3*
Ratio M:F	9.4:1	7.22:1	11.6:1	4.68:1	6.76:1	5.27:1	

*Non-normal distribution, summary statistics are based on a two-value trimmed mean.

Table 2.3. Individual home range sizes (km^2), weight, age and reproductive history for female American black bears captured from April to August 2003 on Oaky Woods and Ocmulgee Wildlife Management Areas in central Georgia, USA and radio-tracked from May 2003 to August 2004.

Bear	Capture date	Censor	Locations	Weight (kg)	Age (Yr.)	Reproductive history	MCP home range	95% Fixed kernel	50% Fixed kernel home range core
8	5/29/03	7/19/04	164	53.5	8	5, potentially 7	10.6	11.9	2.8
9	5/30/03	10/13/03	65	40.8	3	nd	3.4	4.0	1.1
13	6/25/03		175	61.2	4	nd	7.3	6.2	1.5
16	7/7/03		183	52.1	7	5	15.7	11.0	2.5
20	7/16/03		168	63.4	11	4, 6, 8, 10	15.6	19.0	5.1
25	8/14/03		160	45.3	7	7	6.6	10.1	3.2
26	8/20/03		145	70.7	14	14	18.0	20.5	5.5
27	8/26/03		151	61.2	10	4, other years not clear	76.0	24.3	3.2
28	8/28/03	6/23/04	118	54.4	5	nd	6.2	7.2	1.9

Table 2.4. Individual home range sizes (km^2), weight and age of male American black bears captured in August 2003 on Oaky Woods and Ocmulgee Wildlife Management Areas in central Georgia, USA and radio-tracked by VHF and GPS signal from May 2003 to August 2004.

Males	Capture date	Censor	Locations	Weight (kg)	Age (yr.)	MCP home range (km^2)	95% Fixed kernel	50% Fixed kernel home range core
1	4/2/03	8/1/03	37	135.9	4 or 5	33.2	56.51	12.59
2 (GPS)	4/3/03	9/11/03	288	135.9	5	54.91	111.94	16.13
3 (GPS)	4/16/03	Release fail, VHF signal malfunction		99.7	4		Nd	nd
4 (GPS)	4/17/03	10/30/03	414	115.5	6	139.18	218.1	52.9
5	4/18/03	7/15/04	168	73.4	4	118.6	86.29	11.73
6	4/24/03	4/11/04	124	86.1	5	109.6	154.3	39.5
7	5/21/03	6/1/04	134	176.7	7	408.8	381.6	89.5
10 (GPS)	6/10/03	Release fail, location bias		65.7	3		Nd	nd

Table 2.4. Continued.

Males	Capture date	Censor	Locations	Weight (kg)	Age (yr.)	MCP home range (km^2)	95% Fixed kernel	50% Fixed kernel home range core
11	6/14/03	7/20/03	nd	155.0	6		Nd	nd
12	6/13/03	9/15/03-11/1/03, 5/1/04	100	125.0	11	513.8	657.60	118.42
14	6/27/03		136	104.6	3	226.2	212.6	46.6
17	7/8/03	3/18/04	93	79.3	3	128.2	149.3	34.7
19	7/15/03	5/16/04	103	39.4	2	40.7	32.8	4.0
21	7/17/03		151	86.1	3	205.3	75.5	16.9
22	7/18/03		156	88.4	4	39.3	36.0	9.0
23	7/29/03		124	102.8	5	60.8	44.0	11.5
24	7/31/03	6/1/04	105	90.6	9	197.6	155.8	15.2

Table 2.5. Mean home range overlap between American black bears in central Georgia, USA based on data collected during May 2003 – August 2004. Core area is the 50% fixed kernel annual home range core and home range is the 95% fixed kernel annual home range and the 95% confidence interval is in parentheses.

	Individual females		Individual males	
Overlap with other bears	Core area	Home range	Core area	Home range
Any one male	0.5 (0.264 - 0.73)	0.66 (0.432 - 0.891)	0.2 (0.06 - 0.34)	0.297 (0.242 - 0.352)
Any one female	0.034 (-0.01 - 0.087)	0.156 (0.041 - 0.271)	0.04 (0 - 0.08)	0.068 (0.031 - 0.105)
All other males	0.594 (0.322 - 0.866)	1	0.39 (0.21 - 0.57)	0.845 (0.69 - 0.99)
All other females	overlap only among 2 bears	0.331 (0.039 - 0.623)	0.041 (0.032 - 0.114)	0.182 (0.137 - 0.227)

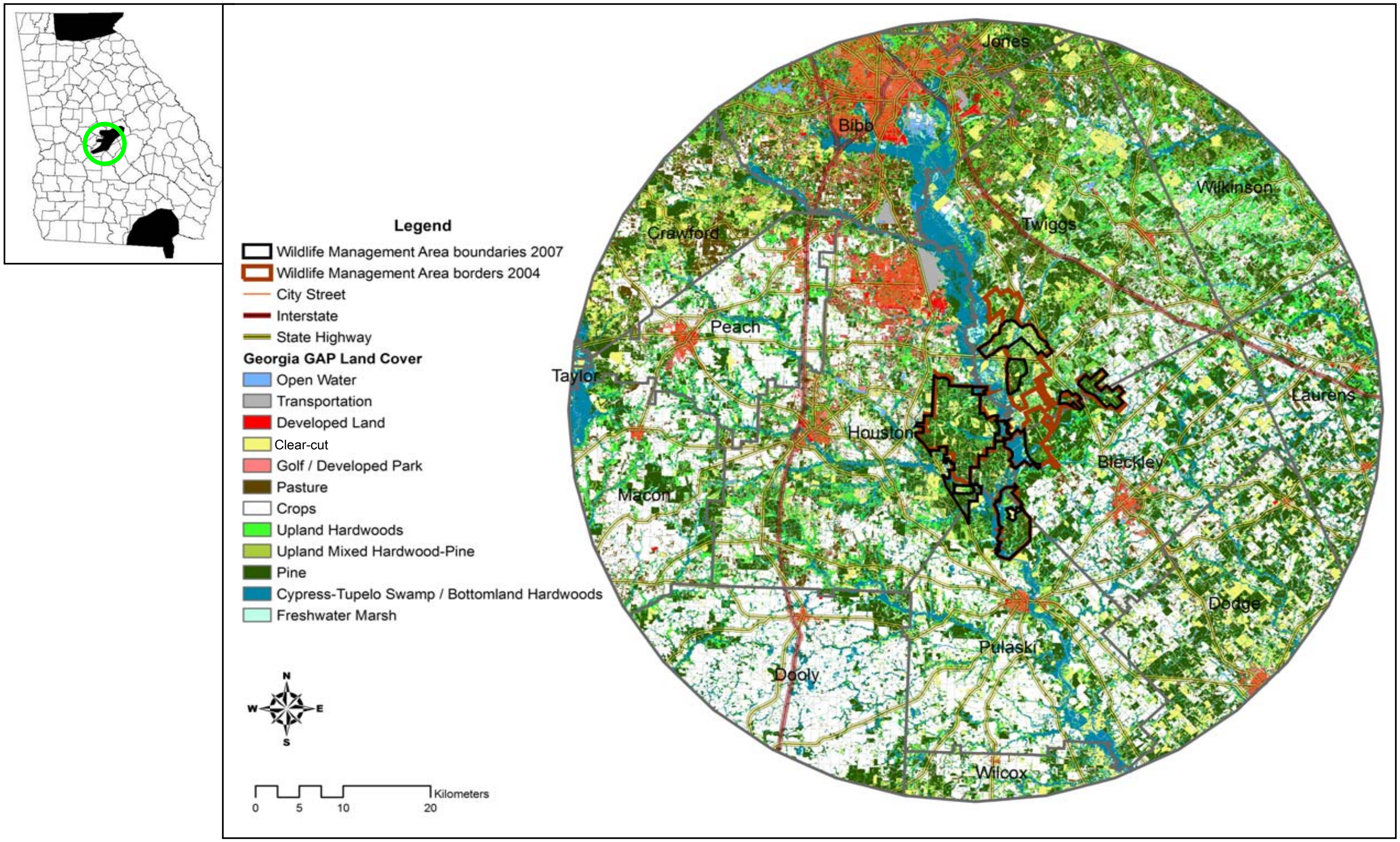

Figure 2.1. a.) Current American black bear distribution in Georgia, USA (Carlock et al. 1999). The central population estimated range is 1,200 km^2 b.) Study area (6,700km^2) with a radius of the length of the longest bear home range. Cities and towns in numbered order are Macon, Warner Robins, Bonaire, Perry, Hawkinsville and Cochran.

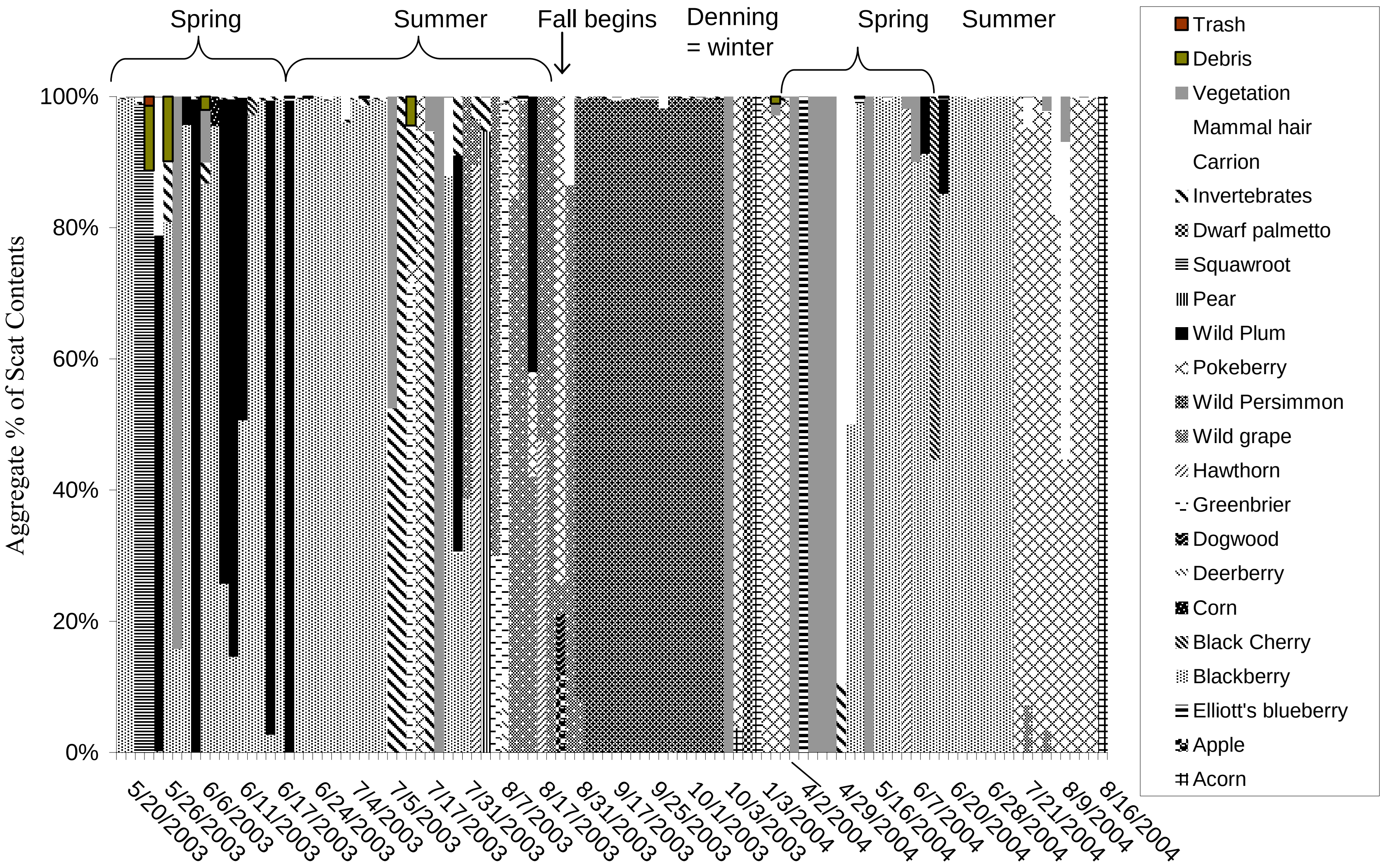

Figure 2.2. Graphical analysis and cut-off dates for seasonal analyses from American black bear scat and change point analysis. Data was collected from May 2003 to August 2004 in central Georgia, USA.

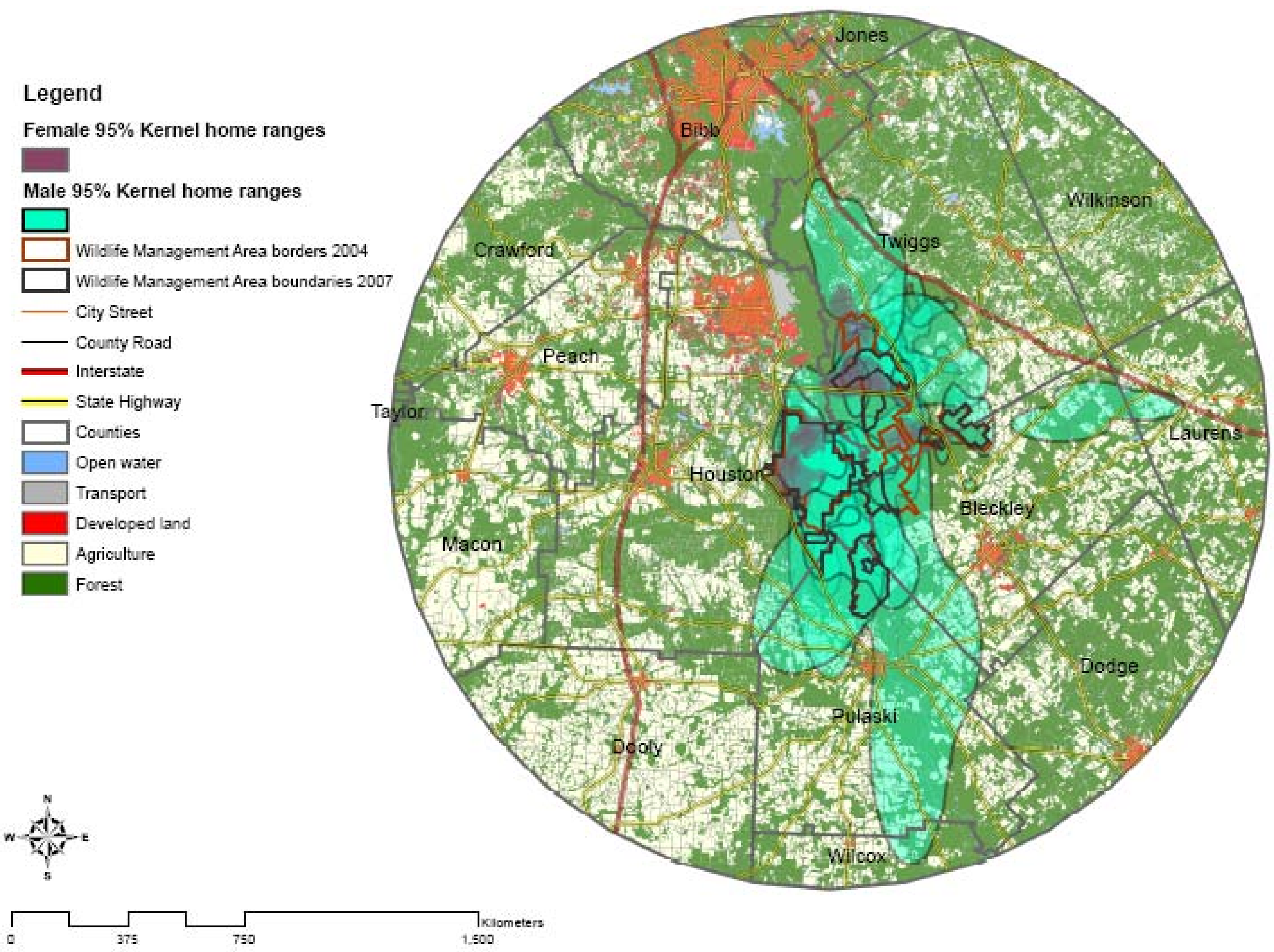

Figure 2.3. Annual and seasonal home range sizes (km^2) for adult American black bears in central Georgia, USA, from May 2003 to August 2004. Estimates are based on a 95% fixed kernel unless stated otherwise.

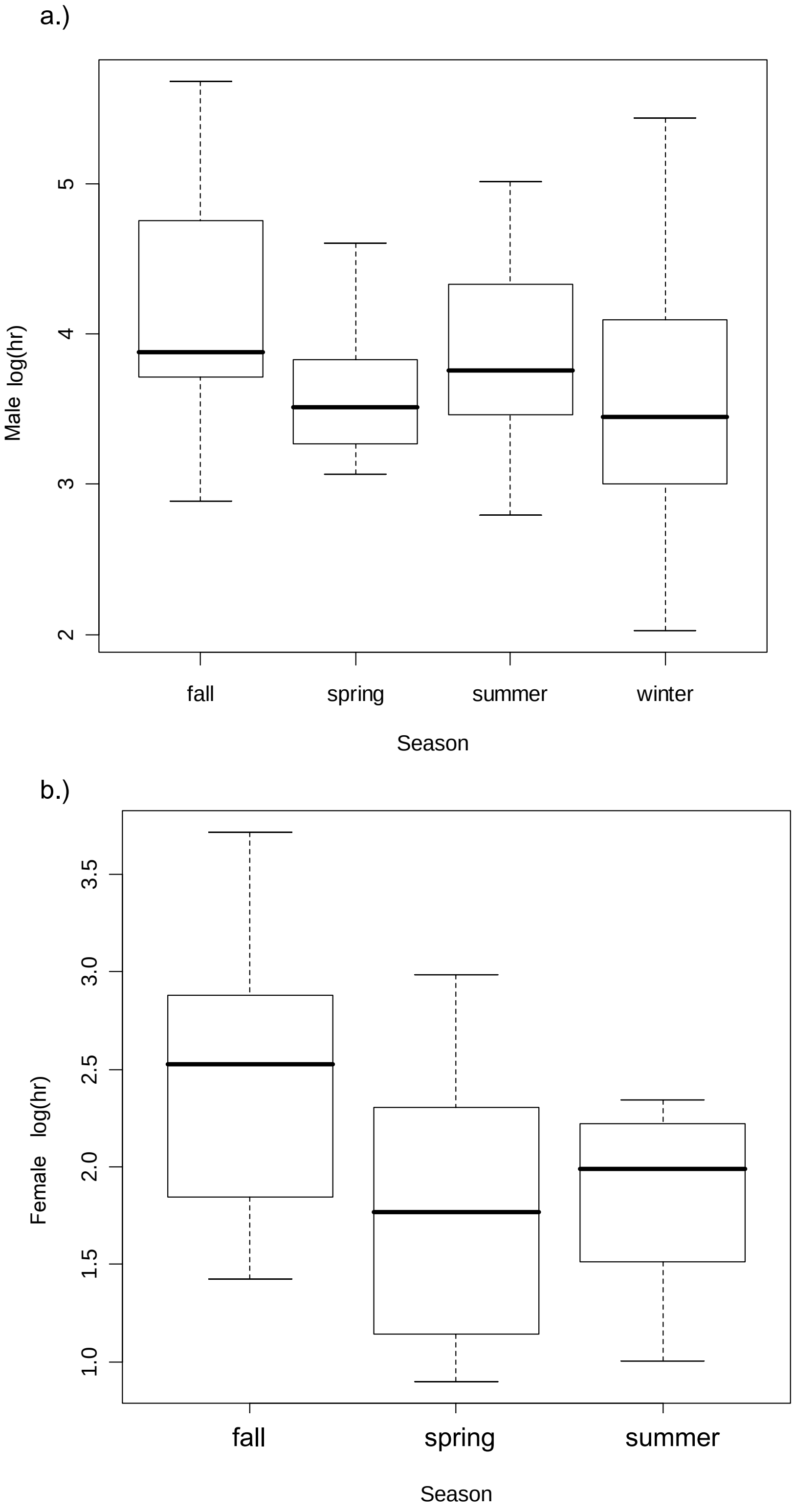

Figure 2.4. Male (a.) and female (b.) American black bear log home range size (log(hr)) and variation by season in central Georgia, 2003-2004.

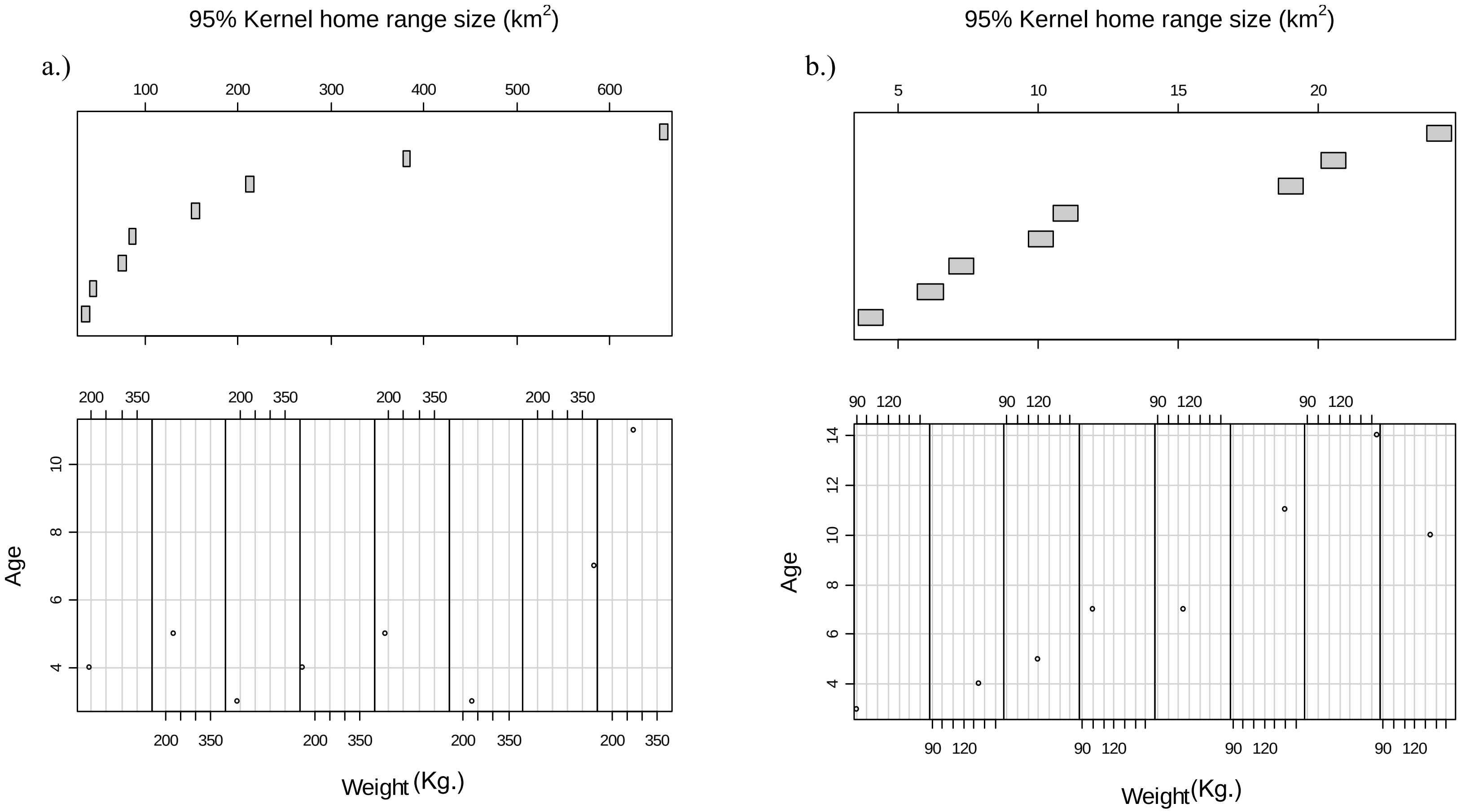

Figure 2.5. Age (yr.) and weight of male (a.) and female (b.) American black bears in central Georgia related to annual home range size, May 2003 to August 2005 (n=8).

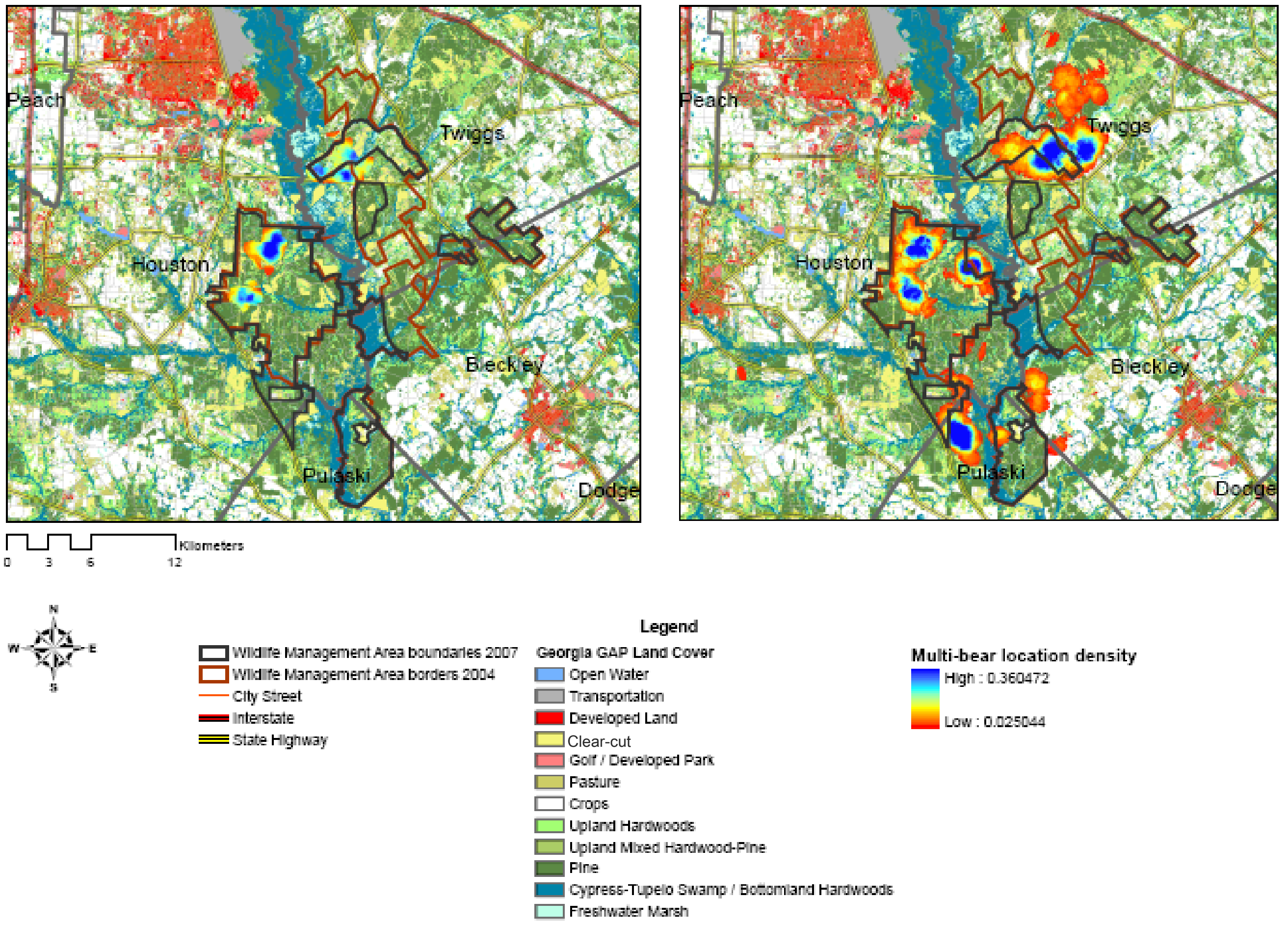

Figure 2.6. Overlap of locations for multiple female (a.) and male (b.) American black bears in central Georgia, 2003-2004. Location density for each bear was measured within a window size equal to the average female and male home range core. These density grids were then standardized and added to form a grid that shows where multiple bears had the greatest density of locations.

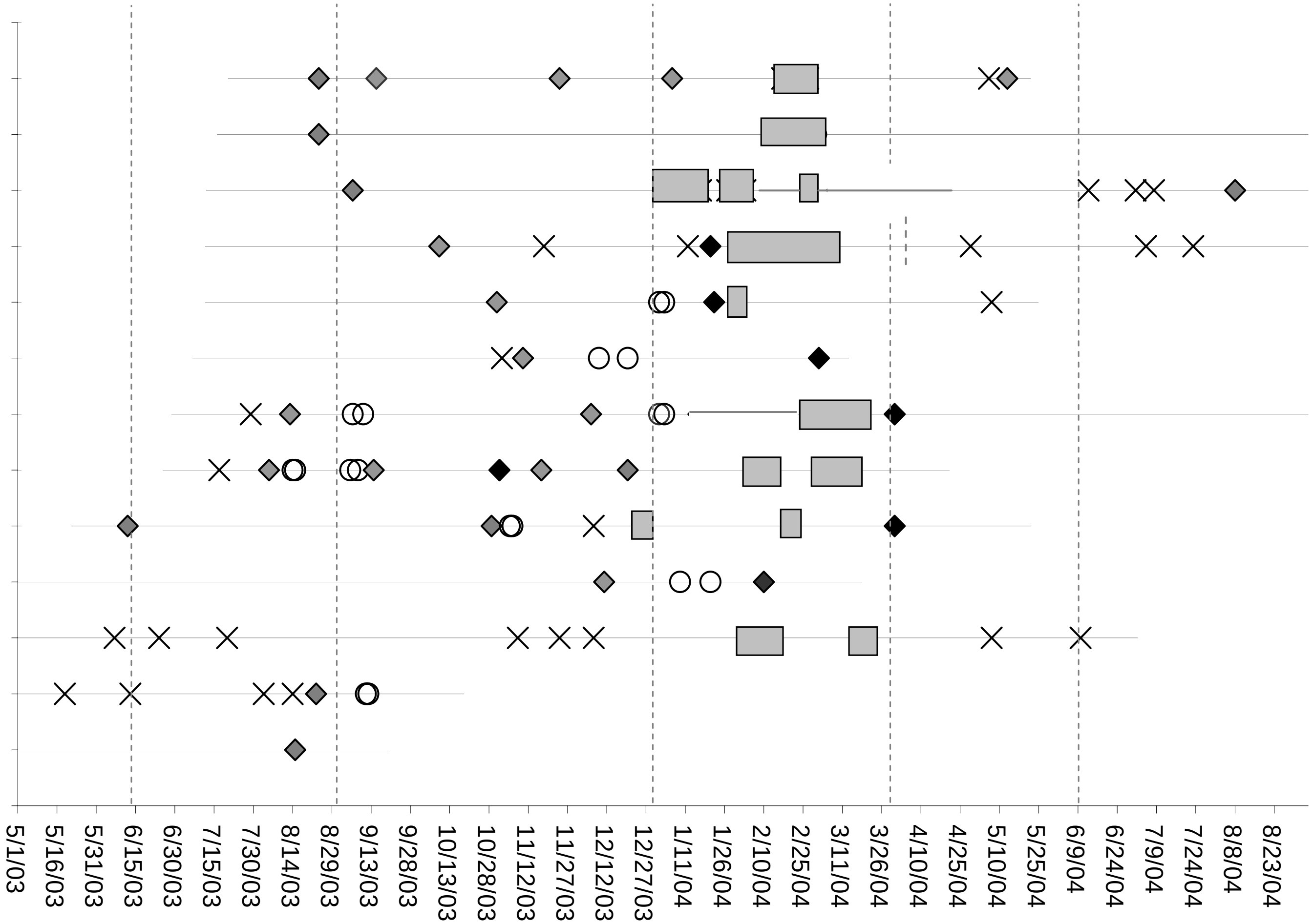

Figure. 2.7. Time line of excursions (x,○), activity center shifts (◆,◆) (ACS), and denning periods (▭) for male American black bears in central Georgia, USA May 2003 – August 2004. The line that represents each bear has a length equal to the period that they were tracked. Open circle excursion symbols signify a return to the previous range and black diamonds signify an activity shift back to a previous activity center. Dashed lines represent seasons used in home range analyses delineated by scat analysis and by denning period.

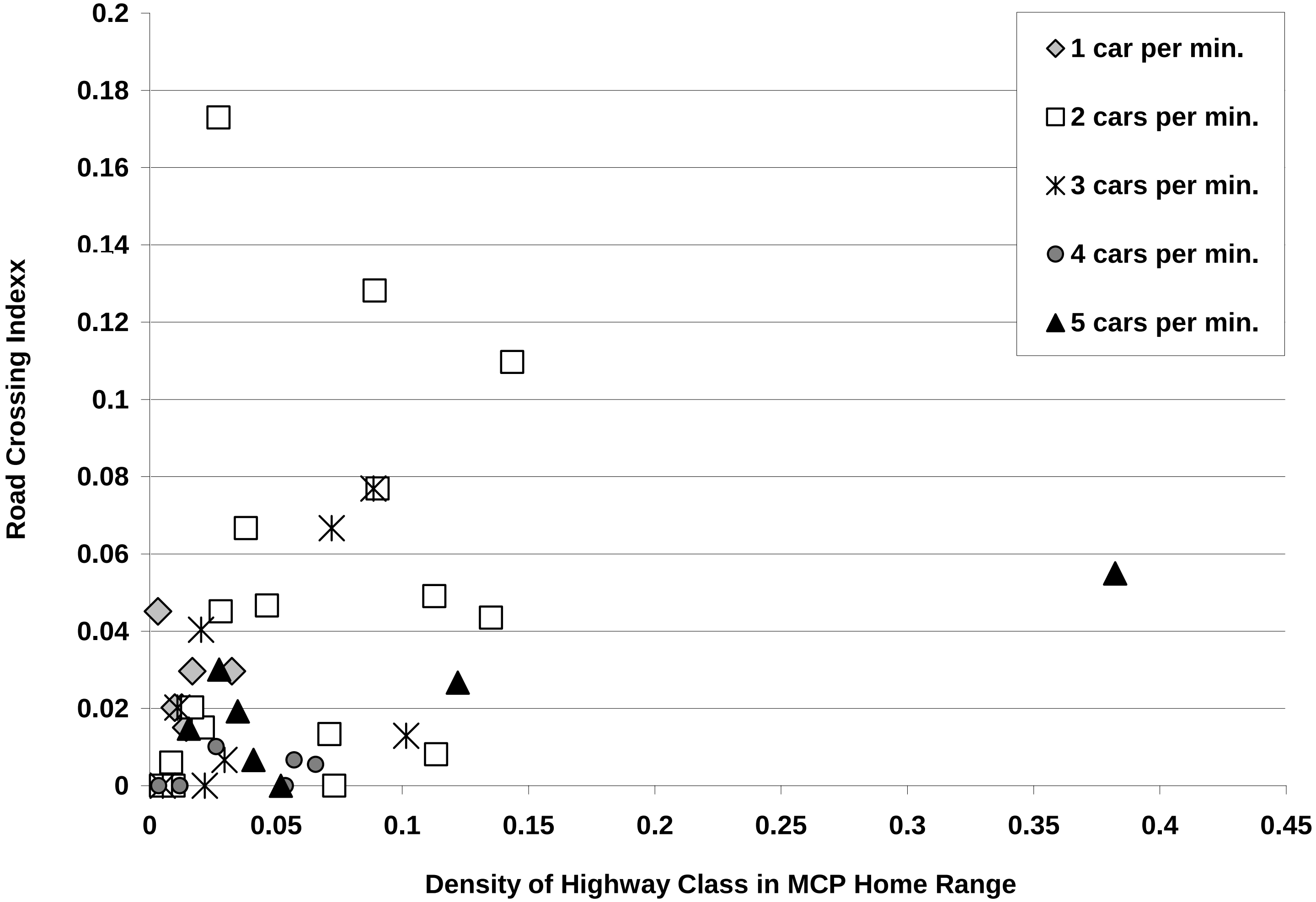

Figure 2.8. Road Crossing Index (RCI: # crossings/ total locations) of American black bears in central Georgia, USA by density of highway in the MCP home range and traffic volume class.

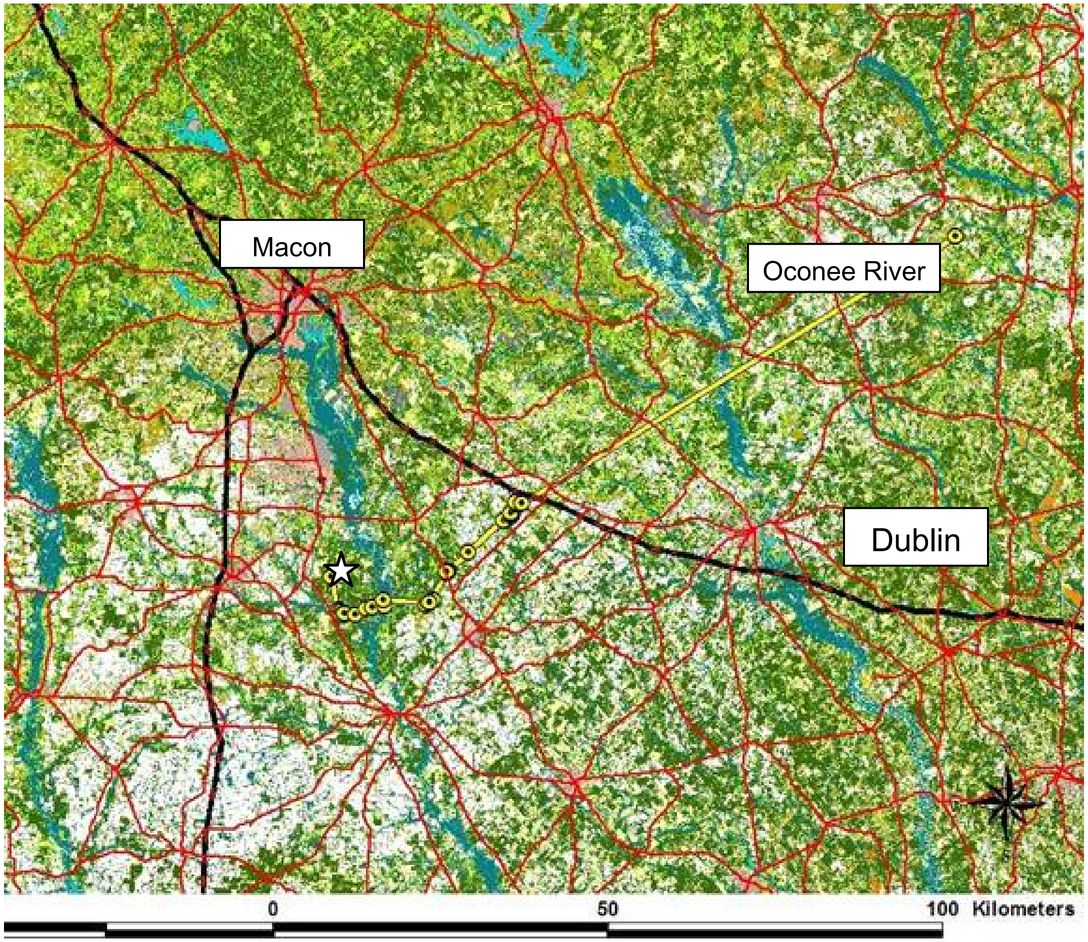

Figure 2.9. Movement path of American black bear female 15, originally captured in Atlanta, Georgia, USA and released on Oaky Woods WMA (☆), from July 1 to July 24, 2003 in central Georgia, USA. State highways are in red and Interstates are in red and black dashed lines. Green on the map represents forest, blue are river cypress-tupelo swamps and light colors are open areas and pink is urban.

CHAPTER 3

HIERARCHICAL PREDICTIVE MODELS OF BLACK BEAR HABITAT IN CENTRAL GEORGIA[1]

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[1] Cook, K. L., M. J. Conroy and J. P. Carroll. To be submitted to *The Journal of Wildlife Management.*

Abstract: The central Georgia American black bear (*Ursus americanus*) population exists mainly on private land in a landscape where residential development could increase markedly. Our study was undertaken to inform habitat conservation and management for this population, one of 3 remaining in Georgia. We predicted annual and seasonal black bear habitat use from a sample of 9 female and 14 male radio-tagged bears with Bayesian, hierarchical models. We modeled the probability of within-home-range, location-level habitat use conditioned on the probability of within-study-area, home range-level habitat use, accounting for telemetry error and autocorrelation. We employed an information theoretic approach to incorporate model uncertainty in posterior parameter estimates, which were input in a Geographic Information System to map predicted annual bear habitat use in central Georgia. We validated models with an independent data set on the frequency of bear hair detections. We accounted for the probability of false absence and calculated a prediction error rate as the proportion of bear detections minus habitat use probability. The mean prediction error rate averaged 0.377 over 409 hair snares (95%CI: 0.355 – 0.398) and 0.367 (95%CI: 0.350 - 0.390), respectively, for female and male annual habitat use models. Model averaged annual and seasonal habitat model results were similar for males and females. The top ranking annual habitat use models comprised more than 97% of model weights and only included correlation between the probability of bear habitat use and home-range-level variables (home range habitat compared to the study area). Seasonal and annual habitat use was nonselective within bear home ranges according to model selection results. There was a negative relationship between the presence of an annual bear home range and county / residential road density within the study area for females (n = 9, $\hat{\theta}$ = -2.79, 95% Bayesian Credibility Interval: -4.42 - -1.38) and males (n = 14, $\hat{\theta}$ = -2.244, 95% BCI: -3.81- -0.77). This was also the case for highway density for females ($\hat{\theta}$ = -

2.57, 95% BCI: -5.22 - -0.33). However, there was more uncertainty in the relationship between highway density and predicted presence of a male annual home range ($\hat{\theta}$ = -1.37, BCI: -3.77 – 0.92). Predicted annual home range habitat use had a weak, positive relationship to forest-associated habitat diversity (among clear-cut, hardwoods, pine and cypress-tupelo swamp) for females ($\hat{\theta}$ = 0.32, 95% BCI: -0.148 – 0.85) and males ($\hat{\theta}$ = 0.188, 95% BCI: -0.346 – 0.72). Our findings suggest that within the landscape, bear home ranges are likely to occur in areas with low road density and that home range habitat diversity may be a factor in predicting bear home range occurrence. Management and conservation of bear habitat likely depend on maintaining extensive areas of low road density that provide a mix of natural and plantation upland and lowland pine and hardwood forest in this developing region. In order to manage and conserve habitat on a landscape scale working with county governments and private landowners is important in addition to considering land acquisitions that connect and expand public lands.

Key words: American black bear, *Ursus americanus*, habitat use, road density, Bayesian hierarchical model, model validation

Introduction

American black bear (*Ursus americanus*) populations in Georgia have been reduced by approximately 95% (Wooding et al. 1994, Carlock et al. 1999, Clark et al. 2005). The three populations that are known in Georgia are likely to be isolated geographically (Miller 1995); however, there are occasional reports of bears in most counties (Georgia Dept. Nat. Res. unpublished data). The central Georgia population (CGP) exists mostly on private land and the majority of high quality habitat is thought to exist in and around 2 Wildlife Management Areas (Oaky Woods and Ocmulgee WMAs); comprising the only general areas where reproduction has been documented (Clark et al. 2005). Approximately half of these WMAs were recently sold, and most of this land is projected to be or is currently being developed. Given the diversity of land tenure and the desire to conserve bears in this region for hunting and their inherent value, there is interest in predicting potentially suitable habitat to identify management priorities and strategies in the region.

American black bears (hereafter, 'black bears') exploit a variety of natural and anthropogenic habitat types over large areas; at the landscape scale, for seasonally available foods, mating and refuge resources; as such, management is a challenge. Although black bears are habitat generalists, they require abundant, high carbohydrate food sources (Kimball et al. 1998). Feeding efficiency is somewhat affected by plant fruit density, especially for bears > 100 kg, (Welch et al. 1997) which suggests that certain fruiting plants are optimal and their presence increases habitat quality. There is evidence that climatic factors which affect inter-annual food availability affect population dynamics such as recruitment and emigration (McLaughlin et al., 1994, Coley, 1995). Upland and wetland hardwood and mixed forests that provide high calorie mast in fall, such as black gum (*Nyssa sylvatica*) (Dobey et al., 2005) oaks (*Quercus spp.*)

(Elowe and Dodge 1989, Eiler et al. 1989, Costello et al. 2003) and soft mast from berries (Rogers 1987) have been tied to female reproductive success. Use of agriculture, which provides high calorie crops such as corn, soybeans, and peanuts, is correlated with increased bear weight and reproduction (Dobey et al. 2005). Little research has been conducted on habitat use and quality in pine plantations of the southeastern USA (Jones and Pelton 2003). However soft mast sources available in pine are known to support reproduction, although they can be less productive for bear foods (Clark et al. 1994). A lack of sufficient mast production in dense pine habitats correlated to a reduction in bear abundance on an island in Washington (Lindzey et al. 1986). Forest and clear-cuts in bottomland hardwoods and cypress-tupelo swamp were also less productive for bear foods than in upland hardwood habitats (Hersey et al. 2005). Bear nuisance (Oka et al. 2004) and harvest (Noyce and Garshelis 1997) are related to increased bear movements in years of poor mast abundance.

Habitat availability to bears appears constrained by fragmentation of escape cover and roads. (Beausoleil, 1999, Boersen et al., 2003, Dixon et al., 2007). High-traffic volume highways limit bear movements (Brody and Pelton 1989, Beringer et al. 1990, Simek et al. 2005) and appear to restrict gene flow through populations (Dixon et al. 2006, Dixon et al. 2007). Bear use of agriculture appears to be constrained by adjacency to forested patches (Beausoleil 1999, Jones and Pelton 2003). Black bear response to landscape configuration, as measured by landscape metrics such as road density or habitat diversity, has received little attention, although these variables are important features of black bear habitat. Variables measured at ecologically relevant scales offer improved inference about habitat use (Hobbs, 2003, Addicott et al., 1987). It is important to assess habitat use by the central Georgia black bear population (CGP) in terms of habitat configuration in addition to composition to assess habitat connectivity and fragmentation. Many landscape metrics are correlated and may fail to provide an accurate measure of spatial arrangement of landscape features and should be selected with care (Hargis et al. 1998).

Wildlife habitat use and selection is a hierarchical process, which depends on the availability of resources at multiple scales. A population range within the geographic range may relate to the availability of certain habitat factors. Within the population range animals may select certain resources for establishment of the home range. Animals may select resources within their home range and at their locations (Johnson 1980). Human land uses occur at these scales and habitat conservation and management may be better informed by multi-scale habitat analyses (Apps *et al.*, 2001, Marzluff et al. 2002). Due to increasing pressure on ecosystems from land use, the expense of large scale, on-the-ground surveys and the utility of Geographic Information Systems (GIS) spatial analysis, natural resource management often relies on the spatial prediction of potentially suitable habitat to prioritize actions in decision making (Clevenger et al., 1997, Coops and Catling, 2002, Johnson et al., 2004). Increasing evidence suggests that habitat information and prediction may be improved when the hierarchical process of wildlife habitat use is modeled (Orians and Wittenberger 1991, Aebischer et al. 1993, Poizat & Pont, 1996, Rettie & F. Messier, 2000, , Lindenmayer 2000, Thompson & Mcgarigal, 2002, Meyer and Thuiller 2006), and when habitat availability is accounted for (Brotons et al., 2004). Studies have shown this to be the case specifically for black bears in the southeastern USA (Benson 2005, Dobey et al. 2005).

Although hierarchical habitat analysis can provide improved inference about habitat use, frequency of habitat use may be an index of habitat quality; an index that oftentimes is biased (Garshelis 2000). For the purposes of this paper, the term, “habitat use” will replace the term of, "resource selection" due to the issues of bias regarding the fact that true selection is difficult to measure by observation of bear locations due to instances of preferred habitat avoidance from avoidance of conspecifics or other unobservable factors. Additionally habitat selection does not always relate to increased fitness, which relates directly the habitat suitability. We define habitat use as, "the extent to which different vegetative associations are used," (Garshelis 2000). Habitat use by black bears can in fact have an inverse relationship to apparent habitat quality in some cases. Exclusion of females from high quality food sources by male bears has been confirmed experimentally (Beckmann & Berger, 2003) and suggested by observational research (Clarke et al.. 1994). Black bears were found to avoid (use less than the availability) natural upland pine habitats, likely due to hunter avoidance. However, foods found in natural pine habitats were common in bear diets (Dobey *et al.* 2005). Both of these studies report these findings as within-home-range habitat use, therefore, bears may select areas within home ranges solely as refuge from direct mortality risk, while avoiding, but requiring, habitats that are necessary food sources that pose a high mortality risk. This is a major challenge to interpreting habitat analyses, requiring careful evaluation of inference (Garshelis 2000). In lieu of data relating habitat use to fitness (research that is rare due to prohibitive costs), it is possible that validated hierarchical predictive models will offer an approximation of resource selection. For example, Dobey et al. (2005) also found that bear home ranges contained a higher relative proportion of upland pine habitat than the study area, thus bias may be mitigated by hierarchical analyses.

The probability that an animal occurs at a place in the landscape generally depends on the probability of the presence of a home range. It may be less likely that an animal would be found in a patch of suitable habitat surrounded by extensive unsuitable habitat. The home range theoretically should not contain a large proportion of unsuitable habitat since these areas would be avoided. Thus, if the probability of presence is estimated solely by modeling location habitat use within the home range, the probability of presence may be overestimated. If we account for the probability of home range habitat use in a hierarchical model whereby location-level habitat use depends on the probability of home range presence, we may improve prediction. To model this hierarchical structure of habitat use, it may be possible to account for the variation in habitat use at the location-level (within-home-range habitat use) with variables measured at the home-range-level (home range compared to the study area characteristics). Differences in habitat use between populations in disparate study areas could be modeled in the case of a fully realized hierarchical analysis. For the purpose of our research, based on one black bear population and a limited sample size, it is practical to use 2 levels of hierarchy to model the variation of black bear location-level habitat use with home-range-level habitat parameters measured within the study area.

Previous approaches to hierarchical habitat modeling of radiotelemetry data, though rigorous, such as compositional analysis (Aebischer et al. 1993), and approaches, which rank habitats (Johnson 1980) or employ Analysis of Variance (Bergin 1992), have primarily emphasized null hypothesis testing rather than prediction. Alternately other techniques that focus on prediction, such as Ecological Niche Factor Analysis, ENFA (Hirzel et al. 2002), discriminant function analyses (DFA), and distance metrics, do not lend themselves to hierarchical analysis or model updating. Further, habitat availability is an essential component to resource use prediction when measured appropriately (Aebischer et al. 1993, Brotons et al. 2004), but cannot be estimated by many distance metrics used in presence data-only, analysis such as ENFA or DFA. Many factors affect the quality and relevance of multi-scale habitat analyses including inappropriate sample units that do not account for autocorrelation, non-independence of habitat proportions, and the spatial extent used to measure habitat availability (Aebischer et al. 1993). We aimed to construct and validate hierarchical models that could be evaluated using likelihood theory, which incorporated various sources of uncertainty, and allowed for model updating after additional research.

Objectives and model hypotheses

Our objective was to create, validate, and map models of potential annual and seasonal CGP bear habitat. We aimed to model presence-only habitat data for variables measured within home ranges and the study area (Table 3.1), while accounting for telemetry error and autocorrelation and by using individual bears as the sample unit. Our hypotheses that correspond to annual and seasonal habitat use variables (Table 3.2) are based on bear response to food sources and avoidance of potential sources of mortality, and aggression from conspecifics. Candidate models to evaluate multiple hypotheses are presented in table 3.3 for annual habitat use and table 3.4 for seasonal habitat use.

Methods

Study Area

The extent of the central Georgia black bear population is estimated to exist within an area of 1,200km^2 where bear sightings are reported south and east of Macon Georgia along the Ocmulgee River (Carlock et al. 1999). Reproduction has only been documented over an area of 203.4 km^2 in and around the Oaky Woods and Ocmulgee WMAs. The known breeding range is bordered on either side by interstate highways and to the south by extensive agriculture (Figure 3.1). This region lies in the Upper Coastal Plain and is the 2nd largest wildland urban interface in Georgia; an area where wildland vegetation comprises more than 75% of census blocks within

2.4 km of a US census block with > 6.17 houses/km^2 (Radeloff et al. 2005). The Oaky Woods WMA totals 21,000 ac. and the landowners plan extensive development of this WMA over the next 30 years (Crenshaw 2006). Until recently, the WMAs were managed for loblolly pine and consisted of approximately 45% planted pine of more than 5 years of age, 20% of planted pine less than 5 years of age, 30% bottomland hardwoods, and 5% upland pine-hardwood forest (Carlock et al. 1999). There is a lack of information on plant communities in central Georgia. The one quantitative study (Froeschaer 1989) documented the following dominant habitat types and species relevant to bear biology: upland hardwood forests include Scrub Oak (*Quercus ilcifolia)*, Black Jack Oak (*Q. marilandica*), White Oak (*Q. alba*), Hickories (*Carya* spp.), Elms (Ulmus spp.), Hackberry (*Celtis tenuifolia*), Hawthorne (*Crataegus* spp.), Sassafras (*Sassafras albidum*), Black Cherry (*Prunus serotina*), Sourwood (*Oxydendrum arboreum*), Flowering Dogwood (*Cornus florida*) and Sparkleberry (*Vaccinium arboreum*); mixed pine – hardwood: comprised mostly of Loblolly (*Pinus taeda*) and Shortleaf Pine (*P. echinata*), Scrub Oak, Black Jack Oak, Southern Red Oak, Northern Red Oak (*Q. rubra*), Southern Red Oak (*Q. falcata*), Sassafras, Hackberry, Hawthorne, , Southern Magnolia(*Magnolia gradnifolia*), Black Cherry, Flowering Dogwood, Sparkleberry, Possumhaw (*Ilex decidua*), and Dwarf Paw Paw (*Asimina parviflora*); bottomland hardwood consisting generally of the following bear food plants, Hickories, Water Oak (*Quercus nigra*), Willow Oak (*Quercus phellos*), Hackberry, Holly (*Ilex* spp.), Cane (*Arundinarea gigantea*), Privet (*Ligustrum japonicum*), American Serviceberry (*Callicarpa americana*) and Dwarf Paw Paw. The Georgia GAP Analysis Program classifies the majority of the Ocmulgee River Swamp to be comprised by Cypress and water tupelo (Kramer et al. 2003).

Field Methods

Bear capture techniques

Georgia Department of Natural Resources wildlife biologists trapped bears in the Oaky Woods and Ocmulgee WMAs from March 14 through August 30 of 2003. Twenty-four Fremont foot trap snares (Fremont 1986) were placed in clearings along logging roads such that four sets of traps lied within 15 km^2, the general female home range in the southeastern USA (Dobey 2005). Trap grids on either side of the river were moved after no less than 4 females were captured. We moved individual traps with no bear sign after 5 days. Biologists immobilized bears with a 2:1 mixture of ketamine hydrochloride (Ketaset) and xylazine hydrochloride (Rompun) at a dosage of 4.4 mg/kg of Ketaset and 2.2 mg/kg of Rompun, for estimated body weights. We collared bears with VHF (very high frequency), MOD 500 radio collars with mortality and motion signals and 2 males were tracked by GPS collars (Advanced Telemetry Systems, Asanti MN). All collars were equipped with a leather spacer to enable breakaway after one year (Hellgren et al. 1988).

Radio-telemetry

We obtained 3 to 4 locations per week over the 24-hour diel period. We located females more frequently (> 16 hr.) (Clark 1991) because home ranges are significantly smaller than those of males and thus time to location independence was expected to be shorter. We located bears by ground radiotelemetry from May 1, 2003 to August 30, 2004 using a rooftop whip antenna for continuous reception and a 3- element yagi antenna (Advanced Telemetry Systems, Isanti, MN). We included locations collected after one week from capture in analyses to avoid bias from bear capture response. We estimated locations by the loudest signal method by acquiring the azimuths of the edges of the signal and calculating the midpoint (Springer 1979). We recorded coordinates in UTM Universal Transverse Mercator with a Garmin GPS 12 (Garmin Ltd., Olathe KS). Location error was minimized by obtaining 2 or more azimuths at as close to a 90^o angle intersection as possible with no inter-bearing angle $< 60^o$ or $> 120^o$ (White and Garrott 1990). Location attempts were made as close to the bear as possible and usually within 1 km, until two or more bearings were taken within 15 minutes of one another.

Statistical Analyses

We aimed to account for the hierarchical structure in wildlife habitat relationships and to incorporate important sources of uncertainty such as location error, spatial autocorrelation, and model misspecification. Habitat use within home ranges was modeled by location-level parameters conditioned on home-range-level presence data in a hierarchical logistic regression model. Models that did not include location-level parameters modeled nonselective habitat use within home ranges and home-range-level habitat use within the study area. Location data incorporated positional errors and we ran model simulations on subsets of location data (1 or 2 locations per season per bear; see below) to avoid introduction of bias from spatial autocorrelation. Our models included habitat variables collected for 14 males, 10 of which had annual home ranges and 12 of which had seasonal home ranges; and 9 females, 7 with annual home ranges and 9 with seasonal home ranges. To facilitate hierarchical modeling and model selection under these constraints we used a Bayesian analysis framework enabled by Monte Carlo simulation via Markov Chain Monte Carlo. Modeling was conducted using the python programming language (freeware available at www.python.org) within the module PyMC, for MCMC analysis developed by Fonnesbeck (2005). Bayes theory (Bayes, 1763) and Markov Chain Monte Carlo (MCMC) simulation offer an analysis framework necessary for multilevel, multi-model inference (Link et al. 2002, Howell 2004). We employed an information theoretic approach to model selection using Akaike's Information Criterion (AIC), to weight models according to uncertainty (Aikaike 1973, Burnham and Anderson 2002).

Telemetry Error

Bearings of animal locations obtained remotely by radiotelemetry, are imprecise due to signal bounce from vegetative and topographic features and error in compass use (White and Garrott 1990). The exclusion of telemetry error from location estimates can bias habitat analyses (Samuel and Kenow 1992, Kenow et al. 2001). We incorporated telemetry error measured in a beacon study (White and Garrott 1990) in location estimates.

After observers trained in radiotelemetry, we assessed observer location error. Test collars were placed above the ground in 6 areas where bears were commonly located and which represented common topographic and vegetation conditions encountered over the entire study area. Differences in hearing can cause observer bias and so we examined error by habitat type and distance. Three collar locations were in forest, 3 were in open areas, and collar locations were unknown to observers. Observers obtained bearings at set stations over 5 distances from collars of 0.2, 0.5, 1.0, 1.5 and 2.0 and such that one bearing could be for each of 3 inter-bearing angles of approximately 90, 115, and 75 degrees.

A 2-way ANOVA showed no evidence of bias among observers by distance (F (10, 327) = 0.33, P>0.93) and error estimates were pooled. We developed a SAS program (SAS Institute Inc. 2001) to simulate a, "location cloud" plot of 300 points (Figure 3.2 c) to record location habitat values based on a Gaussian error model. Location cloud points were the intersection of random bearings simulated about field recorded bearings with a normal distribution and the standard deviation in the error angle (White and Garrott 1986). These location clouds thus reflected the irregular error distribution due to inter-bearing angle and distance.

GIS analyses habitat and landscape metrics

Habitat and landscape metrics (Table 3.1) were obtained using a GIS created in ArcView 3.2 (ESRI 1998) and ArcInfo (ESRI 2001). The GIS was comprised of the Georgia GAP land cover map (Kramer et al. 2003) and all roads including remote dirt roads at a scale of 1:12,000 (Georgia Department of Transportation 1997). The GAP map was created from 1998 LandsatTM satellite images and is a grid with a pixel grain of 30m, which was our mapping unit for all modeling. GAP land cover accuracy is reported as 75% measured at a 4 pixel scale against field collected vegetation point data. We also measured GAP land cover accuracy in the study site using habitat data collected at bear hair snares in another research project. To update the GAP land cover with new clear-cuts and pine re-growth we digitized these cover types, comparing the 2001 LandsatTM satellite images to those for 1998. Pine re-growth was assumed if the reflectance had been that of clear-cut in 1998, but had changed to deep red (pine signature) in 2001. Landscape metrics were calculated using moving window analysis in Fragstats (McGarigal and Marks 1995) and we attempted to make window extents ecologically relevant to black bear ecology by making the size equal to that of the female home range or home range core. Road densities were calculated for each pixel at the center of a window the size of the average female % 50 fixed kernel home range core (3.198 km^2). Habitat diversity was calculated for center pixels in moving windows of size 0.283 km^2 (Table 3.1). This size was necessary to ensure independence to other variables and model convergence.

Habitat data structure

Habitat model input was obtained by overlaying error clouds, bear home ranges and bear study areas (study area minus the individual home range) (Figure 3.2 a – c) on habitat and landscape metrics layers and sampling points within these levels. Home ranges for these purposes were estimated by MCP (Mohr 1947) delineated about the error clouds. Home range and study area habitat data were obtained from a grid of points within each bear home range at a 90 m interval and within the study area at a 450 m interval. Home range points were sampled at a finer scale in order to capture the distribution of available habitat within the relatively limited area used intensely by bears. The study area had an extent with a radius determined by the longest bear MCP home range (46.3 km^2) centered at the trapping area centriod. We later selected random samples from the distribution of point data to avoid the need to load large data sets during model simulations. Habitat proportions and landscape metric distributions within the respective extents were compared to those sampled with points and no differences were detected. Home range points were sampled at a finer scale in order to capture the true distribution of available habitat within the relatively limited area.

Model Construction

We employed a Bayesian hierarchical logistic regression model to predict the probability of habitat use by male and female black bears in central Georgia. We attempted to fit a 2 level model which modeled random effects about the intercept of the location-level habitat model of habitat use within the home range (Level 1: L1) (7a) as a factor of the home-range-level model of habitat use within the study area (Level 2: L2) (7b)

$$u_{ij} = \beta_{oj} + \left(\sum_{i=1}^{J} \beta_{ij} X_{hij} \right) + e_{ij} \tag{7a}$$

$$\beta_{oj} = \gamma_{00} + \left(\sum_{i=1}^{N} \gamma_{0n} Y_{ij} \right) + E_{0n} \tag{7b}$$

where u_{ij} is the logit of the probability of habitat use, β_{oj} is the intercept of the L1 model which is modeled by the L2 level model of home-range-level habitat parameters. The L2 model intercept term is γ_{00}. In the absence of additional explanatory variables the L1 and L2 intercept terms would represent the null model at either level which equates to nonselective habitat use within the home range for the L1 model or within the study area for the L2 model. The non-intercept terms are the series of habitat parameters at L1 or L2 (Table 3.2) and the error terms. The intercept of the L1 model was fit by the L2 model with home range presence data and thus was conditioned on the presence of a home range. The L1 parameters were fit to presence – conditional absence data (defined below) at the L1 scale. The parameter estimates for the L2 model were then to fit home range presence – conditional absence data (Figure 3.2. a-c).

Ideally, we would have employed a fully realized hierarchical model whereby each L1 parameter β_{ij} was modeled as a function of an L2 model with error (E_{1nj})

$$\beta_{ij} = \gamma_{k0j} + \gamma_{1nj} Y_{1nj} + E_{1nj} \tag{8}$$

where γ_{k0j} was an intercept term for an L2 model that represented interactions among each L1 parameter and an L2 parameter (γ_{1nj}). This would have provided additional inference on interactions between L1 and L2 variables, for example whether specific habitat parameters were affected by home range road density. However, this was not practical due to our limited sample of bears.

We attempted to account for location autocorrelation by using one location per male bear and 2 locations per female (due to a small sample size and problems of quasi complete separation) per season as presence data input for the in the logistic model. The locations came from the location cloud representing telemetry error. The logistic model was then simulated 300 times using these subsets of location data (methodology detailed below). Final posterior parameter distributions were generated by sampling from a compilation of these 300 simulations, which were deemed sufficient because cumulative parameter and deviance means were asymptotic for all global models. Each of the 300 simulations consisted of 50,000 iterations of the Metropolis Hastings algorithm with a burn-in period of 5,000 or 10,000 iterations and a thinning interval of 10. Model convergence was assessed for 5 chains (simulations) of each model with the Gelman and Rubin (1992), Geweke (1992), Raftery and Lewis (1992) and the Heidelberger and Welch (1983) convergence diagnostics to ensure convergence.

Posterior parameter distributions were formed from the 300 simulations of the logistic model as follows in order to account for autocorrelation and telemetry error. Refer to Figure 3.2 (a – c) for a schematic. Fore each simulation:

1) L1 presence data was sampled as 1 random location from the location cloud per season per male and 2 cloud locations per season per female. Two locations were necessary for females to ensure presence data for each habitat type to avoid quasi-completion.
2) One land cover value for each of these locations was sampled randomly from the home range by a method below and comprised the L1 conditional absence data.
3) This L1 conditional absence point within the home range, was used as the presence point for L2.
4) A conditional L2 absence was sampled at random from that bear's study area.

We employ the term, “conditional absence,” because inference about absence was conditional on the time of the location sample and the improbability that the bear presence and absence point could occupy the same map pixel at the same point in time. The conditional absence point is unlikely, within any simulation, to occupy the same coordinates also for a different bear location. Conditional absence at the home range scale followed the same logic; random home range presence data was compared to conditional absence data from a random datum outside of the home range, within the study area. Since the study area was the constrained space outside of each bear home range (Figure 3.2 a), the conditional absence point is relative to the particular bear at the L2 level since the conditional absence point may occupy the same coordinates as another bear home range at time t.

In order to take random samples for the L2 data, code was written into the simulator in which the multinomial distribution of habitat types with the respective extent was sampled. Distributions for the continuous variables were developed for each habitat type and the distribution was sampled conditional on habitat type selected to obtain the random continuous variable value.

Model Selection and Uncertainty

We did not include variables that with $|r\text{-}s| > 0.3$ using a Spearman Rank correlation. Correlation was measured for variables within the composite home ranges of males and females and over the composite study area.

Due to the small sample size of female black bears (n=9) it was not possible to conduct model selection for annual habitat use models based on a single multi-level global model, a model which would have contained 10 parameters. We conducted model selection for female annual habitat use models on a, “final model set,” that was formed as follows. A global model was constructed that included L1 only variables (L2 model was null), defined as an, “L1 (L2 null) model,” and a global model was formed at the L2 where the L1 model was null, defined as an, “L2 (L1 null) model.” Parameters from those models with AIC model weights > 0.1 (excluding the null) were then included in the final model set comprised of a global model, L1 (L2 null), L2 (L1 null) models and models that included variables at both levels. The final model set global model and multi-level models (for which neither level was a null model) were rerun so that model selection could be carried out on the final model set for female annual habitat use. A null model (L1 null and L2 null) was assessed for all model sets because telemetry error and the GAP vegetation map introduce considerable sources of uncertainty, allowing for the chance that little variation would be accounted for by variables at either level. Also within L1, nonselective habitat use is a plausible, biologically relevant, hypothesis based on bear ecology. We used model-averaged estimates in model validation and to create predictive maps. Parameter estimates were averaged over all candidate models.

Model output from the most parsimonious model is a relative probability of black bear habitat use at the map unit scale (30 m^2). This is not absolute because the overall probability of black bear presence required in a pure Bayesian analysis (equation 1) was unknown.

Model Validation

We employed an independent presence-absence data set collected in the study area to evaluate model predictions for male and female bears. We compared the frequency of bear detections at hair snares to the predicted probability of habitat use. The dataset was comprised of hair detections at 230 hair snares in 9 trap webs, used for a concurrent population research project during 2 years following our habitat research (J. L. Skvarla, University of Georgia, unpublished data). Since the most parsimonious model for males and females did not differ considerably, we felt it was appropriate to evaluate male and female models against this same independent data set for which sex was unknown. Nine trap webs, each with 22 to 35 hair snares were sampled 1 to 3 times per trapping web over each year, except the denning period. Habitat model prediction error rates were estimated for each snare by calculating the difference in the proportion of bear habitat use at the snares (# detections/ total detections at the snare) to that predicted by the habitat models at those locations. We incorporated the probability of false absence to validate models. Probability of detection was estimated in program Presence V2.0 (Hines 2007). Akaike's Information Criterion was used to select the most parsimonious model among candidate occupancy models to estimate detection probability (*p*) .

We calculated the probability of false absence as

$$(1-p)^{N} \tag{10}$$

where N is the number of visits at the snare when bear hair was not detected (McArdle 1990). We used the probability of false absence in place of the 0 in the detection history. The prediction error rate was calculated separately for male and female habitat models as

$$r = \left(\frac{\sum_{i=1}^{T} \left(1 - \left| (O\ ) - p_i \right| \right)}{n} \right) \tag{11}$$

where *r* is the mean prediction error rate estimated over all traps *T* as the mean of 1 minus the absolute value of the difference between the proportion of habitat use at the trap O_i (sum of the probability of detection at a trap divided by total sampling events) and the predicted habitat use from the model at that trap p_i. The mean prediction error rate was the average over all trapping events (*n*). This method of validation is more appropriate than using an independent data set of telemetry locations, which are inaccurate.

We used the web prediction error to enhance inference. We calculated the mean predicted habitat use within the polygon of each web compared to the probability of occupancy for each web. Web polygons were delineated by connecting the outermost snares and were the approximate size of a female annual home range.

Results

Telemetry Error

Telemetry error did not differ by distance between observers ($F(10,327) = 0.33$, $P > 0.93$). The mean bias over all observers was $-0.79^{o} \pm 12.2^{o}$ for forest and $\pm 12.04^{o}$ for open habitats. We used the conservative estimate of 12.2^{o} as the standard deviation to produce location clouds. The mean error distance from the true location follows the relationship:

Error distance = 26.25 + 0.1044*receiver distance, SE = 135.4 (Figure 3.3)

which resulted in an average error distance of 137.7 m, SD = 146.6 for an average receiver distance to transmitter of 1067.5 m. The average distance from the receiver to estimated bear locations during bear tracking was 605.3 m, SD = 515.49 and since the range of inter-bearing angles in the beacon study reflected those in the field, on average locations were erroneous by approximately 89.4 m, SE = 135.4. A comparison of true collar locations and error clouds revealed that collars were within approximately 90% of error cloud extents.

Model and Validation Results

We attempted to fit models that incorporated random effects (equations 7 a and b), however, these models did not converge and a residuals analysis of the global models for male and female bears revealed no differences in residual distributions among bears. Thus the model intercept had a constant mean among bears. We report results for models with Δ AICc < 5 that have a reasonable level of support (Anderson et al. 2001). We calculated the detection probability for model validation using model-averaged estimates for parameters in the confidence set of models with AIC weight > 0.1 (Table 3.5). There was no discernable difference in maps of female and male predicted habitat use, due to similarity in parameter estimates and thus the map of predicted female habitat is presented (Figure 3.4) because models of population dynamics are shown to be sensitive to female recruitment (Clark 1991), and thus habitat used by females may predict suitable bear habitat more closely.

Multi-scale female black bear habitat

The null model in the L1 (L2 null) model set was the only model with reasonable support (Table 3.6). Therefore the L1 variables from the top 3 ranked L1(L2 null) models outside the confidence set (Appendix B, Table B.1) were used in the final model set. In contrast, L2 level variables did predict home range habitat use (Table 3.7). The final model set for females yielded support only for models of habitat use where location habitat use was nonselective (L2(L1 null)) and home range-level habitat could be predicted by L2 variables (Table 3.8). These L2(L1 null) models accounted for 97.3% of model weight and included county road density, highway density and habitat diversity. The top model, which included only home-range-level county road and highway density, had a higher level of support than that which contained habitat diversity. L1 parameters in the non-null multi-level models demonstrated a change in sign, with values close to zero and thus were unreliable. The most parsimonious model was considered as that with model-averaged estimates where the coefficient for habitat diversity was dampened due to its low model weight (Table 3.9). Posterior parameter estimates for the annual habitat use model confidence sets are listed in tables 3.19 – 3.22.

The null model comprised over 68% of model weights in location-level seasonal models (Tables 3.10-3.12). Models weights of the non-null candidate models with the same number of parameters had similar weights. Thus candidate variables may be important to prediction but the nature of the effects is unreliable due partly to small sample size. Models with the second highest ranks (ΔAICc < 3.812) for the spring and summer seasons included county road density. There was a consistent, slight positive relationship between predicted bear occurrence and county road density over all candidate models and the 95% BCI included 0 at below the 25th quartile, thus there is some potential support for the importance of this variable to predict within-home-range seasonal habitat use. Posterior parameter estimates for seasonal models are listed in tables 3.20 – 3.22.

Multi-scale male black bear habitat use

The top ranking annual habitat models for males (AICc weight > 0.1) also included only L2 variables for county road density, highway density and habitat diversity (Table 3.13). Weights for non-null multi-level models with variables at both levels were above 0.1, but the direction of the relationship of L1 variables was opposite to that for L1 (L2 null) models, as occurred for females, with the exception of county roads. Thus L1 variables may be important to prediction but did not produce reliable estimates based on our data. In contrast to female results, county road density consistently had a slight negative coefficient. Model averaged estimates for male annual habitat use (Table 3.14) had a substantially lower coefficient value for habitat diversity, as was the case for models of female annual habitat. Posterior parameter estimates are listed in table 3.25.

Regarding male seasonal models, the null model ranked highest among all seasonal candidate models, comprising more than 56.6% of model weight in every candidate set. Models with a total of 2 parameters tended to have almost equal model weights and ranked high among the remaining candidate models (Tables 3.26 – 3.29). The 95% Bayesian Credible Interval for all seasonal habitat parameters contained 0 and so no posterior habitat parameters explained seasonal habitat use. As for female seasonal models, those with the fewest number of parameters ranked highest, suggesting a lack of sufficient data to estimate parameters. Therefore seasonal habitat variables included may be important to prediction but estimates are unreliable likely due to small sample size. However, some mean posterior parameters were consistently slightly above or below zero, suggesting that these habitat relationships can be tested with additional data in the future.

Model validation

The probability of detection from model-averaged parameters in the confidence model set (Table 3.5) was 0.706. The mean prediction error rate estimate for the female annual habitat use model was 0.323 (n = 409, 95%CI: 0.304 – 0.342). The mean prediction error using the probability of occupancy (0.912) for snare webs for both years was 0.194 (n = 17, 95%CI: 0.247-0.140). Prediction error rate for the male annual habitat use model based on model averaged parameter estimates was 0.316 (n = 409, 95%CI: 0.335 – 0.298). Mean prediction error measured against the probability of occupancy by web was 0.195 (n = 17, 95%CI: 0.253 – 0.138).

Discussion

Validation results for the most parsimonious annual habitat use model suggested moderate predictive ability, that is better than chance. Therefore, our results and maps for predicting annual bear habitat use will likely aid in focusing management and conservation actions. The Bayesian analysis we applied was useful to reduce the complexity associated with modeling the hierarchical data structure, most appropriate for local and landscape level habitat analyses. The prediction error rate was somewhat high for models of male and female annual home range habitat use. The prediction error based on the probability of web occupancy was less than the predicted error rate, likely due to measurement at a larger scale, however this result suggests that overall models did predict black bear occurrence reasonably well; better than chance alone. Our predicted error rate was comparable to other studies. A logistic regression model for bat habitat reported a precision estimate of 0.37 (Greaves et al. 2006), a multivariate resource selection function model reported a c statistic of 0.77 (Apps et al. 2006), and a logistic regression model reported a prediction error rate of 0.16, using a cut-off value of 0.5 to define presence (Woolf et al. 2002). There was a slight positive bias in the mean predicted error rate and the bias was slightly negative when measured using the probability of web occupancy, suggesting the model over-predicts habitat use at the 30 x 30 m pixel scale and under-predicts black bear habitat slightly at the scale of the female home range. Our predicted habitat use model could improve decision-making about black bear habitat management in central Georgia. However, inference should be tempered by the constraint that the predicted habitat models are based on a non-random sample of bears that were trapped within the WMAs, an area of contiguous forest, and were not representative of any bears that may use more fragmented habitats or areas with more human access, if such bears exist in the CGP.

Sampling error in our study was increased by relatively high telemetry error due to limited road access. An additional potential source of variation was land cover misclassification of the Georgia GAP Program land cover grid used we used to infer habitat type. The GAP classification reports an accuracy of 75% (Kramer et al. 2003), and this is comparable to the accuracy using habitat data at hair snare traps of 73.2%. We speculate that model bias was partially caused by habitat configuration, the technique we used to incorporate telemetry error and the non-random sample of bears that were tracked. Bears habitat use of fragmented habitat types in our study, such as upland hardwoods, may be underestimated because correct habitat classification by telemetry increases with habitat patch size (Samuel and Kenow 1992, Findholt et al. 2002). Estimates for probability of habitat use for large patch habitat types such as plantation pine, clear cut and cypress-tupelo swamp were likely more accurate. Landscape classification of hardwoods in the study area was the most inaccurate with a misclassification rate of 19.1% of the total 26.8% rate and therefore likely biased parameters for upland hardwood in the model. It is most appropriate to conduct model selection for landscape level variables at multiple scales (McComb et al. 2001, Boyce et al. 2003), however MCMC simulation required extensive computing capacity and time and this was not practical.

The sampling technique used in our simulation methods may have resulted in some bias in posterior parameter distributions. We may have needed to sample more locations over the location error clouds. Other studies which did not account for spatial autocorrelation, but which did estimate habitat parameters from a distribution of > 50 points that represented telemetry error did demonstrate different habitat use patterns compared to analysis that did not account for telemetry error (Kenow et al. 2001). We sub sampled only 3 to 6 locations per animal per simulation of the model used to generate posterior parameter distributions. This may have resulted in a reduction in bias of only 20%, compared to a sub sample of 30 points per location which reduced bias by 50% according to an evaluation of a similar technique to account for telemetry error in habitat parameter estimates (Samuel and Kenow 1992). Each model required 15 to 24 hours to run on 6 computers and it was not possible to sample more than 1 to 2 locations per bear for each of the 300 model runs we deemed necessary to avoid spatial autocorrelation. Our results also may be biased due to the non-random sample of bears we tracked; bears caught in continuous remote forest. Random effects models that model a bear random effect were not appropriate for our data ,which suggests that inference should be constrained to bears that inhabit continuous forest.

We found that the probability of home range presence within the study area did not relate to any single habitat type and that habitat use appeared to be nonselective within annual and seasonal home ranges. This finding is supported by other studies, which reported no habitat selection for within-home-range habitat use in regions dominated by pine plantations as compared to hardwoods habitats (Clark et al. 1994), and dominated by bottomland hardwoods (Benson 2005). We did find that habitat diversity had a slight positive relationship to predicting home range presence. Research in Arkansas reported an inverse correlation of home range size to forest cover diversity (Smith and Pelton 1990) a habitat characteristic that was also reported to be selected by females (Clark et al. 1994). It is expected that if bears did use habitat at random in the year they were tracked, that they would distribute home ranges in areas of higher habitat diversity in order to access multiple habitats. This finding also suggests that bears exploited a mixture of upland hardwoods, pine, clear cuts and riparian areas throughout the year and that in this year food sources were distributed such that no one habitat offered an abundant preferred food type over another during the course of the year.

Our results do not support a conclusion that habitat type is unimportant in the CGP range. Black bears, although a generalist species, respond to the quality and productivity of mast associated with certain habitats, which affects reproductive rates (Elowe and Dodge 1989, Kasbohm et al. 1996, Costello et al. 2003, Dobey et al. 2005), movement (Garshelis and Pelton 1980, Rogers 1987, Kasbohm et al. 1998) and female harvest rates (Kasbohm et al. 1994, Noyce and Garshelis 1997, Oka et al. 2004). Additionally timber production lands in areas with limited natural habitat can be productive for bear foods, especially soft mast (Lindzey and Meslow 1986, Jones and Pelton 2003, Mitchell and Powell 2003) and it is possible that sufficient habitat existed during our study such that bears used all habitats equally. Soft mast indices were high along logging roads in a landscape dominated by plantation pine in Arkansas, however forests with a hardwood component had greater mast productivity (Clark et al. 1994). We observed an abundance of soft mast foods along skid trails and logging roads in loblolly stands and loblolly pine was the dominant vegetation type in the study area for each bear and within bear home ranges, with twice as much coverage as any other habitat type. Females exhibited nonselective habitat use according to our model whereas females were shown to be located less frequently in clear-cuts in more natural and patchy habitat due to likely to avoidance of males (Clark et al. 1994) and were excluded from more productive habitats in Appalachian timberlands dominated by hardwoods (Mitchell and Powell 2003). There is a general lack of habitat research on bears in pine plantations (Jones and Pelton 2003) and it is unclear why females may not avoid clear-cuts in our study area, although one plausible reason may be that most females appeared to be solitary in our study and as such may have been less sensitive to male aggression.

We were able to detect and validate relationships between the probability of bear home range habitat use within the study area and variables measured at the home range scale. However, actual habitat use depends on many fine-scale factors related to bear response to specific conditions and our study was observational and not designed to identify causal relationships. We found an association between predicted home range presence in areas with low county road and highway densities, which suggests a negative association with human access and perhaps to vehicle-collision mortality risk. These factors were not important to predicting within-home-range habitat use. Bears inhabiting the WMAs may have distributed their home ranges in areas with a tolerable density of roads and highways such that travel was relatively uninhibited. Predicted male home range habitat use had less of a negative relationship to highway density, which is expected due to greater mobility of males throughout the study area. Road density in areas with human residence has a negative relationship to occurrence of other large mammals such as wolves (*Canis* spp.) (Mladenoff et al. 1995, Corsi et al. 1999, Potvin et al. 2003) and grizzly bears (*Ursus arctos horribilis*) (Mace et al. 1996). Few studies have evaluated road density in black bear habitat models. However, predicted habitat suitability for black bears was diminished by proximity to paved roads (Gaines et al. 2005) in the southeastern USA and other regions and many studies have documented black bear avoidance of roads open to human access and high traffic (Bordy and Pelton 1989, Beringer et al. 1990, Dixon et al. 2006). Black bears are adaptive in their response to roads in human residences and may even be more abundant in residential areas in order to avoid grizzlies where their geographic ranges overlap (Apps et al. 2006). They may exploit human food resources at night in urban areas (Beckman and Berger 2003, Lyons 2005). The ability of bears and other large mammals to inhabit human populated areas depends largely on human tolerance and sufficient natural habitat or agricultural food sources and escape cover (Beausoleil 1999, Corsi et al. 1999, Lyons 2005). This proximate avoidance of roads or habitat due to human presence was also a source of error in our model. For example, it can be seen for hair snare web A (Figure 3.5) that road density, in this area logging roads, was high, and predicted use was low yet the area was heavily used. Overall an important limitation of the CGP bear habitat models is the inability to account for the actual habitat availability due to tolerance or exclusion by people through the ultimate effects of disturbance, poaching and vehicle mortality on realized habitat suitability; effects that can partially affect bear fitness. Estimating fitness relative to predicted habitat suitability is important (Mitchell et al. 2002, Mitchell and Powell 2003) and should be addressed in future analyses which incorporate measures of reproductive success and survival with habitat use as part of an adaptive management approach for the CGP.

In addition to predicting potential bear habitat, another potential use of the CGP bear habitat models is to provide a preliminary prediction for placement of highway underpasses in areas of high predicted black bear use, although fine scale movement analyses should be pursued to identify exact locations and underpass efficacy should be evaluated. Predicted habitat use in our model is low where highway density is high, however, black bears have been shown to cross highways more often at intersections where mortality is not related to crossing frequency (Simek et al. 2005). This would be expected since cars reduce speed approaching an intersection, which increases the chance that a bear will cross successfully. Therefore, although CGP black bears may establish home ranges less often in areas with high highway density, they may use stopping intersections as crossing areas.

Our model can be used over a larger geographic area mainly to identify areas of sufficiently low road density measured at an ecologically relevant scale for bears. We were able to follow a limited number of bears for only one year and additional data should be incorporated into models in the future. It is likely that the study area extent may have biased the model and underestimated importance of habitat diversity since there were extensive areas of potential habitat that went unused by bears north of an interstate, which we did not observe bear crossing. The bias caused by the delineation of available habitat for the study area is well documented (Porter and Church 1987, Milspaugh and Marzluff 2001, Boyce et al. 2003) and should be assessed in future analysis of CGP habitat. Due to the capture locations of bears we could not observe their habitat use in areas that had little to no bottomland hardwood or cypress, where streams are less dense and may be an important factor for habitat use. Additionally, observed habitat in central Georgia may not be preferred by bears but may represent remote land away from human encroachment. Therefore predicted bear habitat may simply reflect avoidance of people while habitat may be of relatively low quality. Use of the model to identify potential habitat in regions outside central Georgia where plant communities, elevation and access to other life requisites such as water differ, should rely on surveys of bear plant foods and other resources, in areas where models predict high bear habitat use, before management actions begin.

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Table 3.1. Habitat variables used in models of American black bear habitat in Central Georgia, USA.

Clear-cut	Forest regeneration of 0 – 6 years.
Agriculture	Crops such as soybeans, corn and wildlife food plots.
Hardwood forest	A combination of the classes for mesic and xeric hardwood and mixed pine-hardwood forest.
Pine plantation	Loblolly pine
Cypress-tupelo swamp	Cypress-tupelo gum swamp and bottomland hardwood forest combined
Habitat diversity	Habitat diversity is a unit-less metric measured with Simpson's diversity index $(SDI = 1 - \sum_{i=1}^{m} P_i^2)$ which is 1 minus the sum, of the squared proportion of each patch type in a moving window, across all patch types (m). The moving window * radius was 300 m (the average size of approximately 1/2 female bear home range core). Habitat classes were as above but omitted agriculture. All open habitat classes were omitted from the calculation of SDI so that habitat diversity is a measure of forest diversity and contiguity.
County/residential road density	Within timberlands these are logging roads and in other areas are paved 2-lane roads. Density (km/km^2) was measured in a moving window with a moving window size of equal to the mean female home range size of 13.8 km^2.

Table 3.1. Continued.

Highway density	Highway and Interstate combined density (km/km^2) in a moving window of size equal to the mean female home range size of 13.8 km ^{2}. Highways generally had > 2,000 cars/day volume.

* For the moving window analyses (McGaragal and Marks 1995) the value within an area of some radius (window) is appropriated to the cell at the window's center.

Table 3.2. Hypotheses relating to predictor variables used in models of habitat use by male (M) and female (F) American black bears in central Georgia, USA. The signs indicate the following hypotheses: (+) use is greater than availability, (-) less than availability or (=) equal to availability.

Annual Habitat Use			
Predictor variable	Sex	Level	Hypothesis
Clear-cut	M	Location	(+) Important soft mast food source
	F	Location	(=) Important soft mast food source, exclusion from open habitats by males
	F & M	Home range	(=) Important soft mast food source but abundant clear cuts in study area
Agriculture	M	Both	(=) Food source, abundant agriculture in home ranges and study area
Hardwood forest	F & M	Both	(+) Important food source, scarce in study area
Cypress-tupelo swamp	F	Location	(+) Food source, scarce within home range
	M	Location	(-) Abundant in large home ranges, escape cover, low food production
Habitat diversity	F & M	Home range	(+) Bears exploit clear-cuts, cypress, hardwoods and pine plantations and home ranges would contain a diversity of these for use throughout the year
Highway density	F & M	Home range	(-) Avoidance of risk from vehicle collision mortality
County / residential road density	F & M	Home range	(-) Avoidance of risk from vehicle collision mortality and encounters with people

Table 3.2. Continued.

Within-home-range Seasonal Habitat Use			
Predictor variable	Sex	Season	Hypothesis
Clear-cut	F & M	All	(+) Important soft mast food source
Agriculture	M	Summer	(-) Not a food source in summer, abundant agriculture in home ranges
		Fall	(+) Abundant food source, hardwoods are scarce
Hardwood forest	F	Spring	(-) Mature hardwood forest is scarce and high exposure to the weather due to lack of trees with den conditions
	F & M	Summer	(-) Lack of soft mast plant foods
	F & M	Fall	(+) Abundant hard mast foods such as acorns (*Quercus* spp.)
	M	Winter	(+) Abundant hard mast foods
Pine plantations	F & M	Spring	(+) Important source of soft mast foods such as blueberries (*Vaccinium* spp.)
	F & M	Summer	(-) Soft mast foods abundant on edge, however habitat type is abundant
	M	Winter	(-) Low food abundance
Cypress-tupelo swamp	M	Spring	(-) Low food abundance
	F & M	Summer	(-) Low food abundance

Table 3.2. Continued.

Within-home-range Seasonal Habitat Use			
Predictor variable	Sex	Season	Hypothesis
Cypress-tupelo swamp	F & M	Fall	(+) Potential food source for hard mast such as water tupelo *(Nyssa aquatica*)
	M	Winter	(-) Low food abundance
County / residential road density	F & M	Spring	(+) Foods can be found on edge of roads within relatively small home ranges, roads in home ranges are not very high density or traveled often by people
	F	Summer & fall	(+) Foods can be found on edge of roads within relatively small home ranges, roads in home ranges are not very high density or traveled often by people
	M	Summer, fall & winter	(-) Home ranges are large and more residential type roads are present in home ranges

Table 3.3. Hierarchical models for the relative probability of annual American black bear habitat use, where *p* is the probability of habitat use. Variables are specific by sex. Candidate models that include variables at both the location and home range levels were post-hoc and multi-level variables were selected from the confidence set of location and home-range-level models below. The final global models contained all variables run in the final model set for both sexes.

Location-level only models $\mathit{logit}\,(p) = (\gamma_{00})\ +\beta_i X_i + ...\beta_j X_j$, where (γ_{00}) is the intercept at the home-range-level, representing nonselective home range habitat use within the study area.			
1 * Global (males)	Clear-cut, agriculture, hardwood forest, cypress-tupelo swamp, county / residential road density	7	Clear-cut, hardwood forest
2*	Clear-cut, agriculture, hardwood forest, cypress-tupelo swamp	8	Clear-cut, county / residential road density
3 Global (females)	Clear-cut, hardwood forest, cypress-tupelo swamp, county / residential road density	9	Clear-cut
4	Clear-cut, hardwood forest, county / residential road density	10	hardwood forest, county / residential road density
5	Clear-cut, cypress-tupelo swamp, county / residential road density	11	county / residential road density
6	Clear-cut, hardwood forest, cypress-tupelo swamp	Null model**	γ_{00}

Table 3.3. Continued.

Home range-level models $logit(p)_2 = \gamma_{00} + \gamma_{0i}X_{0i} + ...\gamma_{0j}X_{0j}$			
12* Global (males)	Clear-cut, agriculture, hardwood forest, county / residential road density, habitat diversity, highway density	18	Hardwood forest, highway density
13*	Clear-cut, agriculture, hardwood forest, highway density	19	Clear-cut, hardwood forest
14 Global (females)	Clear-cut, hardwood forest, county / residential road density, habitat diversity, highway density	20	Habitat diversity, highway density
15	Clear-cut, habitat diversity, highway density	21	Highway density, county / residential road density
16	Clear-cut, hardwood forest, highway density	22	Habitat diversity
17	Habitat diversity, highway density, county / residential road density	23	Highway density

Models including multi-level variables $logit(p) = (\gamma_{00} + \gamma_{0i}X_{0i} + ...\gamma_{0j}X_{0j}) + \beta_iX_i + ...\beta_jX_j$	
24 (male) Final global model	Clear-cut$_{2,}$ agriculture$_2$, hardwood forest$_2$, county / residential road density$_2$, habitat diversity$_2$, highway density$_2$, Clear-cut$_1$, agriculture$_1$, hardwood forest$_1$, cypress -tupelo swamp$_1$, county / residential road density$_1$
25 (females) Final global model	county / residential road density$_2$, habitat diversity$_2$, highway density$_2$, clear-cut$_1$, hardwood forest$_1$, county / residential road density$_1$

Table 3.3. Continued.

Models with variables at both the home range and the location-level			
26	County / residential road density$_2$, highway density$_2$, Clear-cut$_1$, hardwood forest$_1$	28	County / residential road density$_2$, highway density $_2$, hardwood forest$_1$
27	County / residential road density$_2$, highway density$_2$, clear-cut$_1$,	29	County / residential road density$_2$, highway density $_2$, county / residential road density $_{1,}$

Models that were not assessed for females are marked with an asterisk *.

The null model** was run for all levels and for the final model set.

[a] A subscript of 1 or 2 signifies the variable was measured at the location-level or the home-range-level respectively.

Table 3.4. Seasonal models for within-home-range habitat use by American black bears in central Georgia, USA, May 2003 to August 2004. Models were hierarchical and assumed no explanatory variables for home range habitat use within the study area.

Spring (Males)			
1	Clear-cut, pine plantation, cypress-tupelo swamp, county / residential road density	5	Pine plantation, county / residential road density
2	Clear-cut, pine plantation, cypress-tupelo swamp	6	Pine plantation
3	Clear-cut, pine plantation, county / residential road density	7	Clear-cut
4	Clear-cut, pine plantation	8	Null model **
Spring (Females)			
1	Clear-cut, hardwood forest, pine plantation, county / residential road density	4	Hardwood forest, pine plantation
2	Clear-cut, hardwood forest, pine plantation	5	Pine plantation, clear-cut
3	Pine plantation, county / residential road density	6	Pine plantation
Summer (Males)			
1	Clear-cut, agriculture, pine plantation, hardwood forest, cypress-tupelo swamp, county / residential road density	5	Clear-cut, pine plantation, county / residential road density
2	Clear-cut, agriculture, pine plantation, hardwood forest, cypress-tupelo swamp	6	Clear-cut, pine plantation

Table 3.4. Continued.

Summer (Males)			
3	Clear-cut, pine plantation, county / residential road density	7	Clear-cut, county / residential road density
4	Clear-cut, agriculture, cypress-tupelo swamp	8	Clear-cut
Summer (Females)			
1	Clear-cut pine plantation, hardwood forest, cypress-tupelo swamp, county / residential road density	4	Clear-cut, cypress-tupelo swamp
2	Clear-cut, pine plantation, hardwood forest, cypress-tupelo swamp	5	Clear-cut, pine plantation
3	Clear-cut, pine plantation, county / residential road density	6	Clear-cut, hardwood forest
Fall (Males)			
1	Clear-cut, agriculture, hardwood forest, cypress-tupelo swamp, county / residential road density	5	Hardwood forest, agriculture
2	Hardwood forest, clear-cut, county / residential road density	6	Hardwood forest, county / residential road density
3	Agriculture, hardwood forest, cypress-tupelo swamp	7	Cypress-tupelo swamp, agriculture
4	Hardwood forest, cypress-tupelo swamp	8	Hardwood forest

Table 3.4. Continued.

Fall (Females)			
1	Hardwood forest, clear-cut, cypress-tupelo swamp, county / residential road density	4	Hardwood forest, county / residential road density
2	Hardwood forest, clear-cut, county / residential road density	5	Hardwood forest, clear-cut
3	Hardwood forest, cypress-tupelo swamp	6	Hardwood forest
Winter (males only)			
1	Agriculture, cypress-tupelo swamp, pine plantation, hardwood forest	4	Agriculture, diversity
2	Agriculture, cypress-tupelo swamp, pine plantation	5	Cypress-tupelo swamp, pine plantation
3	Agriculture, cypress-tupelo swamp	6	Cypress-tupelo swamp

The null model** was run for both males and females for all seasons and did not include any explanatory variables and assumed that within-home-range and within-study-area habitat use is nonselective or can not be explained by the variables used.

Table 3.5. The number of parameters (*K*), Akaike's Information Criterion (AIC), delta AIC and AIC model weights (*w*) for occupancy models used to estimate probability of detection for American black bear habitat model validation for central Georgia, USA. Data are detections of bears at hair snares (n=409) within trapping webs ('web') over 2 years (yr.) from May – August, 2003 – 2005.

Candidate models	*K*	AIC	Δ AIC	*w*
psi(web), gamma(.), eps(.), p(yr*web)	22	2109.3	0	0.7764
psi(web), gamma(.), eps(.), p(web)	20	2112.05	2.75	0.1963
psi(yr*web), gamma(.), eps(.), p(web)	22	2116.05	6.75	0.0266
psi(.), gamma(.), eps(.), p(web)	12	2123.84	14.54	0.0005
psi(.), gamma(.), eps(.), p(yr*web)	8	2127.25	17.95	0.0001
psi(.), gamma(.), eps(.), p(web)	6	2129.09	19.79	0
psi(.), gamma(.), eps(.), p(yr)	5	2294.92	185.62	0
psi(.), gamma(.), eps(.), p(yr)	5	2294.92	185.62	0

psi = probability of occupancy, gamma = probability of colonization, eps = probability of extinction and p = probability of detection

Table 3.6. The confidence set of models for the evaluation of location-level variables to be included in the final model set for predicting annual habitat use by female American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975) of the mean AICc, Δ AICc, and Akaike weights (*w*) for candidate models (*i*) that included only location-level variables measured within the home range and compared to bear locations, May 2003 – August 2004.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	w_i
Intercept only	1	299.471	302.043	268.74	344.183	0.000	0.919

Table 3.7. The confidence set of models for the evaluation of home-range-level variables to be included in the final model set for predicting annual habitat use by female American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975) of the mean AICc, Δ AICc, and Akaike weights (*w*) for candidate models (*i*) that included only home-range-level variables measured within the study area and compared to the home range, May 2003 – August 2004.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Home range-level: county / residential road density, Highway density	3	255.302	266.102	227.559	304.112	0	0.813
Home range-level: county / residential road density, highway density, habitat diversity	3	251.041	269.041	229.494	306.58	2.939	0.187

Table 3.8. The final confidence set of models for predicting annual habitat use by female American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during May 2003 – August 2004.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Home range-level: county / residential road density, highway density	3	255.302	266.102	227.559	304.112	0	0.791
Home range-level: county / residential road density, highway density, habitat diversity	4	251.041	269.041	229.494	306.580	2.939	0.182

Table 3.9. Mean model averaged estimates ($\bar{x}$) for predicted annual female American black bear habitat use in central Georgia, USA based on data collected during 2003 – 2004, and the associated lower an upper 95% Bayesian Credibility Intervals (q025, q975).

Parameter	$\bar{x}$	q025	q975	Unconditional Variance
Intercept	1.497	0.490	2.587	0.478
Home range-level county/ residential road density	-2.788	-4.419	-1.382	0.615
Home range-level highway density	-2.568	-5.218	-0.329	1.615
Home range-level habitat diversity	0.322	-0.148	0.846	0.730

Table 3.10. The confidence set of within-home-range spring habitat use models for female American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during April 1 – June 13, 2003 and 2004.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Intercept only	1	375.301	377.873	376.8704	380.715	0.000	0.74444
County / residential road density	2	375.453	381.453	377.9510	386.170	3.580	0.12429
Pine plantation	2	375.684	381.684	377.7627	386.722	3.812	0.11069

Table 3.11. The confidence set of within-home-range summer habitat use models for female American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during June 14 – August 31, 2003 and 2004.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Intercept only	1	375.300	377.871	376.870	380.711	0.000	0.689
County / residential road density	2	374.929	380.929	377.087	385.711	3.058	0.149
Clear-cut	2	375.305	381.305	376.139	386.411	3.434	0.124

Table 3.12. The confidence set of within-home-range fall habitat use models for female American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during September 1 – Den entry, 2003.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Intercept only	1	373.303	377.589	376.585	380.439	0	0.821
Hardwood forest	2	375.038	381.038	374.972	386.892	3.4487	0.147

Table 3.13. The confidence set of candidate models for predicting annual habitat use by male American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during May 2003 – August 2004.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Home range-level: county / residential road density, highway density	3	257.444	265.844	225.637	305.444	0.000	0.473
Home range-level: county / residential road density, highway density, diversity	4	255.070	267.514	232.437	305.976	1.671	0.205
Home range-level: county / residential road density, highway density, hardwood forest	4	256.170	268.615	226.101	308.577	2.771	0.118
Home range-level: county / residential road density, highway density, Location-level county / residential road density	4	256.285	268.729	228.354	311.576	2.885	0.112

Table 3.14. Mean model averaged estimates ($\bar{x}$) for predicted annual male American black bear habitat use in central Georgia, USA based on data collected during 2003 – 2004, and the associated lower an upper 95% Bayesian Credibility Intervals (q025, q975).

Parameter	$\bar{x}$	q025	q975	Unconditional variance
Intercept	1.203	0.245	2.200	0.327
Home range-level county/ residential road density	-2.244	-3.812	-0.768	0.618
Home range-level highway density	-1.373	-3.765	0.919	1.384
Home range-level habitat diversity	0.188	-0.346	0.722	0.466
Location-level hardwood forest	-0.022	-0.259	0.219	0.126
Location-level level county/ residential road density	-0.065	-0.257	0.127	0.115
Location-level clear-cut	-0.017	-0.250	0.222	0.151

Table 3.15. The confidence set of within-home-range spring habitat use models for male American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during April 1 – June 13, 2003 and 2004.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Intercept only	1	433.524	435.857	434.857	438.708	0.000	0.566
Pine plantation	2	433.585	438.676	434.152	444.122	2.819	0.138
Clear-cut	2	433.619	438.709	434.050	444.379	2.852	0.136
County / residential road density	2	433.741	438.832	436.815	442.867	2.974	0.128

Table 3.16. The confidence set of within-home-range summer habitat use models for male American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during June 14 – August 31, 2003 and 2004.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Intercept only	1	466.796	469.129	469.794	473.637	0.000	0.560
Clear-cut	2	468.533	471.624	468.825	480.171	2.494	0.161
Pine plantation	2	469.072	472.163	471.037	480.042	3.034	0.123
County / residential road density	2	469.465	472.555	472.2	480.012	3.426	0.101

Table 3.17. The confidence set of within-home-range fall habitat use models for female American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during September 1 – December 31, 2003.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Intercept only	1	433.525	435.858	434.857	438.699	0.000	0.693
Hardwood forest	2	433.507	438.598	433.641	444.632	2.740	0.176

Table 3.18. The confidence set of within-home-range winter habitat use models for male American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during January 1 – March 31, 2004.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Intercept only	1	366.984	369.318	368.315	372.168	0.000	0.721
Cypress-tupelo swamp	2	367.145	372.236	367.503	377.938	2.918	0.168
Agriculture	2	364.783	373.183	367.295	378.625	3.865	0.104

Table 3.19. The mean posterior parameter estimate ($\bar{x}$) from the confidence set of candidate models for the evaluation of location-level variables to be included in the final model set for predicting annual habitat use by female American black bears in central Georgia, USA based on data collected during May 2003 – August 2004.

		95% Bayesian Credible Interval	
Parameter	$\bar{x}$	q025	q975
Intercept	0.000	-0.267	0.270

Table 3.20. The mean posterior parameter estimates ($\bar{x}$) from the confidence set of candidate models for the evaluation of home-range-level variables to be included in the final model set for predicting annual habitat use by female American black bears in central Georgia, USA based on data collected during 2003 – 2004 .

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
County / residential road density, highway density			
Intercept	1.730	0.853	2.660
County / residential road density	-2.865	-4.452	-1.374
Highway density	-2.678	-5.280	-0.218
County / residential road density, highway density, habitat diversity			
Intercept	0.711	-1.153	2.492
County / residential road density	-2.873	-4.553	-1.300
Highway density	-2.479	-4.916	-0.185
Habitat diversity	1.770	-0.909	4.541

Table 3.21. The mean posterior parameter estimates ($\bar{x}$) for the confidence set of models from the final set of models for predicting annual habitat use by female American black bears in central Georgia, USA based on data collected during 2003 – 2004.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Home range-level: county / residential road density, highway density			
Intercept	1.730	0.853	2.660
County / residential road density	-2.865	-4.452	-1.374
Highway density	-2.678	-5.280	-0.218
Home range-level: county / residential road density, highway density, habitat diversity			
Intercept	0.711	-1.153	2.492
County / residential road density	-2.873	-4.553	-1.300
Highway density	-2.479	-4.916	-0.185
Habitat diversity	1.770	-0.909	4.541

Table 3.22. Mean parameter estimates ($\bar{x}$) for the confidence set of models outside the confidence set of within-home-range spring habitat use models for female American black bears in central Georgia, USA based on pooled data collected during den exit - June 13, 2003 and 2004.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Intercept only			
Intercept	0.000	-0.239	0.239
County / residential road density			
Intercept	-0.060	-0.348	0.228
County / residential road density	0.468	-0.779	1.728
Pine plantation			
Intercept	-0.008	-0.273	0.256
Pine plantation	0.066	-0.911	1.032

Table 3.23. Mean parameter estimates ($\bar{x}$) for the confidence set of within-home-range summer habitat use models for female American black bears in central Georgia, USA based on pooled data collected during June 14 – August 31, 2003 and 2004.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Intercept only			
Intercept	0.000	-0.237	0.240
County / residential road density			
Intercept	-0.082	-0.370	0.203
County / residential road density	0.625	-0.567	1.825
Clear-cut			
Intercept	-0.012	-0.264	0.237
Clear-cut	0.294	-1.441	2.080

Table 3.24. Mean parameter estimates ($\bar{x}$) for the confidence set of within-home-range fall habitat use models for female American black bears in central Georgia, USA based on data collected during September 1 – Den entry, 2003.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Intercept only			
Intercept	0.000	-0.239	0.239
Hardwood forest			
Intercept	-0.021	-0.279	0.237
Hardwood forest	0.278	-1.084	1.712

Table 3.25. Mean parameter estimates ($\bar{x}$) for the confidence set of candidate models for predicting annual habitat use by male American black bears in central Georgia, USA based on data collected during 2003 – 2004.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Home range-level: county / residential road density, highway density			
Intercept	1.282	0.516	2.098
County / residential road density	-2.235	-3.799	-0.785
Highway density	-1.334	-3.720	0.953
Home range-level: county / residential road density, highway density, habitat diversity			
Intercept	0.771	-0.874	2.417
County / residential road density	-2.164	-3.745	-0.648
Highway density	-1.368	-3.750	0.942
Habitat diversity	0.919	-1.685	3.522

Table 3.25. Continued.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Home range-level: county / residential road density, highway density, location-level County / residential road density			
Intercept	1.405	0.581	2.275
Home range-level county / residential road density	-2.297	-3.868	-0.780
Home range-level highway density	-1.523	-4.008	0.740
Location-level County / residential road density	-0.580	-2.304	1.138

Table 3.26. Mean parameter estimates ($\bar{x}$) for the confidence set of within-home-range spring habitat use models for male American black bears in central Georgia, USA based on pooled data collected during April 1 – June 13, 2003 and 2004.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Intercept only			
Intercept	0.000	-0.222	0.223
Pine plantation			
Intercept	-0.020	-0.265	0.226
Pine plantation	0.192	-0.750	1.163
Clear-cut			
Intercept	-0.002	-0.234	0.229
Clear-cut	0.049	-1.770	1.874
County / residential road density			
Intercept	0.041	-0.223	0.300
County / residential road density	-0.374	-1.632	0.896

Table 3.27. Mean parameter estimates ($\bar{x}$) for the confidence set of within-home-range summer habitat use models for male American black bears in central Georgia, USA based on pooled data collected during June 14 – August 31, 2003 and 2004.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Intercept only			
Intercept	0.000	-0.213	0.215
Clear-cut			
Intercept	-0.014	-0.240	0.208
Clear-cut	0.346	-1.395	2.103
Pine plantation			
Intercept	-0.002	-0.234	0.229
Pine plantation	0.049	-1.770	1.874
County / residential road density			
Intercept	-0.006	-0.258	0.246
County / residential road density	0.051	-1.082	1.187

Table 3.28. Mean parameter estimates ($\bar{x}$) for the confidence set of within-home-range fall habitat use models for male American black bears in central Georgia, USA based on pooled data collected during September 1 – December 31, 2003.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Intercept only			
Intercept	0.000	-0.221	0.224
Hardwood forest			
Intercept	-0.010	-0.247	0.228
Hardwood forest	0.163	-1.209	1.544

Table 3.29. Mean parameter estimates ($\bar{x}$) for the confidence set of within-home-range winter habitat use models for male American black bears in central Georgia, USA based on pooled data collected during January 1, 2003 – April 1, 2004.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Intercept only			
Intercept	0.000	-0.241	0.242
Cypress-tupelo swamp			
Intercept	-0.007	-0.261	0.249
Cypress-tupelo swamp	0.156	-1.414	1.796
Agriculture			
Intercept	-0.017	-0.270	0.237
Agriculture	0.428	-1.411	2.340

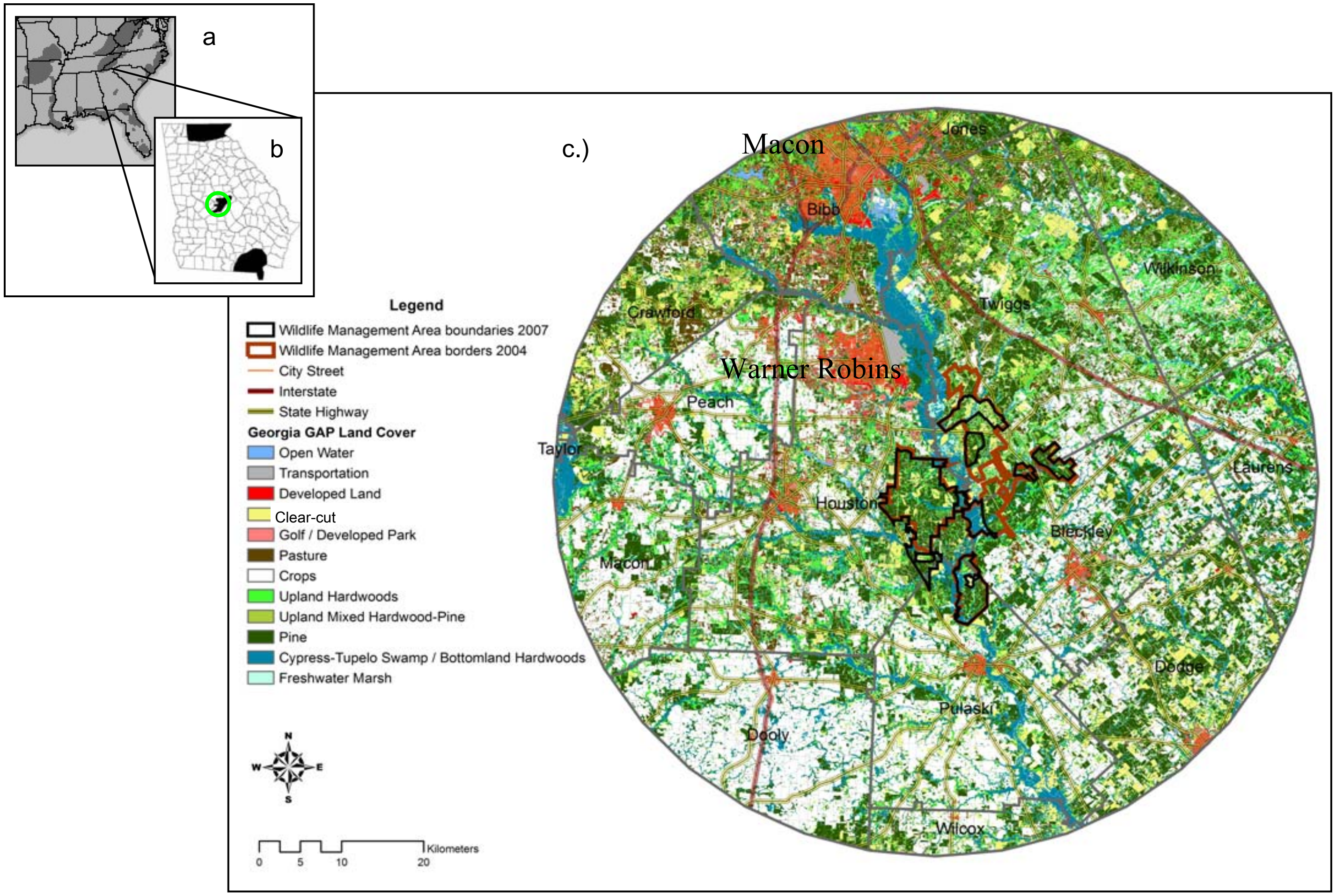

Figure 3.1. a) Distribution of black bears in the southeastern USA (Pelton et al. 1999), b) Distribution of black bears in Georgia, estimated by frequency of sightings (Carlock et al. 1999). c.) The Central Georgia population ranges over the Counties of Houston, Bibb, Pulaski, Bleckley, Twiggs and Wilkinson. Study area for habitat analysis of black bears in central Georgia, 2003 – 2004.

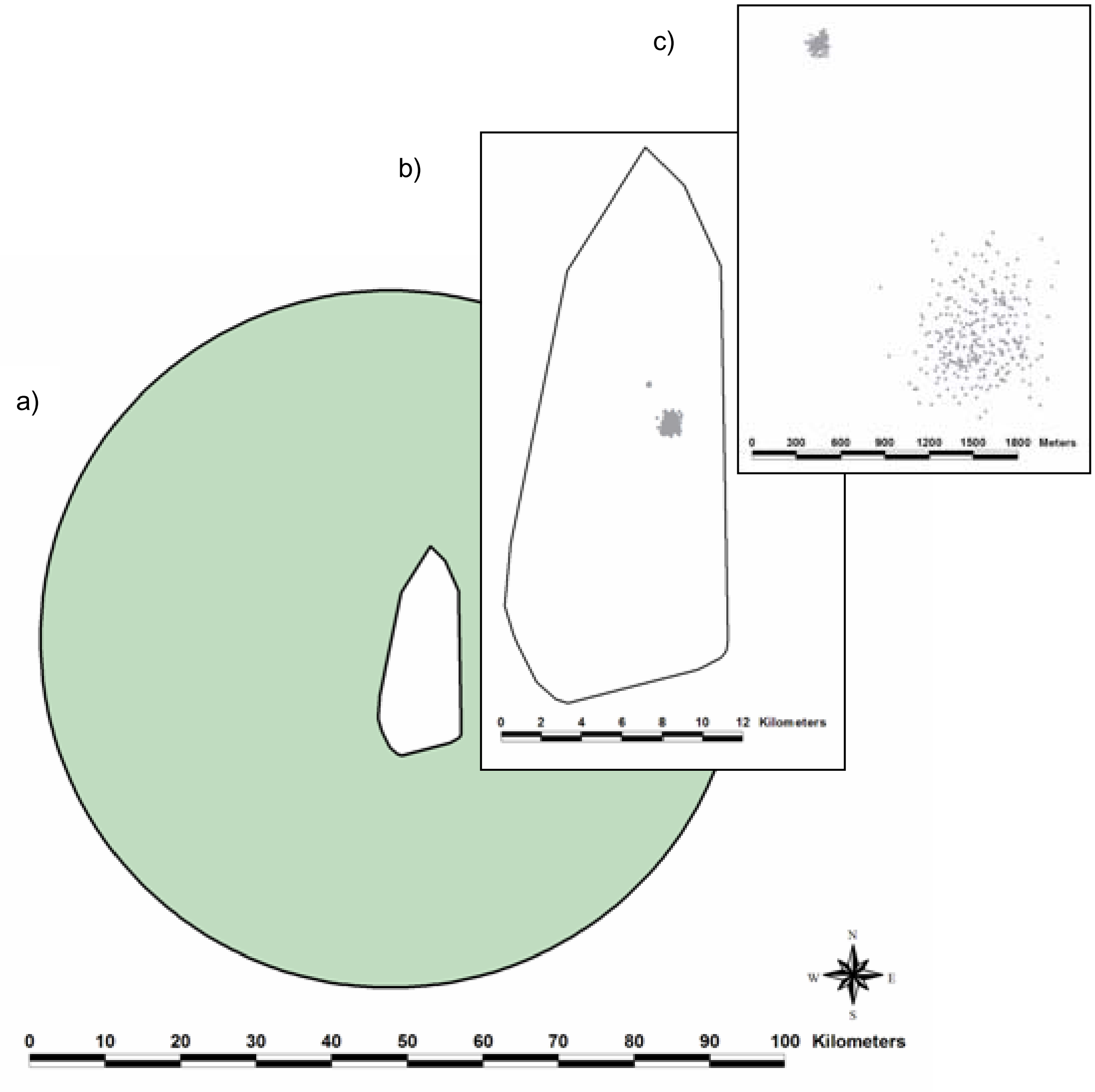

Figure 3.2. Schematic to depict habitat sampling points for 2 scales of within-home-range location habitat and within-study-area home range habitat. Random points were sampled within error clouds (a) that represented the distribution of location error. These location presence data were compared to random conditional absence points in home ranges (b) and these home range points were then considered home range presence data and were compared to random points within individual study areas of each bear outside the MCP home range (c), which were considered conditional absence data at the home range scale.

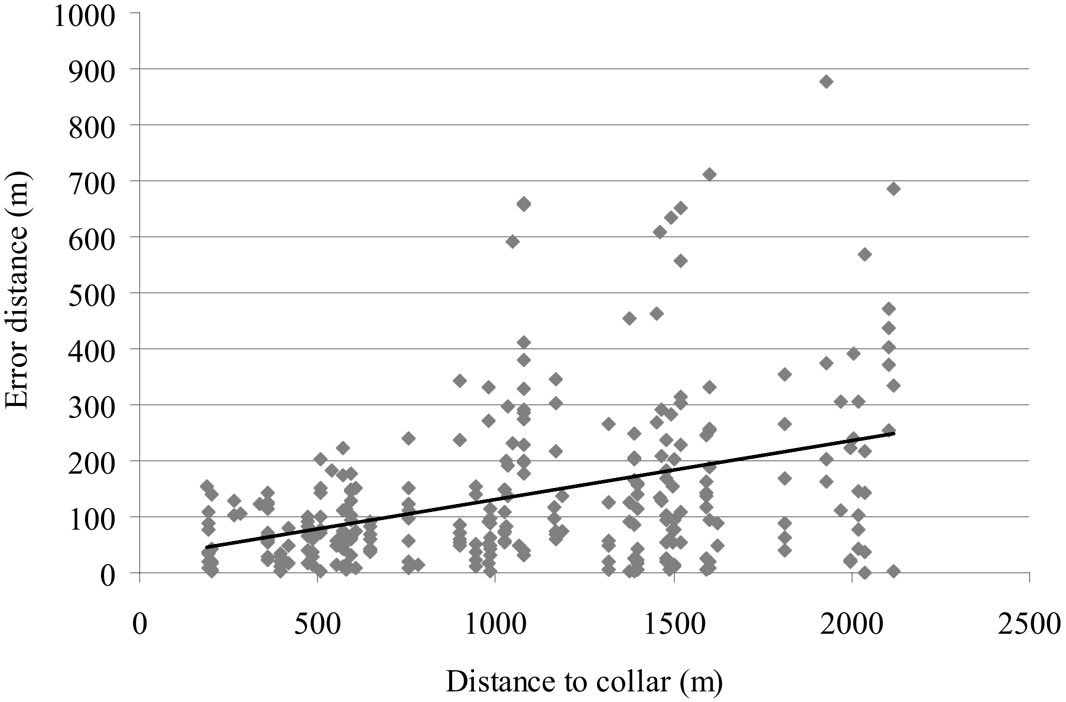

Figure 3.3. Radio telemetry error in a study of American black bear (*Ursus americanus*) habitat use in central Georgia, USA. Error distance (m) from estimated radio-transmitter locations to known radio-transmitter locations is plotted against distance between radio-transmitters and receivers.

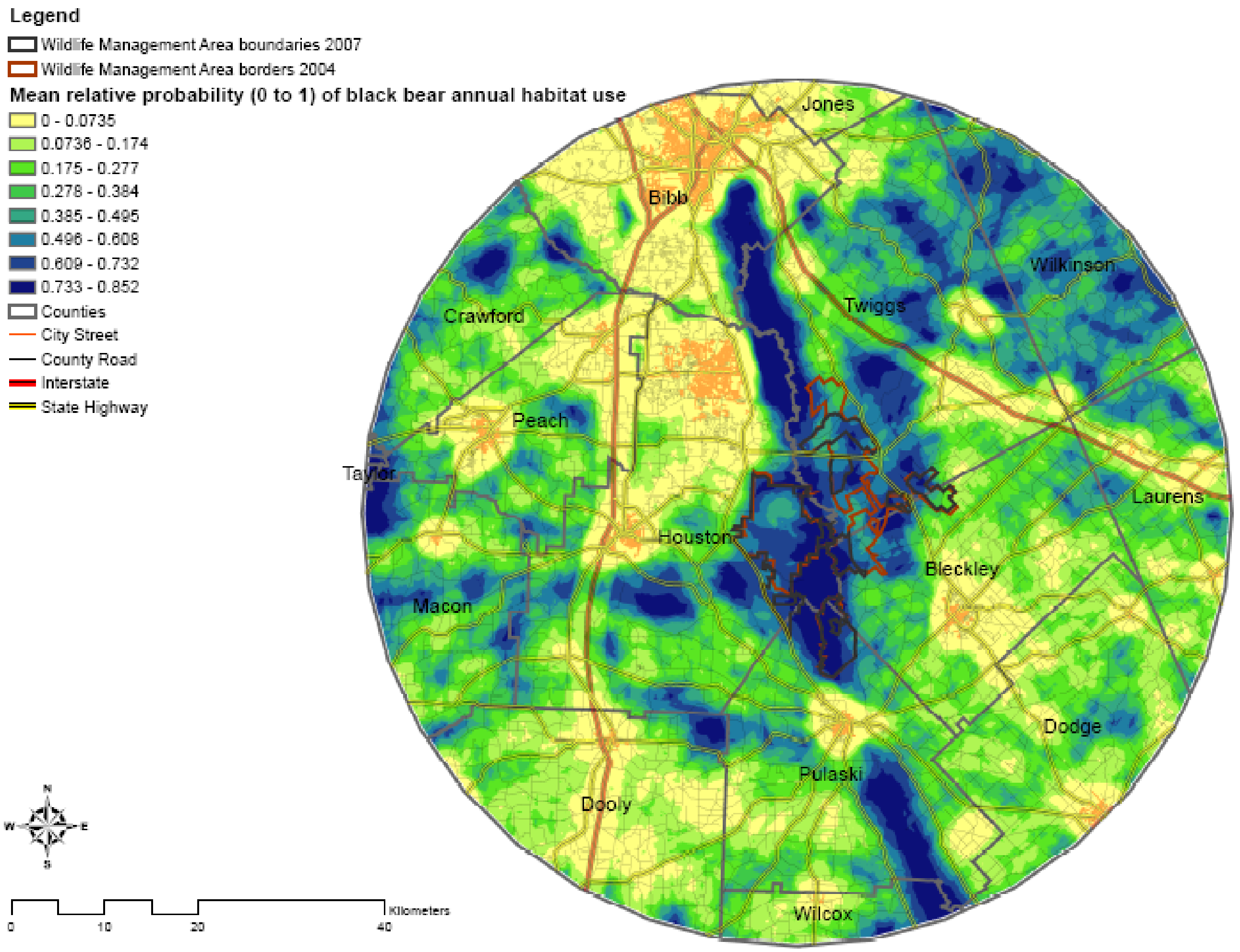

Figure 3.4. Mean predicted relative probability of female American black bear (*Ursus americanus*) annual habitat use in central Georgia, USA 2003-2004, based on county / residential road density, highway density and habitat diversity. Male predicted annual habitat use did not differ visibly from that of females.

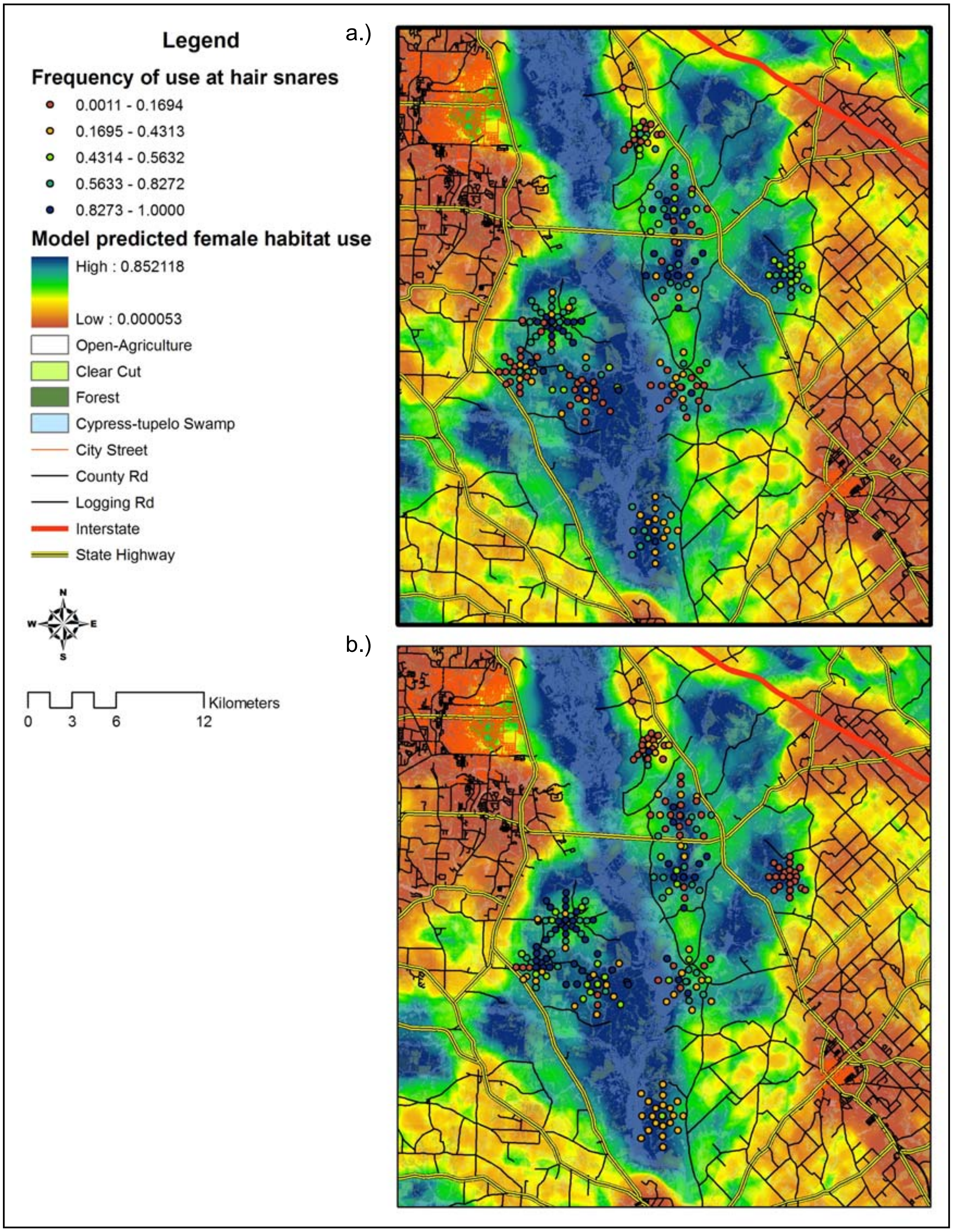

Figure 3.5. Schematic of bear hair trap frequencies, which include the probability of false absence, as compared to predicted female mean annual habitat use (2003 – 2004), for hair snares (dots) sampled in a.) 2004 and b.) 2005 in central Georgia, USA

CHAPTER 4

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

We gathered data and conducted analyses that would provide holistic, initial information about the space requirements, movement patterns and habitat used by bears in central Georgia from which more in-depth studies and management can take place. Central to the health of populations of American black bear and all wildlife are habitats that provide sufficient quality food sources that sustain reproduction and recruitment coupled with sufficient proximity of other populations to facilitate genetic exchange. The availability of these resources for the black bear, which is now a species that is predated almost exclusively by humans in the southeastern USA, depends on the relative mortality risk to bears from poaching and vehicle collisions. Habitat fragmentation and loss, facilitated by roads, exposes bears to this human-induced mortality. These factors, in addition to human population growth, have been cited as one of the primary management concerns for black bear populations, especially in the Southeast US (Hellgren and Maehr 1992, Hellgren and Vaughan 1994, Pelton et al. 1999, Maehr et al. 2003, Dixon et al. 2004, Simek et al. 2005). We found that the probability of habitat use, and bear movement were constrained by highway and county / residential road density and traffic volume. Thus, habitat fragmentation and loss particularly from roads should be considered in habitat management plans for the CGP.

According to our hierarchical models, bears exhibited what appeared to be nonselective annual and seasonal habitat use within their home ranges and within the study area from 2003 to 2004. This finding was supported by scat content analysis. Although within-home-range habitat use appeared to be nonselective, the presence of bear home ranges was somewhat related to areas of relatively high forest associated habitat diversity within the study area and this requires further study. The availability and use of upland hardwoods should be studied with ground surveys and more accurate telemetry and vegetation maps, since this habitat type is reportedly an important source of fall nutrition tied to reproductive success (Elowe and Dodge 1989, Eiler et al. 1989, Costello et al. 2003). This habitat accounted for 73% of misclassification in the GAP vegetation map. It was also the most fragmented causing potential bias in our habitat models from telemetry error (Samuel and Kenow 1992). Despite the possibility of sampling error, there is support that bears did not use any habitat type above its availability within its home range. When habitat use is nonselective it is expected that habitat diversity would be a component in predicting the location of a bear home range and we found evidence of this. , The results of the scat analysis do support the conclusion that nonselective habitat use likely occurred within home ranges. Scat analysis can also be somewhat biased against easily digested foods. However, we found that shifts in male centers of activity in fall coincided with changes in the major fall scat contents which suggest that items detected in scats were likely important food sources. Scats were dominated by soft mast plant foods that occur in all forestry related non-agricultural habitats where bears were tracked (Burns and Honkala 1990, Clark et al. 1994).

It appeared that sufficient habitat productivity existed in the year of our study to provide sufficient food for reproduction. However, changes in habitat productivity and loss should be monitored due to the predominance of private lands and potential increases in development in the CGP range. Limited research shows that pine timberlands are productive habitats for hard and soft mast (Clark et al. 1994). In a region of extensive pine plantation with a prolonged growing season, soft mast can be sufficient for reproduction provided it is abundant (Kasbohm et al. 1996, McDonald and Fuller 2005). However in the Coastal Plain of North Carolina a landscape dominated by loblolly pine plantations, human infrastructure and development, bear annual and seasonal home ranges were significantly larger than in a paired landscape with less development and more natural plant communities (Jones and Pelton 2003). Pine stands of all age classes were the least productive for bear soft mast foods in Arkansas and were used less than expected, while mixed pine-hardwood and upland hardwoods were most productive in both soft and hard mast (Clark et al. 1994). Studies in Washington State demonstrated a black bear population decline on an island dominated by evergreen forest after clear cuts matured and timber operations ceased (Lindsey and Meslow 1986). If pine timberlands are converted to residential land uses, or are managed more intensely by heavy suppression of other plants, the availability of bear foods will likely decrease. This may cause bears to attempt to travel more widely or to emigrate from the CGP range or during seasons of low food availability, exposing bears to higher mortality risk from roads and encounters with people. Management and restoration of highly productive habitats comprised by diverse plant communities may be necessary to accommodate bears in increasingly limited habitat.

Fall availability of soft and hard mast foods and their associated habitat types are particularly important to consider in management plans. Fall mast abundance is known to have the greatest effect on black bear reproductive success in the southeastern USA (Dobey et al. 2005), bear nuisance (Garshelis and Pelton 1981, Oka et al. 2004), non-harvest mortality (Ryan et al. 2007) and harvest (Noyce and Garshelis 1997). We found that common persimmon (*Diospyros virginiana*) was dominant in fall scats while acorns and other hard mast were virtually absent. Persimmon is probably ubiquitous among all habitat types in the CGP but does not produce fruit until the age of 10 yr. with optimal mast production at 25 yr. (Burns and

Honkala 1990) and so forest stand age is a management concern. Persimmon is similar to the nutrition quality of acorn hard mast (Short and Epps 1976, Inman and Pelton 2002). However, persimmon may not be an optimal food source as it was detected at scat volumes less than its availability in areas of Arkansas with abundant acorns (Clapp 1990) and later in the fall after black gum and acorns became less abundant (Hellgren et al. 1989). Thus we can not conclude that persimmon is an optimal fall food type. We only followed bears for one year and it was possibly a poor year for hard mast yield, which was the case in the north Georgia mountains in 2003. Mast from water tupelo (*Nyssa aquatica*), present in Cypress-tupelo swamps, and any black gum (*Nyssa sylvatica*) that might exist in the CGP range was also not detected although these species provide fall hard mast food sources, so these may also have been in low abundance. We also sampled less scat in forested wetlands because these contained few roads. Female home ranges did not overlap extensively which does suggest that resources were limited during our study (Powell et al. 1997). Temporal variability in precipitation affect the productivity of bear food species and thus a variety of available mast species and their associated habitats are needed to safeguard sufficient seasonally available food sources.

The extensive cypress-tupelo swamp, which contains limited bottomland hardwood forest, is largely devoid of roads and was predicted to be among the most suitable for black bear home range use in our models. We cannot conclude, however, that these linear systems are potentially suitable bear habitat without further research concerning the abundance of bear foods in these plant communities. Cypress-tupelo swamp and bottomland hardwoods in Louisiana, with similar plant composition to central Georgia, have been shown to contain low abundance of soft mast, available in the spring and summer, and a low abundance of fall hard mast (Hersey et al. 2005). Bears were thought to use cypress swamps mainly as escape cover and the majority of food items found in scat originated in other habitats in the Okefenokee (Dobey et al. 2005). Water tupelo (*Nyssa aquatica*), a dominant tree in the Cypress-tupelo vegetation class, has been found to yield 7 times fewer seeds than black-gum (*Nyssa sylvatica*) (Stiles 1980), an important bear food in the Okefenokee, the abundance of which is unknown in central Georgia. Without the presence of diverse upland habitat, these linear systems would likely support less year-round food abundance for black bears or sufficient space through which bears could move without disturbance.

It is unknown whether bear habitat in central Georgia is preferred by bears, or whether the CGP exists in their range because it is relatively remote from human encroachment. A wealth of information exists regarding black bear habitat quality and food sources in the southeastern USA. We recommend that a vegetation survey should be planned to sample the CGP range as has been done in other parts of the Southeast US (Hersey et al. 2005) in order to assess mast availability for bears, which will better inform habitat management. This would be particularly important for what is classified as cypress-tupelo swamp and limited bottomland hardwoods along river corridors, to provide more fine-scale information in what is one of the least accessible habitats for people. If productive habitat is found to be limited in timber plantations and if significant habitat loss occurs in the CGP, restoration of productive natural habitats should be undertaken, a management strategy that has been successful for the Louisiana black bear (Black Bear Conservation Committee 1997). Lands to the north of I-16, where bear reproduction is unknown, are sparsely settled, dominated by mining operations and are comprised by fairly extensive upland hardwoods and low road densities, thus plant foods and the potential for bear conservation and management should be assessed in this area.

CGP bears ranged over large home ranges and crossed potential barriers such as highways and rivers with results that are comparable to other Southeast US bear populations. The Ocmulgee River did not pose a barrier to males that crossed it regularly and thus may not be a barrier to females without cubs. Although habitat models demonstrated that habitat use was somewhat constrained by county / residential road and highway density, especially for males that traveled widely, highway 96 in the study area at 3,000 to 7,400 cars per day was a passable obstacle to CGP bears. Crossing usually occurred only during shifts in activity centers and during infrequent excursions. This in addition to habitat model results for road density suggests that highway crossing is somewhat avoided and poses a potential risk to bears in the CGP, but is necessary in pursuit of resources. The relationship between road and highway density is less certain for females which rarely ventured off the WMAs, however it is unlikely they would have a more favorable response than males. Due to excessive processing time necessary to run our habitat models it was not possible to test the effects of the study area extent used to delineate available female habitat. Females traveled less widely than males and it is likely that the study area extent was more limited for them. Use of a more limited study area to define availability for females could reveal more accurate habitat and road density relationships.

The need for connective highway underpasses should be evaluated by subsequent genetic research, especially if the CGP in the region of the WMAs shows signs of genetic isolation. The I-16 Interstate was not observed to be crossed by male bears, except by the emigrating female from Atlanta. An interstate highway in Florida was found to be a genetic barrier to bears (Dixon et al. 2004) and the existence of such a barrier should be assessed for the I-16 corridor, especially if suitable habitat exists on the north side. If highway 96, which bisects the WMAs is widened, this would be the best opportunity to install fencing and underpasses and these actions should be seriously considered, especially if significant development may occur on the west side of the river, in order to ensure sufficient habitat access and genetic exchange should hwy. 96 traffic volume increase.

Bears exhibited use of the same widely disperse areas and males traveled to agricultural areas in the fall in the CGP range, a behavior also exhibited by females during poor mast years (Elowe and Dodge 1989). We observed that some bears took excursions to future seasonal ranges including those dominated by agriculture. Bears may have taken excursions to check fruiting phenology or female reproductive status, which would suggest that home ranges are somewhat stable in the CGP. Stable inter-annual home ranges were reported for populations in the Appalachian mountains and in the Okefenokee (Mitchell and Powell 2002, Dobey et al. 2005). Bears using agricultural and common areas may use the same general locations each year. Common areas visited and used by multiple bears outside of the WMAs were mostly on hunting clubs, where they were observed to feed at wildlife feeding stations, or lands near agriculture. Therefore it is important that wildlife managers work with the lease and land owners to educate them about the status of the CGP, once more is known, to facilitate conservation. This spatial information may also help to document important food sources or the presence of breeding females outside of the WMAs more efficiently and may help to mitigate human-bear conflicts.

Future analysis should use population parameters tied to habitat variables to estimate the sufficient extent of habitat necessary to sustain the CGP. This analysis should include measures of uncertainty to attempt to ensure that sufficient habitat is conserved. The area of habitat needed to sustain the CGP will likely be too great for acquisition. CGP managers should explore cooperative habitat conservation agreements and work in partnerships with landowners, land trusts, agencies and local government on a sustainable agreement that will secure habitat for the CGP on private land. A public education effort should also be undertaken so that poaching and nuisance situations can be minimized in this increasingly developed region.

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APPENDIX A

PLANT COMMUNITIES OF CENTRAL GEORGIA, USA

According to the report of the 1987 Soil Conservation Survey (Froeschaer 1989), upland hardwood forests include Scrub Oak (*Quercus ilcifolia)*, Black Jack Oak (*Q. marilandica*), White Oak (*Q. alba*), Hickories (*Carya* spp.), Elms (Ulmus spp.), Sweet Gum (*Liquidamber styraciflua*), Hackberry (*Celtis tenuifolia*), Hawthorne (*Crataegus* spp.), Sassafras (*Sassafras albidum*), American Beech (*Fagus grandifolia*), Red Maple (*Acer rubrum*), Black Cherry (*Prunus serotina*), Sourwood (*Oxydendrum arboreum*), Flowering Dogwood (*Cornus florida*) and Sparkleberry (*Vaccinium arboreum*); mixed pine – hardwood is comprised mostly of Loblolly (*Pinus taeda*) and Shortleaf Pine (*P. echinata*), Scrub Oak, Black Jack Oak, Southern Red Oak, Northern Red Oak (*Q. rubra*), Southern Red Oak (*Q. falcata*), Sassafras, Hackberry, Hawthorne, Sweet Gum, Elms, Southern Magnolia(*Magnolia gradnifolia*), Black Cherry, Flowering Dogwood, Sparkleberry, Buckeye (*Aesculus*), Possumhaw (*Ilex decidua*), and Dwarf Paw Paw (*Asimina parviflora*); bottomland hardwood consists generally of Sweetgum, American Beech, River Birch (*Betula nigra*), Hickories, Water Oak (*Quercus nigra*), Willow Oak (*Quercus phellos*), Yellow Poplar (*Lidodendron tulipifera*), Florida Maple (*cer. batrtatum*), Green Ash (*Fraxinus pennsylvanica*), Hackberry, Musclewood (*Carpinus caroliniana*), Holly (*Ilex* spp.), Eastern Sycamore (*Platanus occidentalis*), Cane (*Arundinarea gigantea*), Privet (*Ligustrum japonicum*), American Serviceberry (*Callicarpa americana*) and Dwarf Paw Paw. Loblolly-Shortleaf Pine plantations were additionally observed during this study to contain Sparkleberry, Blueberry (*Vaccinium* spp.), Persimmon (*Diospyros virginiana*), Muscadine (*Vitis* spp.). Black berry (*Rubus* spp.) was common in clear cuts and along roadsides.

APPENDIX B

MODEL SELECTION RESULTS CONTINUED FOR MODELS OUTSIDE THE CONFIDENCE SET OF AMERICAN BLACK BEAR HABITAT USE MODELS

Table B.1. Candidate models outside the confidence set for the evaluation of location-level variables to be included in the final model set for predicting annual habitat use by female American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975) of the mean AICc, Δ AICc, and Akaike weights (*w*) for candidate models (*i*) that included only location-level variables measured within the home range and compared to bear locations, May 2003 – August 2004.

Candidate model	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Clear-cut, hardwood forest	3	297.678	308.478	268.342	340.232	6.435	0.037
County / residential road density	2	302.633	308.633	263.099	346.633	6.590	0.034
County / residential road density, hardwood forest	3	300.247	311.047	275.321	352.983	9.004	0.010

Table B.1. Continued.

Candidate model	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Clear-cut, cypress-tupelo swamp, hardwood forest	4	301.27	319.270	279.081	356.601	17.228	$1.668\text{x}10^{-04}$
County / residential road density, clear-cut, hardwood forest	4	302.077	320.077	282.597	359.909	18.034	0.000
County / residential road density, clear-cut, cypress-tupelo swamp	4	304.436	322.436	283.489	358.464	20.393	0.000
County / residential road density, clear-cut, cypress-tupelo swamp, hardwood forest (Global model)	5	305.899	330.899	292.784	376.111	28.856	0.000

Table B.2. Candidate models outside the confidence set for the evaluation of home-range-level variables to be included in the final model set for predicting annual habitat use by female American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975) of the mean AICc, Δ AICc, and Akaike weights (*w*) for candidate models (*i*) that included only home-range-level variables measured within the study area and compared to the home range, May 2003 – August 2004.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Highway density, habitat diversity	3	283.899	289.8994	253.042	340.48	23.7974	5.5×10^{-6}
Highway density	2	289.23	295.2304	257.838	338.236	29.1284	3.8×10^{-7}
Habitat diversity	2	291.808	297.8081	252.697	331.118	31.7061	1.1×10^{-7}
Highway density, hardwood forest	3	289.708	300.5076	261.617	343.224	34.4056	2.7×10^{-8}
Intercept only	1	299.471	302.0427	268.74	344.183	35.9407	1.3×10^{-8}
Highway density, habitat diversity, clear-cut	4	285.405	303.4052	264.546	345.221	37.3032	6.5×10^{-9}
Highway density, habitat diversity, clear-cut, hardwood forest (Global model)	5	249.655	303.6548	267.231	345.588	37.5528	5.7×10^{-9}
Highway density, hardwood forest, clear-cut	4	290.741	308.7407	271.013	350.154	42.6387	4.5×10^{-10}

Table B.3. The final set of candidate models outside the confidence set for predicting annual habitat use by female American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during May 2003 – August 2004.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Home range-level: county / residential road density, highway density, location-level: county / residential road density	4	256.766	274.766	235.656	312.560	8.664	0.010
Home range-level: county / residential road density, highway density, location-level: hardwood forest	4	257.027	275.026	238.850	323.469	8.924	0.009
Home range-level: county / residential road density, highway density, location-level: clear-cut	4	257.312	275.312	232.186	311.936	9.210	0.008
Home range-level: county / residential road density, highway density, location-level: hardwood forest, clear-cut (Global model)	5	256.548	286.548	248.266	333.036	20.446	$2.872\text{x}10^{-05}$

Table B.3. Continued.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Home range-level: highway density, habitat diversity	3	283.899	294.699	253.042	340.480	28.597	$4.877\text{x}10^{-07}$
Intercept only	1	299.471	302.043	268.740	344.183	35.941	$1.240\text{x}10^{-08}$
Home range-level highway density	2	289.230	295.230	253.083	334.539	29.128	$3.74\text{x}10^{-7}$
Home range-level habitat diversity	2	291.808	297.808	253.833	332.739	31.706	$1.03\text{x}10^{-7}$
Location-level: hardwood forest, clear-cut	3	297.678	308.478	283.489	358.464	42.376	$4.967\text{x}10^{-10}$
Location-level county / residential road density	2	302.633	308.633	263.099	346.633	42.531	$4.597\text{x}10^{-10}$
Location-level: county / residential road density, hardwood forest	3	300.247	311.047	275.321	352.983	44.945	$1.375\text{x}10^{-10}$
Location-level: county / residential road density, hardwood forest, clear-cut	4	302.077	320.077	282.597	359.909	53.975	$1.505\text{x}10^{-12}$
Home range-level: county / residential road density, highway density, habitat diversity, location-level: county / residential road density, hardwood forest, clear-cut (Global model)	7	249.992	375.992	330.519	416.908	109.890	$1.086\text{x}10^{-24}$

Table B.4. The candidate models outside the confidence set of within-home-range spring habitat use models for female American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during April 1 – June 13, 2003 and 2004.

Candidate models	*K*	-2ln(*l*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Clear-cut, plantation pine	3	375.564	386.364	380.5971	392.750	8.491	0.01067
Hardwood forest, plantation pine	3	375.762	386.562	380.6145	393.278	8.690	0.00966
Clear-cut, hardwood forest, plantation pine	4	375.862	393.862	386.5647	401.463	15.990	0.00025
County / residential road density, clear-cut, hardwood forest, plantation pine (Global model)	5	375.284	405.284	396.6165	414.305	27.411	8.3×10^{-7}

Table B.5. The candidate models outside the confidence set of within-home-range summer habitat use models for female American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during June 14 – August 31, 2003 and 2004.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
County / residential road density, pine plantation	3	374.848	385.648	379.434	392.587	7.777	0.014
County / residential road density, clear-cut	3	375.034	385.834	379.926	392.547	7.963	0.013
Clear-cut, plantation pine	3	375.454	386.254	379.550	393.614	8.383	0.010
County / residential road density, clear-cut, cypress-swamp, hardwood forest, pine plantation (Global model)	6	372.793	426.793	415.154	438.297	48.922	0.000

Table B.6. The candidate models outside the confidence set of within-home-range fall habitat use models for female American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during September 1 – Den entry, 2003.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Cypress-tupelo swamp, hardwood forest	3	375.296	386.096	379.787	393.192	8.50762	0.0117
Clear-cut, hardwood forest	3	375.390	386.190	379.407	393.011	8.60118	0.0111
County / residential road density, hardwood forest	3	375.606	386.406	380.828	392.761	8.81702	0.01
County / residential road density, hardwood forest, clear-cut	4	375.661	393.661	385.801	401.219	16.0726	0.0003
County / residential road density, cypress-swamp, hardwood forest, clear-cut (Global model)	5	375.967	405.967	397.954	414.408	28.3781	5.6×10^{-7}

Table B.7. The candidate models outside the confidence set for predicting annual habitat use by male American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during May 2003 – August 2004.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Home range-level: county / residential road density, highway density, location-level clear-cut	4	256.664	269.108	225.946	308.321	3.264	0.092
Home range-level: county / residential road density, highway density, location-level: clear-cut, hardwood forest	5	266.105	286.105	229.750	306.360	20.261	1.883×10^{-5}
Home range-level: county / residential road density, highway density, hardwood forest, agriculture, clear-cut, habitat diversity	7	253.833	286.500	241.804	325.572	20.656	1.546×10^{-5}
Home range-level: highway density, hardwood forest, habitat diversity	4	281.129	289.529	247.147	324.899	23.686	3.398×10^{-6}
Home range-level highway density	2	284.543	289.634	250.324	322.815	23.790	3.225×10^{-6}

Table B.7. Continued.

Candidate models	K	-2ln(L)	AICc	q025 AICc	q975 AICc	Δ AICc	w
Home range-level: highway density, clear-cut, habitat diversity	4	279.733	292.177	250.185	329.861	26.334	9.041×10^{-7}
Home range-level habitat diversity	2	288.252	293.342	254.162	330.334	27.499	5.050×10^{-7}
Home range-level: highway density, hardwood forest	3	284.978	293.378	250.569	335.158	27.534	4.960×10^{-7}
Home range-level highway density, clear-cut, hardwood forest	4	281.392	293.836	248.284	329.173	27.992	3.945×10^{-7}
Intercept only	1	292.125	294.458	260.184	335.191	28.614	2.891×10^{-7}
Location-level county / residential road density	2	292.651	297.742	262.610	331.830	31.898	5.597×10^{-8}
Home range-level: highway density, hardwood forest, clear-cut, habitat diversity	5	280.470	297.970	259.874	335.997	32.126	4.993×10^{-8}
Home range-level: hardwood forest, clear-cut	3	291.915	300.315	261.864	350.517	34.471	1.546×10^{-8}
Location-level: county / residential road density, hardwood forest	3	292.329	300.729	266.000	335.751	34.886	1.257×10^{-8}

Table B.7. Continued.

Candidate models	K	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Location-level: clear-cut, hardwood forest	3	293.759	302.159	270.030	344.960	36.316	6.147×10^{-9}
Location-level: county / residential road density, clear-cut	3	294.200	302.600	269.707	344.350	36.757	4.931×10^{-9}
Location-level: county / residential road density, clear-cut, hardwood forest	4	292.815	305.259	261.630	338.401	39.416	1.305×10^{-9}
Location-level: clear-cut, cypress-tupelo swamp, hardwood forest	4	293.804	306.249	270.798	346.551	40.405	7.955×10^{-10}
Location-level: county / residential road density, clear-cut, cypress-tupelo	4	294.194	306.638	271.012	345.982	40.794	6.548×10^{-10}
Location-level: county / residential road density, clear-cut, hardwood forest, cypress-swamp	5	293.016	310.516	267.004	344.969	44.673	9.419×10^{-11}
Location-level: agriculture, clear-cut, cypress-tupelo, hardwood forest	5	293.330	310.830	274.169	345.761	44.986	8.051×10^{-11}

Table B.7. Continued.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Location-level: county / residential road density, clear-cut, hardwood forest, cypress-swamp, agriculture	6	294.393	318.393	280.602	356.486	52.549	1.835×10^{-12}
Home range-level: county / residential road density, highway density, hardwood forest, agriculture, clear-cut, habitat diversity, location-level: county / residential road density, clear-cut, hardwood forest, cypress-swamp, agriculture (Global model)	12	252.583	588.583	543.248	632.313	322.739	3.913×10^{-71}

Table B.8. The candidate models outside the confidence set of within-home-range spring habitat use models for male American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during April 1 – June 13, 2003 and 2004.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Clear-cut, plantation pine	3	433.733	442.133	435.935	448.553	6.276	0.025
County / residential road density, clear-cut, plantation pine	4	433.241	445.685	437.678	453.559	9.828	0.004
Clear-cut, cypress-tupelo swamp, plantation pine	4	433.672	446.116	437.817	453.723	10.259	0.003
County / residential road density, clear-cut, plantation pine, cypress-tupelo swamp (Global model)	5	432.985	450.485	440.526	459.661	14.628	0.000

Table B.9. The candidate models outside the confidence set of within-home-range summer habitat use models for male American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during June 14 – August 31, 2003 and 2004.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Clear-cut, plantation pine	3	469.785	475.185	472.659	485.447	6.056	0.027
County / residential road density, clear-cut	3	470.155	475.555	472.899	485.986	6.426	0.023
Agriculture, clear-cut, cypress-tupelo swamp	4	469.799	478.244	472.855	490.194	9.114	0.006
County / residential road density, agriculture, clear-cut, cypress-tupelo swamp, hardwood forest, plantation pine (Global model)	7	473.403	499.070	482.776	505.049	29.940	$1.764\text{x}10^{-07}$

Table B.10. The candidate models outside the confidence set of within-home-range fall habitat use models for female American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during September 1 – December 31, 2003.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Agriculture, cypress-tupelo swamp	3	433.461	441.861	435.443	449.287	6.003	0.034
County / residential road density, hardwood forest	3	433.598	441.998	435.469	449.104	6.140	0.032
Agriculture, hardwood forest	3	433.666	442.066	436.413	448.704	6.208	0.031
Cypress-tupelo swamp, hardwood forest	3	433.791	442.191	435.983	448.995	6.333	0.029
County / residential road density, hardwood forest, clear-cut	4	433.611	446.056	437.917	454.441	10.197	0.004
Agriculture, cypress-tupelo swamp, County / residential road density, hardwood forest, clear-cut (Global model)	6	433.763	457.763	448.123	467.705	21.905	0.000

Table B.11. The candidate models outside the confidence set of within-home-range winter habitat use models for female American black bears in central Georgia, USA. The number of parameters (*K*), deviance (-2ln(*L*)), Akaike's Information Corrected Criterion (AICc), the lower and upper 95% Bayesian Credible Interval (q025, q975), Δ AICc, and Akaike weights (*w*) for the set of candidate models (*i*) based on data collected during January 1 – March 31, 2004.

Candidate models	*K*	-2ln(*L*)	AICc	q025 AICc	q975 AICc	Δ AICc	*w*
Agriculture, cypress-tupelo swamp, pine plantation	4	366.361	378.805	370.208	387.723	9.487	0.006
Agriculture, cypress-tupelo swamp, hardwood forest, pine plantation (Global model)	5	367.086	384.586	375.960	393.477	15.269	$3.488x10^{-04}$

Table B.12. The mean posterior parameter estimates ($\bar{x}$) from the models outside the confidence set for the evaluation of location-level variables to be included in the final model set for predicting annual habitat use by female American black bears in central Georgia USA, based on data collected during May 2003 – August 2004.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Location-level: clear-cut, hardwood forest			
Intercept	-0.016	-0.313	0.285
Clear-cut	0.134	-1.996	2.329
Hardwood forest	0.170	-1.434	1.792
Location-level county / residential road density			
Intercept	-0.057	-0.377	0.264
County / residential road density	0.448	-0.930	1.836
Location-level : county / residential road density, hardwood forest			
Intercept	-0.060	-0.383	0.263
County / residential road density	0.454	-1.146	2.066
Hardwood forest	0.043	-1.630	1.773

Table B.12. Continued.

Parameter estimate	$\bar{x}$	95% Bayesian Credible Interval	
		q025	q975
Location-level: clear-cut, cypress-tupelo swamp, hardwood forest			
Intercept	-0.012	-0.319	0.295
Clear-cut	0.163	-1.853	2.250
Cypress-tupelo swamp	-0.090	-2.272	2.120
Hardwood forest	0.148	-1.391	1.708
Location-level: county / residential road density, clear-cut, hardwood forest			
Intercept	-0.060	-0.385	0.263
County / residential road density	0.467	-1.328	2.288
Clear-cut	0.062	-2.187	2.348
Hardwood forest	0.059	-1.722	1.832

Table B.12. Continued.

Parameter estimate	$\bar{x}$	95% Bayesian Credible Interval q025	q975
Location-level: county / residential road density, clear-cut, cypress-tupelo swamp			
Intercept	-0.051	-0.374	0.271
County / residential road density	0.551	-1.079	2.206
Clear-cut	-0.103	-2.399	2.224
Cypress-tupelo swamp	-0.286	-2.399	1.918
Location-level global model			
Intercept	-0.059	-0.384	0.266
County / residential road density	0.664	-1.355	2.746
Clear-cut	0.020	-2.475	2.382
Cypress-tupelo swamp	-0.414	-2.721	1.887
Hardwood forest	0.001	-1.799	1.779
Goodness of Fit	0.13983	0.1328	0.14687

Table B.13. The mean posterior parameter estimates ($\bar{x}$) from models outside the confidence set for the evaluation of home-range-level variables to be included in the final model set for predicting annual habitat use by female American black bears in central Georgia USA, based on data collected during May 2003 – August 2004.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Home range-level: highway density, habitat diversity			
Intercept	-0.906	-2.754	0.723
Highway density	-2.310	-4.745	-0.074
Habitat diversity	2.204	-0.544	5.285
Home range-level highway density			
Intercept	0.344	-0.066	0.756
Highway density	-2.313	-4.499	-0.222
Home range-level habitat diversity			
Intercept	-1.248	-2.824	0.165
Habitat diversity	2.240	-0.239	4.881

Table B.13. Continued.

Parameter estimate	$\bar{x}$	95% Bayesian Credible Interval	
		q025	q975
Home range-level: hardwood forest, highway density			
Intercept	0.304	-0.165	0.784
Hardwood forest	0.280	-0.841	1.400
Highway density	-2.496	-4.904	-0.259
Intercept only			
Intercept	0.000	-0.267	0.270
Home range-level: clear-cut, highway density, habitat diversity			
Intercept	-0.856	-2.522	0.670
Clear-cut	0.260	-1.155	1.644
Highway density	-2.316	-4.567	-0.191
Habitat diversity	2.085	-0.452	4.851

Table B.13. Continued.

Parameter estimate	$\bar{x}$	95% Bayesian Credible Interval	
		q025	q975
Home range-level global model			
Intercept	0.624	-1.460	2.698
County / residential road density	-3.004	-4.713	-1.355
Clear-cut	0.418	-1.163	1.937
Hardwood forest	0.297	-1.002	1.560
Highway density	-2.747	-5.424	-0.242
Habitat diversity	1.859	-1.142	4.905
Goodness of Fit	0.157	0.132	0.181
Home range-level: clear-cut, hardwood forest, highway density			
Intercept	0.233	-0.270	0.739
Clear-cut	0.383	-1.040	1.760
Hardwood forest	0.367	-0.804	1.479
Highway density	-2.433	-4.785	-0.307

Table B.14. The mean posterior parameter estimates ($\bar{x}$) from candidate models outside the confidence set for the final set of models for predicting annual habitat use by female American black bears in central Georgia, based on data collected during 2003 – 2004.

Parameter estimate	$\bar{x}$	95% Bayesian Credible Interval q025	q975
Home range-level: county / residential road density, highway density, location-level county / residential road density			
Intercept	1.814	0.841	2.856
Home range-level county / residential road density	-2.892	-4.467	-1.362
Home range-level highway density	-2.705	-5.323	-0.313
Location-level county / residential road density	-0.385	-2.010	1.204
Home range-level: county / residential road density, highway density, location-level hardwood forest			
Intercept	1.759	0.780	2.784
Home range-level county / residential road density	-2.895	-4.595	-1.253
Home range-level highway density	-2.689	-5.357	-0.139
Location-level hardwood forest	-0.226	-1.929	1.483

Table B.14. Continued.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Home range-level: county / residential road density, highway density, location-level clear-cut			
Intercept	1.721	0.882	2.629
Home range-level county / residential road density	-2.839	-4.355	-1.398
Home range-level highway density	-2.599	-5.167	-0.209
Location-level clear-cut	-0.203	-2.548	2.112
Home range-level: county / residential road density, highway density, location-level: clear-cut, hardwood forest			
Intercept	1.793	0.882	2.745
Home range-level county / residential road density	-2.893	-4.437	-1.396
Home range-level highway density	-2.710	-5.244	-0.327
Location-level clear-cut	-0.136	-2.538	2.146
Location-level hardwood forest	-0.220	-2.016	1.600

Table B.14. Continued.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Home range-level: highway density, habitat diversity			
Intercept	-0.906	-2.754	0.723
Home range-level highway density	-2.310	-4.745	-0.074
Home range-level habitat diversity	2.204	-0.544	5.285
Intercept			
Intercept	0.000	-0.267	0.270
Home range-level highway density			
Intercept	0.344	-0.066	0.756
Home range-level highway density	-2.313	-4.499	-0.222
Home range-level habitat diversity			
Intercept	-1.248	-2.824	0.165
Home range-level habitat diversity	2.240	-0.239	4.881

Table B.14. Continued.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Location-level: clear-cut, hardwood forest			
Intercept	-0.016	-0.313	0.285
Location-level clear-cut	0.134	-1.996	2.329
Location-level hardwood forest	0.170	-1.434	1.792
Location-level county / residential road density			
Intercept	-0.057	-0.377	0.264
Location-level county / residential road density	0.448	-0.930	1.836
Location-level: county / residential road density, hardwood forest			
Intercept	-0.060	-0.383	0.263
Location-level county / residential road density	0.454	-1.146	2.066
Location-level hardwood forest	0.043	-1.630	1.773

Table B.14. Continued.

Parameter estimate	$\bar{x}$	95% Bayesian Credible Interval	
		q025	q975
Location-level: county / residential road density, clear-cut, hardwood forest			
Intercept	-0.060	-0.385	0.263
Location-level county / residential road density	0.467	-1.328	2.288
Location-level clear-cut	0.062	-2.187	2.348
Location-level hardwood forest	0.059	-1.722	1.832
Global model			
Intercept	0.744	-1.279	2.750
Home range-level county / residential road density	-3.009	-4.758	-1.365
Home range-level highway density	-2.928	-5.809	-0.247
Home range-level habitat diversity	2.076	-0.904	5.259
Location-level county / residential road density	-0.495	-2.711	1.728
Location-level clear-cut	-0.115	-2.662	2.343
Location-level hardwood forest	-0.137	-2.125	1.862
Goodness of Fit	0.193	0.177	0.208

Table B.15. Mean parameter estimates ($\bar{x}$) from models outside the confidence set of within-home-range spring habitat use models for female American black bears in central Georgia, based on pooled data collected during May - June, 2003 and 2004.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Clear-cut, pine plantation			
Intercept	-0.023	-0.300	0.250
Clear-cut	0.242	-1.595	2.058
Pine plantation	0.124	-0.870	1.141
Hardwood forest, pine plantation			
Intercept	-0.010	-0.289	0.271
Hardwood forest	-0.051	-1.451	1.356
Pine plantation	0.121	-0.883	1.128

Table B.15. Continued.

Parameter estimate	$\bar{x}$	95% Bayesian Credible Interval q025	95% Bayesian Credible Interval q975
Clear-cut, hardwood forest, pine plantation			
Intercept	-0.023	-0.308	0.262
Clear-cut	0.234	-1.536	2.032
Hardwood forest	-0.016	-1.478	1.410
Pine plantation	0.119	-0.848	1.091
Global model			
Intercept	-0.050	-0.343	0.238
County / residential road density	0.779	-1.550	3.195
Clear-cut	-0.099	-2.173	1.994
Hardwood forest	-0.282	-2.029	1.451
Pine plantation	-0.149	-1.598	1.272
Goodness of Fit	0.139	0.132	0.145

Table B.16. Mean parameter estimates ($\bar{x}$) for models outside the confidence set of within-home-range summer habitat use models for female American black bears in central Georgia, based on pooled data collected during June 21 – August 31, 2003 and 2004.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
County / residential road density, pine plantation			
Intercept	-0.070	-0.358	0.218
County / residential road density	0.775	-0.680	2.245
Pine plantation	-0.264	-1.415	0.885
County / residential road density, clear-cut			
Intercept	-0.081	-0.369	0.207
County / residential road density	0.606	-0.744	1.962
Clear-cut	0.072	-1.754	1.902
Clear-cut, pine plantation			
Intercept	-0.005	-0.278	0.271
Clear-cut	0.250	-1.610	2.167
Pine plantation	-0.045	-1.066	0.956

Table B.16. Continued.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Global model			
Intercept	-0.039	-0.334	0.252
County / residential road density	1.712	-0.943	4.542
Clear-cut	-0.452	-2.596	1.648
Cypress-tupelo swamp	-1.299	-3.909	1.102
Hardwood forest	-0.466	-2.285	1.276
Pine plantation	-0.643	-2.139	0.799
Goodness of Fit	0.130	0.124	0.136

Table B.17. Mean parameter estimates ($\bar{x}$) from models outside the confidence set of within-home-range fall habitat use models for female American black bears in central Georgia, based on pooled data collected during September 1 – Den entry, 2003.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Cypress-tupelo swamp, hardwood forest			
Intercept	-0.020	-0.290	0.247
Cypress-tupelo swamp	0.028	-1.827	1.892
Hardwood forest	0.252	-1.079	1.567
Clear-cut, hardwood forest			
Intercept	-0.021	-0.289	0.245
Clear-cut	0.071	-1.798	1.930
Hardwood forest	0.252	-1.066	1.604
County / residential road density, hardwood forest			
Intercept	-0.050	-0.335	0.236
County / residential road density	0.293	-1.133	1.708
Hardwood forest	0.205	-1.260	1.667

Table B.17. Continued.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
County / residential road density, clear-cut, hardwood forest			
Intercept	-0.047	-0.336	0.239
County / residential road density	0.254	-1.336	1.877
Clear-cut	0.005	-2.133	2.207
Hardwood forest	0.219	-1.280	1.705
Global model			
Intercept	-0.049	-0.340	0.238
County / residential road density	0.384	-1.392	2.167
Clear-cut	0.039	-1.948	2.004
Cypress-tupelo swamp	-0.099	-2.016	1.803
Hardwood forest	0.122	-1.418	1.710
Goodness of Fit	0.144	0.141	0.148

Table B.18. The mean posterior parameter estimates ($\bar{x}$) from candidate models outside the confidence set for predicting annual habitat use by male American black bears in central Georgia, based on data collected during 2003 – 2004.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Home range-level: county / residential road density, highway density, location-level clear-cut			
Intercept	1.332	0.556	2.136
Home range-level county / residential road density	-2.275	-3.812	-0.832
Home range-level highway density	-1.473	-3.689	0.683
Location-level clear-cut	-0.187	-2.709	2.399
Home range-level: highway density, county / residential road density, location-level: hardwood forest, clear-cut			
Intercept	1.361	0.465	2.299
Home range-level highway density	-1.441	-3.869	0.791
Home range-level county / residential road density	-2.309	-3.955	-0.752
Location-level hardwood forest	-0.125	-2.114	1.930
Location-level clear-cut	-0.145	-2.788	2.666

Table B.18. Continued.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Home range-level: agriculture, county / residential road density, clear-cut, hardwood forest, highway density, habitat diversity			
Intercept	0.811	-1.092	2.718
Home range-level agriculture	-0.149	-1.938	1.567
Home range-level county / residential road density	-2.261	-4.103	-0.520
Home range-level clear-cut	0.150	-1.531	1.846
Home range-level hardwood forest	0.126	-1.254	1.437
Home range-level highway density	-1.449	-4.161	1.056
Home range-level habitat diversity	0.857	-2.074	3.821
Home range-level: highway density, habitat diversity			
Intercept	-0.388	-1.837	1.008
Home range-level highway density	-1.816	-4.140	0.427
Home range-level habitat diversity	1.285	-1.125	3.731

Table B.18. Continued.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Home range-level highway density			
Intercept	0.300	-0.135	0.734
Home range-level highway density	-1.748	-3.864	0.228
Home range-level: clear-cut, highway density, habitat diversity			
Intercept	-0.484	-1.942	0.901
Home range-level clear-cut	0.088	-1.586	1.669
Home range-level highway density	-1.655	-4.098	0.603
Home range-level habitat diversity	1.386	-1.081	3.837
Home range-level habitat diversity			
Intercept	-0.759	-2.168	0.545
Home range-level habitat diversity	1.401	-0.972	3.846

Table B.18. Continued.

Parameter estimate	$\bar{x}$	95% Bayesian Credible Interval	
		q025	q975
Home range-level: hardwood forest, highway density			
Intercept	0.262	-0.213	0.742
Home range-level hardwood forest	0.151	-1.171	1.427
Home range-level highway density	-1.768	-4.039	0.283
Home range-level: clear-cut, hardwood forest, highway density			
Intercept	0.243	-0.283	0.774
Home range-level clear-cut	0.211	-1.268	1.665
Home range-level hardwood forest	0.241	-0.985	1.412
Home range-level highway density	-1.881	-4.133	0.216
Intercept only			
Intercept	0.000	-0.271	0.273

Table B.18. Continued.

Parameter estimate	$\bar{x}$	95% Bayesian Credible Interval q025	95% Bayesian Credible Interval q975
Location-level county / residential road density			
Intercept	0.018	-0.303	0.339
Location-level county / residential road density	-0.153	-1.707	1.372
Home range-level: clear-cut, hardwood forest, highway density, habitat diversity			
Intercept	-0.480	-1.923	0.874
Home range-level clear-cut	0.163	-1.396	1.701
Home range-level hardwood forest	0.203	-1.102	1.471
Home range-level highway density	-1.767	-4.203	0.514
Home range-level habitat diversity	1.329	-1.029	3.869
Home range-level: clear-cut, hardwood forest			
Intercept	-0.088	-0.458	0.279
Home range-level clear-cut	0.301	-1.111	1.686
Home range-level hardwood forest	0.278	-0.899	1.406

Table B.18. Continued.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Location-level: county / residential road density, hardwood forest			
Intercept	0.009	-0.315	0.332
Location-level county / residential road density	-0.259	-1.976	1.444
Location-level hardwood forest	0.364	-1.600	2.366
Location-level: clear-cut, hardwood forest			
Intercept	-0.021	-0.320	0.274
Location-level clear-cut	0.180	-2.425	3.160
Location-level hardwood forest	0.260	-1.489	2.016
Location-level: county / residential road density, clear-cut			
Intercept	0.011	-0.310	0.332
Location-level county / residential road density	-0.182	-1.811	1.490
Location-level clear-cut	0.211	-2.515	3.245

Table B.18. Continued.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Location-level: county / residential road density, clear-cut, hardwood forest			
Intercept	0.006	-0.316	0.336
Location-level county / residential road density	-0.238	-2.034	1.607
Location-level clear-cut	0.264	-2.533	2.921
Location-level hardwood forest	0.236	-1.637	2.141
Location-level: clear-cut, cypress-tupelo swamp, hardwood forest			
Intercept	-0.013	-0.323	0.296
Location-level clear-cut	0.176	-2.498	3.034
Location-level cypress-tupelo swamp	-0.726	-2.802	2.485
Location-level hardwood forest	0.252	-1.478	2.032

Table B.18. Continued.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Location-level: county / residential road density, clear-cut, cypress-tupelo swamp			
Intercept	0.015	-0.310	0.336
Location-level county / residential road density	-0.146	-1.898	1.630
Location-level clear-cut	0.200	-2.572	3.235
Location-level cypress-tupelo swamp	-0.691	-2.881	2.622
Location-level: county / residential road density, clear-cut, cypress-tupelo swamp, hardwood forest			
Intercept	0.007	-0.325	0.332
Location-level county / residential road density	-0.192	-2.174	1.769
Location-level clear-cut	0.244	-2.586	2.908
Location-level cypress-tupelo swamp	-0.154	-2.450	1.984
Location-level hardwood forest	0.223	-1.718	2.128

Table B.18. Continued.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Location-level: agriculture, clear-cut, cypress-tupelo swamp, hardwood forest			
Intercept	-0.004	-0.322	0.310
Location-level agriculture	-0.579	-3.274	2.729
Location-level clear-cut	0.277	-2.130	2.722
Location-level cypress-tupelo swamp	-0.275	-2.556	1.918
Location-level hardwood forest	0.210	-1.482	1.929
Location-level: agriculture, county / residential road density, clear-cut, cypress-tupelo swamp, hardwood forest			
Intercept	0.010	-0.317	0.339
Location-level agriculture	-0.101	-3.216	2.847
Location-level county / residential road density	-0.216	-2.470	2.008
Location-level clear-cut	0.187	-2.335	2.715
Location-level cypress-tupelo swamp	-0.169	-2.513	2.103
Location-level hardwood forest	0.271	-1.545	2.155

Table B.18. Continued.

Parameter estimate	$\bar{x}$	95% Bayesian Credible Interval	
		q025	q975
Global model			
Intercept	1.045	-1.054	3.180
Home range-level agriculture	-0.077	-2.125	1.880
Home range-level county / residential road density	-2.506	-4.468	-0.637
Home range-level clear-cut	-0.207	-1.935	2.183
Home range-level hardwood forest	0.119	-1.624	1.843
Home range-level highway density	-1.571	-4.586	1.292
Home range-level habitat diversity	0.887	-2.342	4.141
Location-level agriculture	-0.112	-3.739	3.473
Location-level county / residential road density	-0.476	-3.427	2.427
Location-level clear-cut	-0.331	-3.937	3.045
Location-level cypress-tupelo swamp	-0.697	-3.326	1.965
Location-level hardwood forest	-0.339	-3.038	2.323
Goodness of Fit	0.065	0.050	0.080

Table B.19. Mean parameter estimates ($\bar{x}$) from models outside the confidence set of within-home-range spring habitat use models for male American black bears in central Georgia, based on pooled data collected during April 1 – June 13, 2003 and 2004.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Clear-cut, plantation pine			
Intercept	-0.018	-0.271	0.237
Clear-cut	0.002	-1.862	1.922
Pine plantation	0.167	-0.791	1.159
County / residential road density, clear-cut, plantation pine			
Intercept	0.025	-0.241	0.291
County / residential road density	-0.640	-2.235	0.932
Clear-cut	0.320	-1.630	2.241
Pine plantation	0.294	-0.786	1.398

Table B.19. Continued.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Clear-cut, cypress-tupelo swamp, pine plantation			
Intercept	-0.015	-0.278	0.245
Clear-cut	0.064	-1.864	1.929
Cypress-tupelo swamp	-0.183	-2.010	1.526
Pine plantation	0.186	-0.782	1.135
Global model			
Intercept	0.023	-0.243	0.292
County / residential road density	-0.682	-2.514	1.079
Clear-cut	0.312	-1.626	2.238
Cypress-tupelo swamp	0.032	-1.819	1.910
Pine plantation	0.336	-0.849	1.522
Goodness of Fit	0.149	0.134	0.164

Table B.20. Mean parameter estimates ($\bar{x}$) from models outside the confidence set of within-home-range summer habitat use models for male American black bears in central Georgia, based on pooled data collected during June 14 – August 31, 2003 and 2004.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Clear-cut, pine plantation			
Intercept	-0.031	-0.277	0.215
Clear-cut	0.351	-1.196	1.947
Pine plantation	0.150	-0.788	1.096
County / residential road density, clear-cut			
Intercept	-0.018	-0.272	0.237
County / residential road density	0.039	-1.169	1.273
Clear-cut	0.359	-1.327	2.031

Table B.20. Continued.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Agriculture, clear-cut, cypress-tupelo swamp			
Intercept	0.024	-0.210	0.262
Agriculture	-0.543	-2.970	1.752
Clear-cut	0.263	-1.284	1.891
Cypress-tupelo swamp	-0.646	-2.562	1.197
Global model			
Intercept	-0.008	-0.270	0.254
Agriculture	-0.744	-3.618	1.876
County / residential road density	0.287	-1.717	2.415
Clear-cut	0.249	-1.523	2.027
Cypress-tupelo swamp	-0.611	-2.640	1.347
Hardwood forest	0.079	-1.356	1.503
Pine plantation	0.020	-1.133	1.172
Goodness of Fit	0.127	0.118	0.136

Table B.21. Mean parameter estimates ($\bar{x}$) from models outside the confidence set of within-home-range fall habitat use models for male American black bears in central Georgia, based on data collected during September 1 – December 31, 2003.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Agriculture, cypress-tupelo swamp			
Intercept	0.017	-0.224	0.257
Agriculture	-0.186	-2.233	1.838
Cypress-tupelo swamp	-0.290	-2.067	1.431
County / residential road density, hardwood forest			
Intercept	0.024	-0.239	0.287
County / residential road density	-0.400	-1.791	0.981
Hardwood forest	0.302	-1.140	1.738
Agriculture, hardwood forest			
Intercept	-0.009	-0.255	0.234
Agriculture	-0.039	-2.048	1.999
Hardwood forest	0.173	-1.162	1.529

Table B.21. Continued.

Parameter estimate	$\bar{x}$	95% Bayesian Credible Interval q025	95% Bayesian Credible Interval q975
Cypress-tupelo swamp, hardwood forest			
Intercept	-0.001	-0.246	0.244
Cypress-tupelo swamp	-0.249	-1.876	1.338
Hardwood forest	0.189	-1.085	1.465
County / residential road density, clear-cut, hardwood forest			
Intercept	0.025	-0.238	0.289
County / residential road density	-0.454	-1.972	1.040
Clear-cut	0.126	-1.943	2.115
Hardwood forest	0.279	-1.187	1.775

Table B.21. Continued.

Parameter estimate	$\bar{x}$	95% Bayesian Credible Interval	
		q025	q975
Global model			
Intercept	0.026	-0.240	0.291
Agriculture	0.168	-2.005	2.417
County / residential road density	-0.466	-2.408	1.472
Clear-cut	0.100	-1.905	2.154
Cypress – tupelo swamp	-0.166	-2.085	1.674
Hardwood forest	0.288	-1.139	1.742
Goodness of Fit	0.141	0.133	0.149

Table B.22. Mean parameter estimates ($\bar{x}$) from models outside the confidence set of within-home-range winter habitat use models for male American black bears in central Georgia based on pooled data collected during January 1, 2003 – April 1, 2004.

		95% Bayesian Credible Interval	
Parameter estimate	$\bar{x}$	q025	q975
Agriculture, cypress-tupelo swamp, pine plantation			
Intercept	0.015	-0.269	0.296
Agriculture	0.352	-1.471	2.307
Cypress-tupelo swamp	0.139	-1.615	1.794
Pine plantation	-0.417	-1.744	0.854
Agriculture, cypress-tupelo swamp, hardwood forest, pine plantation			
Intercept	0.001	-0.288	0.295
Agriculture	0.405	-1.475	2.310
Cypress-tupelo swamp	0.150	-1.425	1.710
Hardwood forest	0.108	-1.293	1.509
Pine plantation	-0.358	-1.608	0.868
Goodness of Fit	0.155	0.147	0.163

APPENDIX C

PREDICTED FEMALE BLACK BEAR HOME RANGE HABITAT FROM CENTRAL TO SOUTHEAST GEORGIA

The CGP is likely isolated from the 2 other populations known in Georgia (Miller 1995) and due to extensive projected development within the CGP, managers wished to evaluate a reintroduction effort to increase genetic exchange among populations. I applied the best approximating model for annual CGP female home range habitat to the watersheds surrounding the CGP and leading to the Okefenokee population (Figures C.1 – C.5). This application extends to the Okefenokee black bear population so that managers can begin to evaluate potential reintroduction areas and preliminary travel corridors, which may allow genetic exchange and conservation of the CGP. The predicted habitat maps for central and southeast Georgia should be viewed as a preliminary evaluation of potential female bear home range habitat that is based on a nonrandom sample of central Georgia bears that were trapped in continuous forest with low road densities. Additionally, although habitat in central Georgia appears to support reproduction, it is unknown whether habitat is preferred by bears or is sufficient to support a population that will persist. The habitat of the CGP may simply represent a remote area away from human encroachment and not necessarily high quality or sufficient quality habitat. Although vegetation types differ between the Upper and Southern Atlantic Coastal Plain, we included habitat diversity as a predictive variable because bears are habitat generalists and the diversity variable had little effect on model outcome. This also allowed us to apply and use values from the same best approximating model and respective probability of habitat use as the validated CGP model. Our model did correspond closely with the location of female home ranges observed in a recent study of the Okefenokee black bear population (Figures C.3 a - b) and thus these maps are useful to predict areas were female home ranges or travel corridors could exist outside the CGP range.

The predicted model for central to southeast Georgia shows limited potential bear habitat when the mean predicted probability of home range habitat (p) from the CGP female annual MCP home ranges ($p = 0.527$) is used to define a cut off (Figure C.1). However, if we define potential habitat as that above $p = 0.197$, the lowest habitat use probability value within the CGP female annual MCP home ranges, it is likely that connective habitat is fairly extensive, although limited north of the Okefenokee (Figure C.2). Predicted habitat corresponds heavily with low county/ residential road and highway density (Figure C.4) and fairly large areas of potential habitat appear to exist outside permanent conservation lands (Figure C.2.). Landowners in these areas, especially areas connected to known habitat, could be approached to work cooperatively to identify any bear breeding activity and for cooperation in any subsequent management or reintroduction plans. There is a significant area of potential habitat north of I-16 and extending to the Oconee River and beyond, further supporting the recommendation that bears foods and signs of reproduction should be surveyed there, since this area connects directly with the CGP. Another large area of potential habitat exists on the coast. This area may contain breeding bears but was not surveyed, habitat types may not be sufficient to support bears (though this is unlikely) or bears may have been excluded by human activity such as poaching or over-harvest.

Our predicted habitat models likely depict the probability of escape cover in areas of cypress-tupelo swamp (Figure C.5) and do not necessarily predict habitat that supports sufficient annual black bear foods as these habitats are thought to be low in bear food productivity (Hersey et al. 2005, Dobey et al. 2005). Our model shows extensive areas of low probability for home range occurrence in areas of high county / residential road and highway density much of which is agricultural land. However, other research has shown that bottomland forest patches in extensive food crop agriculture support the highest bear densities reported in the world when bears are not exploited by people (Beasoleil 1999). Bears are habitat generalists, limited by food abundance and are not a forest obligate species. They are found in open habitats in the northern part of their range, which still contains large expanses of unpopulated (human) land (Pelton et al. 1999). Thus land may exist in south-central Georgia that offers connectivity between the CGP and the Okefenokee population where traffic volume and poaching is low enough to allow bears to reside and travel.

In the event that attempts are made to connect habitat between southeast and central Georgia, public opinion regarding the presence of bears should be assessed in areas were bear habitat is predicted to determine the risk of poaching and design public education programs that can reduce poaching. Rigorous research has been conducted concerning public attitude toward bears and population reintroduction in Mississippi and Arkansas, methods which could be employed as part of a reintroduction effort. These public opinion studies (Bowman et al. 2004) focus on gathering data for a wide geographic area of potential habitat ahead of planning a specific reintroduction site. The data can then be mapped and matched to potential habitat in order to ensure a higher chance of project success. Places on the predicted habitat maps with more area comprised of highly probable habitat should be assessed for public opinion first.

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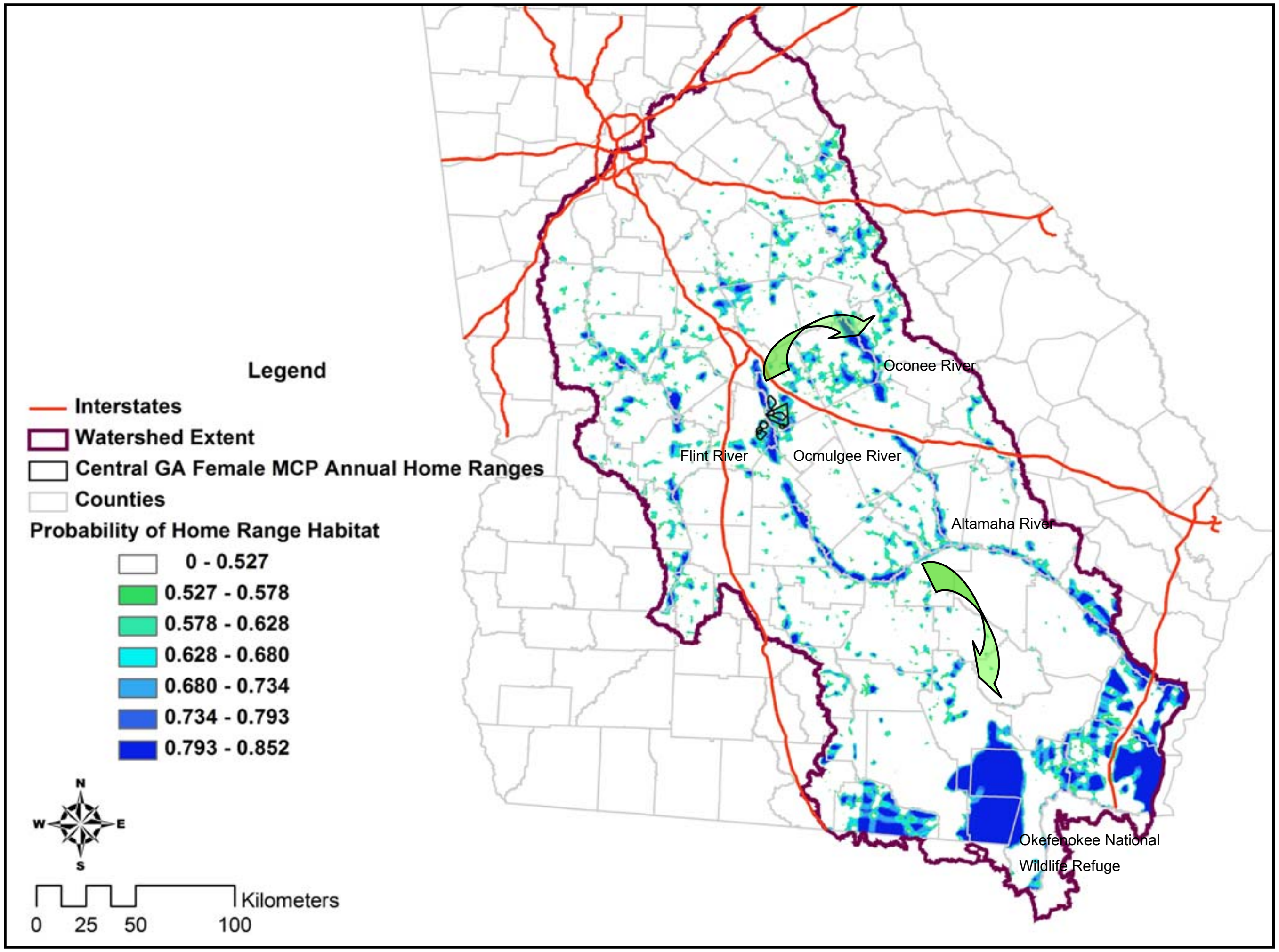

Figure C.1. Predicted female American black bear home range habitat in central and southeastern Georgia, USA. A cut-off value of 0.527 was used because this was the mean probability value within known central Georgia female MCP home ranges. Arrows signify potential travel corridors to larger blocks of known and potential habitat. Habitat prediction is based on observational radiotelemetry data collected ruing May 2003 – August 2004.

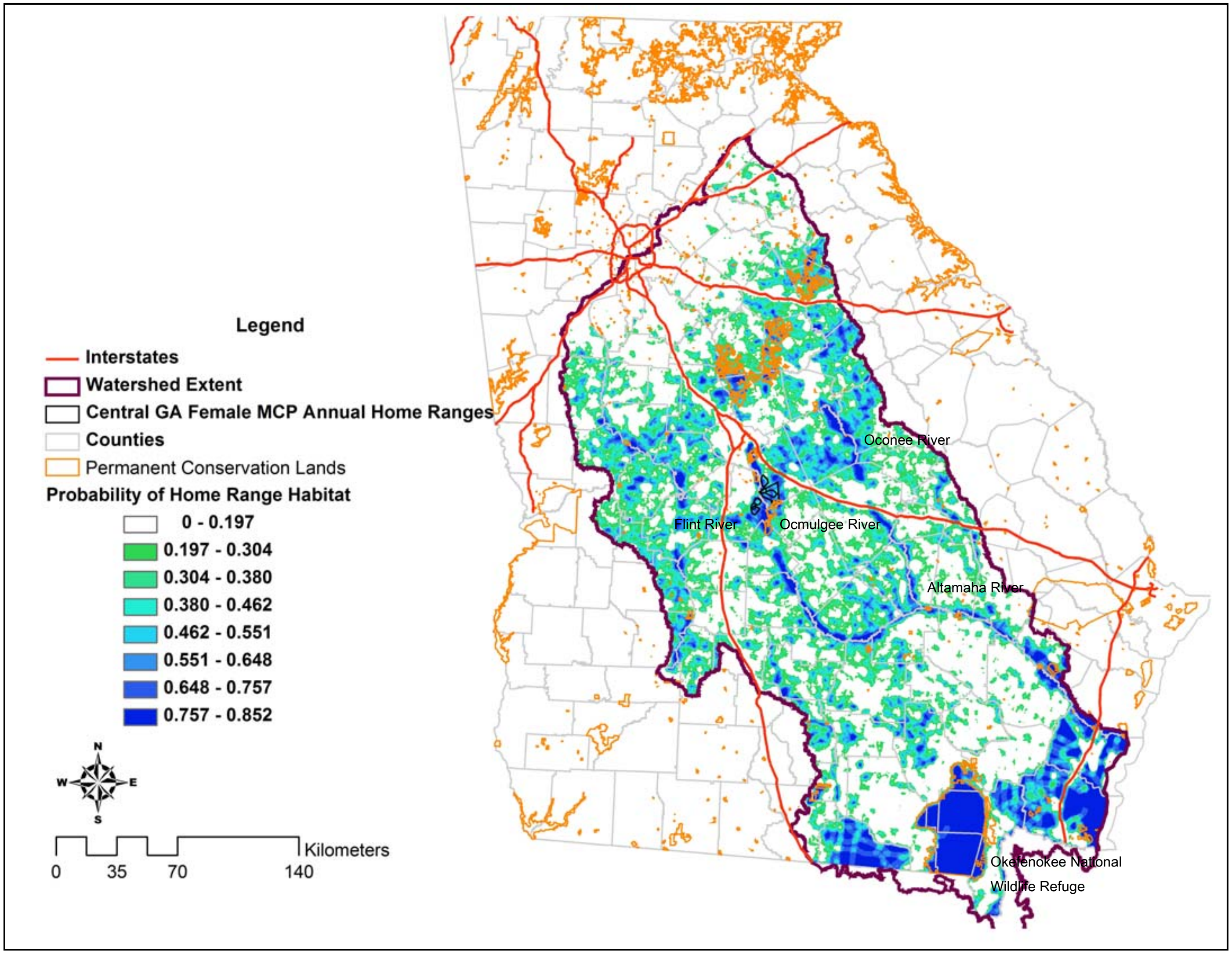

Figure C.2. Predicted female American black bear home range habitat in central and southeastern Georgia, USA with permanent conservation lands imposed. A cut-off value of 0.197 was used because this was the lowest probability value within any known central Georgia female MCP home range.

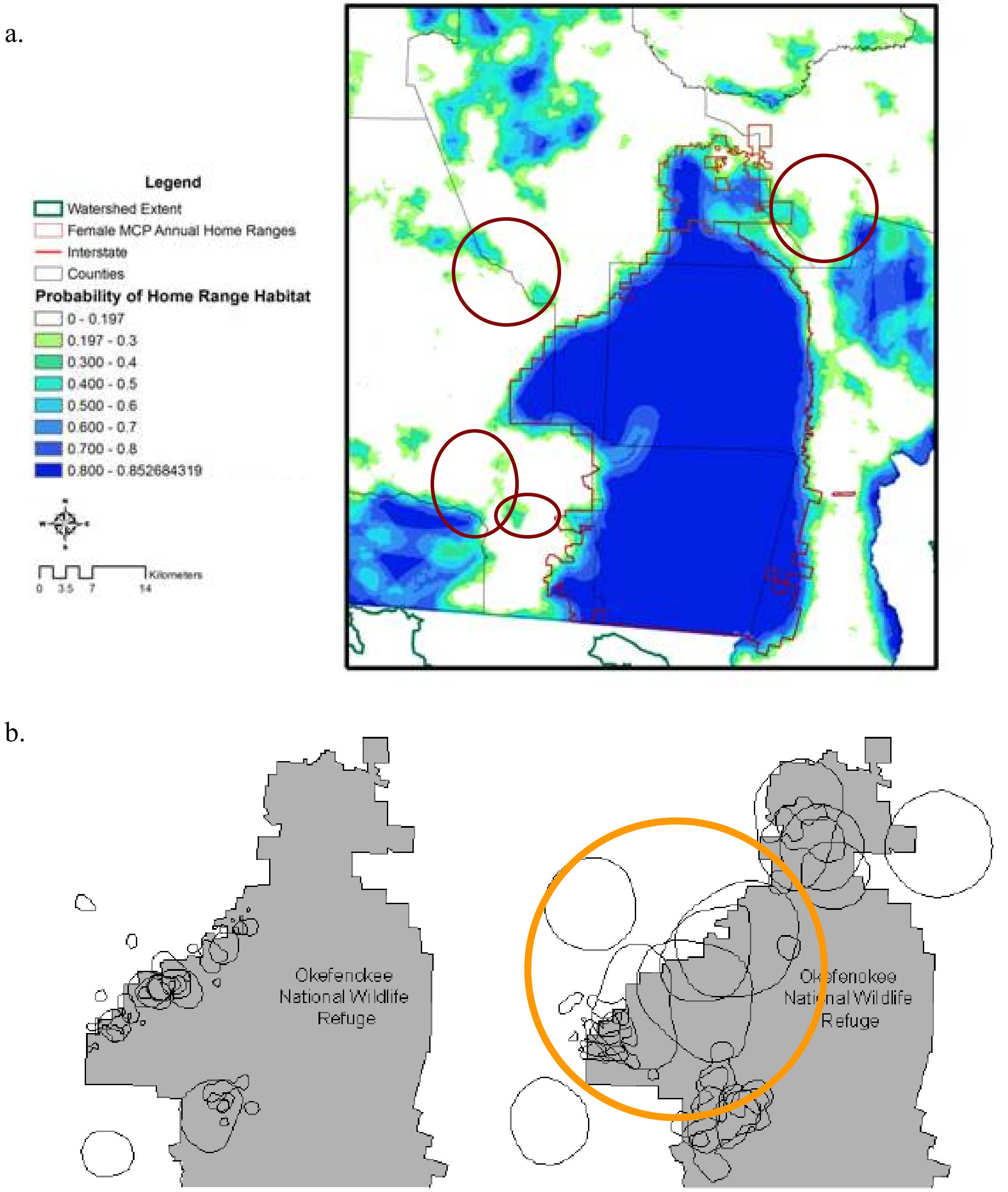

Figure C.3. a.) Predicted central Georgia female American black bear home range habitat from model averaged estimates in this study applied to the Okefenokee Swamp. The minimum habitat use probability within any CGP female MCP home range (0.197) was used to depict predicted bear home range habitat. Areas that correspond to home ranges are in dark red circles. b.) Female bear 95% kernel home ranges from 1998 and 1999 (left to right) from research by Dobey et al. (2005) on the Okefenokee bear population. The orange circle represents the approximate trapping area.

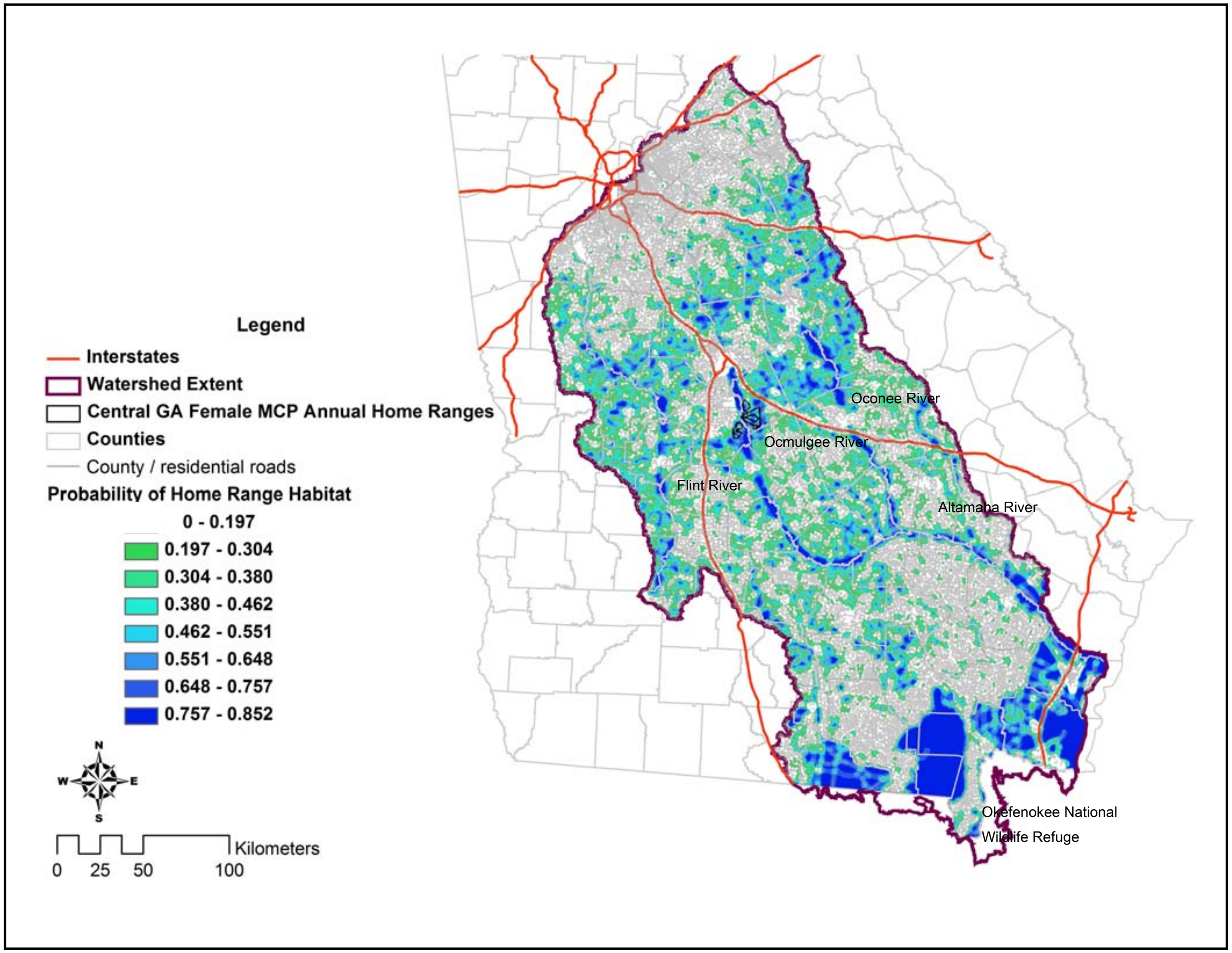

Figure C.4. Predicted female American black bear home range habitat in central and southeastern Georgia, USA and the distribution of county/residential roads and highways. A cut-off value of 0.197 was used because this was the lowest probability value within any known central Georgia female MCP home range.

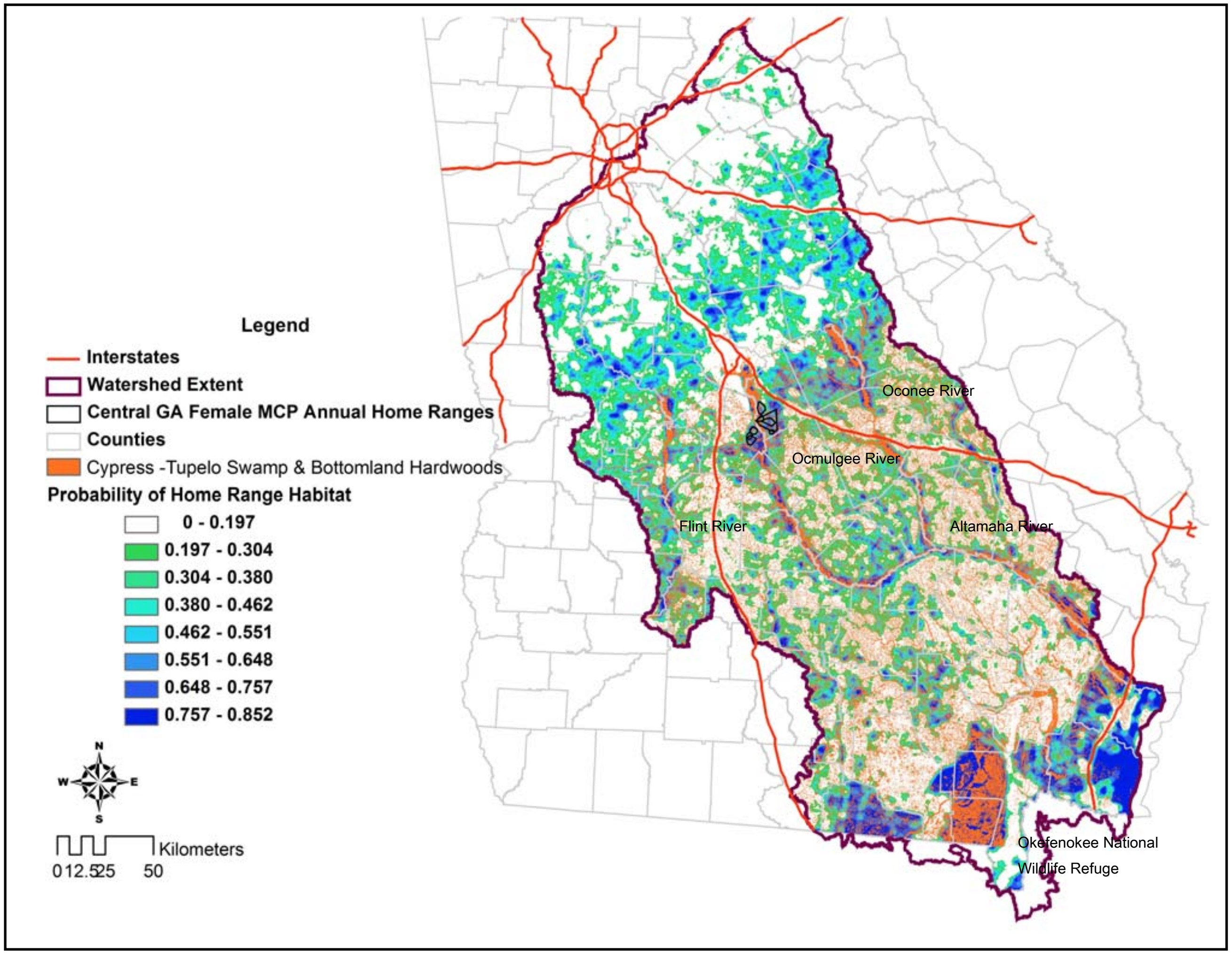

Figure C.5. Predicted female American black bear home range habitat in central and southeastern Georgia, USA with cypress-tupelo and bottomland hardwood forests imposed. A cut-off value of 0.197 was used because this was the lowest probability value within any known central Georgia female MCP home range.