ABSTRACT

GOULD, NICHOLAS PAUL. Ecology of American Black Bears in an Urban Environment. (Under the direction of Dr. Christopher S. DePerno).

Cities now constitute one of the most rapidly growing ecosystems in the world, and with the global spotlight on increasing urbanization and development, the focus on wildlife in 'natural' systems is sharing importance with a focus on wildlife in urban systems, providing unique research opportunities in ecology and conservation. Over four years from April 2014 through June 2018, we investigated the effects of urban development and natural food production on American black bear (*Ursus americanus*) ecology centered on the city of Asheville, North Carolina. Black bears are model animals for study because they are behaviorally flexible omnivores highly adapted to locate and secure high calorie foods and, thus, may benefit from a variety of urban resources.

In chapter 1, we present research on the early growth and reproduction by urban and rural black bears in Asheville, North Carolina, and in 3 nearby rural sites. We used trapping in spring and summer and used winter den visits to assess reproduction by young female black bears. Urban yearling females weighed more than yearling females from the three rural study sites, and 2-year old urban female bears produced cubs, but no 2-year old rural females produced cubs. We hypothesize that reproduction by 2-year old bears may be linked to the permanence of anthropogenic food sources associated with urban environments. To inform population level management decisions further, managers and researchers should quantify urban food sources and the effects on black bear life history. If high population fecundity allows urban populations to sustain relatively high mortality rates, then urban bear populations may be source populations for surrounding, rural areas.

In chapter 2, we present research on the spatial ecology of urban and rural American black bears in North Carolina. Black bears in rural areas are known to shift their spatial distributions in response to available resources but limited information is available on how bears move through developed environments beyond the bears' use of urban areas in years of poor production of natural foods. We used continuous time movement models to estimate annual and seasonal home range sizes to compare bears occupying developed areas (urban bears) and those in undeveloped areas (rural bears). Urban bears had consistently smaller home ranges than rural bears, regardless of variation of natural food production. Furthermore, home range size for urban bears did not vary with housing density or with natural food production. This result suggests that urban areas may be good habitat for bears where they can meet their metabolic requirements and secure adequate resources across the full range of housing development present in our study area.

In chapter 3, we present research on the effects of housing density and road density on the selection of den sites by black bears. We documented that urban bears did not avoid areas with housing or roads at the level of the study area (2nd order) or within the home range (3rd order). At the finer scale (3rd order), slope was the best predictor of den site selection. At both scales of den site selection, we detected no relationship with elevation or land cover type. Median den entry and emergence dates for bears were the third week in December and the third week in March. Reuse of den sites was low, suggesting that dens are not a limiting resource for urban bears in Asheville, North Carolina. Collectively, our results indicate that selection of den sites by black bears in urban areas may not be as critical to their fitness as it is to their rural counterparts.

Ecology of American Black Bears in an Urban Environment

by
Nicholas Paul Gould

A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

Fisheries, Wildlife, and Conservation Biology

Raleigh, North Carolina
2020

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DEDICATION

I dedicate my dissertation to my mom, Michelle Jeanne Starr. She was a kind, supportive, and fiercely loving person. No one could wrong her kids. Small in stature but enormous in character and heart, I only hope she would be as proud of me as I was of her! She was an inspiration, and each and every day I see her in both of my daughters, to whom I also dedicate this dissertation. Their impact on this world has only just begun.

And to my wife, Kelly Ann Gould, no words can express the gratitude I have for you!

BIOGRAPHY

Nicholas Paul Gould was born and raised in Acton, Massachusetts, just west of Boston. He was the youngest of four and the only son to Michelle and Harry. He grew up in a very active family always involved in sports and always content being outside. After graduating from Acton-Boxborough Regional High School (where all of his family attended high school), and playing junior ice hockey in various parts of the country, he spent time at an educational wolf refuge in the mountains of Colorado. With a newly vested interest in wildlife ecology and conservation, he attended the University of Massachusetts-Boston and completed a dual degree in Natural Resource Management and Policy and English Literature. Upon graduation, Nick moved to Fort Collins, Colorado to pursue a master's degree in wildlife biology at Colorado State University, where he graduated in 2010. After two years as a research associate at Colorado State University, Nick spent time at a consulting firm in Laramie, Wyoming, working on a variety of research and compliance projects prior to uprooting his family again to pursue a doctoral position in the Fisheries, Wildlife and Conservation Biology program at North Carolina State University. Upon graduating with his Ph.D. in Fisheries, Wildlife and Conservation Biology, he will begin work at North Carolina State University as a postdoctoral researcher.

ACKNOWLEDGMENTS

bears – you were patient and committed. I appreciated that! Thanks to the many graduate students that have crossed my path over my time at NC State. And a special thanks to Nathan Hostetter and James Garabedian.

I am forever grateful to all the homeowners who granted us permission and access to their properties to place traps, look for bears (or their dropped collars), and work bear dens. Were it not for the homeowners, we would not have had a project – all of our trap sites were on private property! I cannot thank you all one by one, but know that all of you were instrumental collaborators that made this project a success. I would like to say a heartfelt 'thank you' to Tom Noblett. As soon as he heard about the project, he called me…and never stopped. He helped with locating and securing trap sites from his incredible network of friends and colleagues in and around Asheville, processing bears, helping with dens, and just being a wholesome, kind person. He became a good friend and it was a pleasure to have known him.

Most importantly, I thank my family, both here and in Boston. Always providing support and love, there is not much more I could ask for! You are the best. But, to my wife, Kelly, and my two daughters, Samantha and Emerson, you complete my world, and none of this would have been possible without you. Especially you, Kelly. You are the single greatest person I know. Everything you do is unconditional – your love, support, commitment to my success, and dedication to our children's well-being and health. I could not do it without you. I love you and very much look forward to the next chapter in our lives!

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 3: Den site selection, denning chronology and den reuse by American black bears in an urban environment

LIST OF FIGURES

CHAPTER 3: Den site selection, denning chronology and den reuse by American black bears in an urban environment

CHAPTER 1: Growth and reproduction by young urban and rural black bears

ABSTRACT

Human-dominated landscapes contain fragmented natural land cover interspersed throughout an urban matrix. We studied female black bears (*Ursus americanus*) within the city of Asheville, North Carolina, and in 3 nearby forested, rural sites. The extensive literature on black bears indicates that females generally produce litters for the first time at 4 years of age, and that 2-year old black bears almost never give birth. We used trapping in spring and summer and visited winter dens to assess reproduction by female black bears. Urban yearling females weighed more than yearling females from the three rural study sites. Hard mast production during the autumn when the females were cubs did not affect weights of yearlings at any site. Seven of 12 2-year old female, urban bears produced 11 cubs (mean litter size = 1.6 ± 0.8) but no 2-year old rural females produced cubs. Production of hard mast in the autumn that females were yearlings was not correlated with cub production by 2-year old female bears at the urban site. We hypothesize that reproduction by 2-year old bears may be linked to the permanence of anthropogenic food sources associated with urban environments. To inform population level management decisions further, managers and researchers should quantify urban food sources and the effects on black bear life history. If high population fecundity allows urban populations to sustain relatively high mortality rates, then urban bear populations may be source populations for surrounding, rural areas.

INTRODUCTION

As urbanization increases, questions arise related to impacts on wildlife populations. Human demands for space modify the quality, amount, and spatial arrangement of wildlife habitat.

Habitat destruction reduces population sizes and growth rates of many wildlife and increases local extinctions (Pulliam 1988; Runge et al. 2006). Habitat loss to urbanization can alter wildlife diversity and reduce genetic diversity by restricting gene flow between fragmented populations (Gilpin 1987). Development and urbanization causes the loss of wildlife populations in the United States (Olive and Minichiello 2013) yet, approximately 20% of endangered species in the U.S. occur in urban areas, highlighting the important ecological role that urban habitats can serve in protecting biodiversity of local flora and fauna (Dearborn and Kark 2010; Magle et al. 2012; Olive and Minichiello 2013).

Nonetheless, not all documented impacts of urbanization are negative. Wildlife that exhibit the behavioral flexibility to take advantage of resources in urban areas may benefit from high reproductive output and survival (Prange et al. 2003, Gosselink et al. 2007, Beckmann and Lackey 2008; Cyher et al. 2010; Gould and Andelt 2011; Ghalambor et al. 2010; Sih et al. 2011; Lowry et al. 2013; Sih 2013; Fehlmann et al. 2017). Although adaptation to urbanization is highly variable among species, wildlife that use urban areas generally share common characteristics, including a flexible diet (Ryan and Partan 2014; McKinney 2002), relatively small to medium body sizes (Harris and Baker 2007), and flexible or adaptable circadian patterns (Lendrum et al. 2017; Lowry et al. 2013). Red foxes (*Vulpes fulva*), coyotes (*Canis latrans*), raccoons (*Procyon lotor*), opossums (*Didelphis virginiana*) and striped skunks (*Mephitis mephitis*) commonly occur in urban areas, some since the beginning of the 20th century (Bateman and Fleming 2011), have flexible diets and circadian patterns (Beckmann and Berger 2003; Riley et al. 2003), and mostly weigh < 10 kg (Harris and Baker 2007). Being omnivorous in urban areas includes eating refuse, garden foods, urban rodents and birds, as well as pets (Bateman and Fleming 2011).

American black bears (*Ursus americanus*) have many characteristics associated with successful use of urban space. Bears are behaviorally-flexible omnivores highly adapted to find and secure high calorie foods and, thus, benefit from a variety of urban resources (Blair 1996). Although generally diurnal, black bears exhibit flexible circadian patterns in urban (Zeller et al. 2019; Johnson et al. 2015; Baruch-Mordo et al. 2014) and in forested areas. Being able to exploit a wide variety of foods, including garden plants, fruit trees, bird seed and refuse, provides opportunities for black bears to gain weight earlier in life than they can in rural environments. Hence, consistent and abundant resources in urban environments may influence reproduction by black bears. In contrast to other urban wildlife, however, black bears are large, which reduces their abilities to avoid humans in urban areas.

In most areas across the range of black bears, females breed for the first time when 3-years old or older (Alt 1989, Powell et al. 1997, Bridges et al. 2011, Garshelis et al. 2016). At any age, breeding, implantation and gestation, parturition, and lactation all depend on a female's body condition. Additionally, summer and autumn food production affects individual condition and whether a female produces cubs the following winter (Rogers 1976, 1987, Eagle and Pelton 1983, Eiler et al. 1989, Elowe and Dodge 1989, Costello et al. 2003, Laufenberg et al. 2018). Elowe and Dodge (1989) highlighted that, for the black bears they studied, 93% of females with access to hard mast high in fats produced cubs, whereas bears with access to lower quality diets did not produce cubs. Similarly, Costello et al. (2003) documented that litter size regressed positively on acorn production during the previous autumn for the bears that they studied.

Primiparity, or age of first birth, for black bears occurs almost universally at 4 years of age or older (Alt 1989, Eiler et al. 1989, Elowe and Dodge 1989, Costello et al. 2003, Obbard

and Howe 2008, Bridges et al. 2011). In a 10-year study, Beckmann and Lackey (2008) documented that female bears with access to garbage in a developed area weighed more and gave birth at an earlier ages than their wildland counterparts, though the age of primiparity was still 4 years. Earlier work in North Carolina documented 5 instances of primiparity at age 3 in a forested site with high food productivity (Powell unpublished data), and Garrison et al. (2007) documented that 3 of 12 2-year old female black bears in Florida produced cubs.

The consistency and abundance of foods in captive settings (e.g., zoos) may simulate the foods detected in urban environments. For example, literature based on captive or zoo environments have shown a trend towards earlier reproduction than their wild counterparts; female bears matured and reproduced at younger ages than wild bears (Rogers 1976) and captive orca whales (*Orcinus orca*) experienced a reduced age at first conception compared to wild orcas (Robeck et al. 2015), possibly because of the daily reliable food sources provided in the captive setting. Similarly, nutrition associated with captive food sources was indicated as a likely reason that wolves in captivity bred and produced pups at nearly half the age than is typical of wolves in the wild (Medjo and Mech 1976). Also, captive-penned ungulates (e.g., deer) experienced increased or improved growth rates, fecundity rates, earlier time of breeding and fawning related to the daily consumption of increased levels of nutrients (Verme 1969).

Knowledge of the reproductive contribution (or lack thereof) by a segment of a population not generally known to reproduce may alter the outcome of population models used by managers to estimate population dynamics. Our objective was to investigate cub production by 2-year old female black bears living in an urban environment and to determine the factors that influenced early reproduction. We hypothesized 1) that black bear cubs that

gain sufficient weight in their first year and grow large (> 40 kg) can breed as yearlings and produce cubs at age 2, and 2) that abundant natural food facilitates rapid growth of young bears in urban habitats.

STUDY AREA

Our urban study area was in and around the city of Asheville, North Carolina, a 117 km^2 city with a population density of 760 people/km^2 (Kirk et al. 2012; Fig. 1.1). We define "urban" to be landcovers that have high densities of commercial buildings and human housing (Gehrt 2010). Additionally, we studied bears in three rural areas that lacked development and residences (Fig. 1.1). One was on the Pisgah National Forest adjacent to the southwest boundary of our urban study site (Powell et al. 1997; Mitchell et al. 2002; Fig. 1.1). The other two study areas were on the George Washington Jefferson National Forest in western Virginia, one 260 km northeast of Asheville and the other 430 km north of Asheville (Bridges 2005; Bridges et al. 2011a; Bridges et al. 2011b; Fig. 1.1). The Pisgah and the Virginia study sites were on national forests with few private inholdings. All 4 study areas were in the southern Appalachian Mountains, with a climate characterized by mild winters, cool summers, and annual precipitation of 130–250 cm/year, primarily as rain. Forest were predominantly mixed hardwoods with scattered pine (*Pinus spp.*; Kirk et al. 2012) and a pine-hardwood mixes (Mitchell et al. 2002).

METHODS

Bear capture

From April 2014 through September 2018, we captured black bears using diverse culvert-type live-traps on private property across the urban study area. We baited traps with day-old

pastries and checked them twice daily. We immobilized bears with a combination of telazol (50 mg/cc), ketamine hydrochloride (40 mg/cc), and xylazine hydrochloride (10 mg/cc) at a dose of 1cc per 45 kgs. For bears ≥12 months old, we recorded date and capture location, weight, sex, morphological measurements, body condition, and reproductive condition, and we inserted a uniquely numbered ear-tag in each ear, applied a tattoo inside of the upper lip, and removed an upper first premolar to estimate age (Willey 1974; ages estimated by Matson's Laboratory, Milltown, Montana). We fitted each bear with a GPS transmitter-collar (Vectronic, Berlin, Germany) that did not exceed 4% of the bear's weight (Samuel and Fuller 1996; Cattet 2011). We administered a long-lasting analgesic and an antibiotic. We reversed the effects of xylazine hydrochloride with yohimbine hydrochloride (0.15 mg/kg) within approximately 60 minutes of immobilization. Due to their large sizes (> 45 kg), we outfitted a sample of yearling bears (1 to < 2 years old) with GPS collars to investigate bear family dynamics, dispersal, survival rates and causes of mortality. Handling of bears was approved by the Institutional Animal Care and Use Committee at North Carolina State University (14-019-O) and was consistent with the guidelines of the American Society of Mammalogists (Sikes 2016).

We captured black bears on the Pisgah study site in 1981-2002 using home-made barrel traps and spring-activated leg-hold snares modified for bear safety (Powell 2005, Cattet et al. 2008). Traps were baited with sardines, day-old pastries or left unbaited, and checked daily. We immobilized bears with a 2:1 mixture of ketamine hydrochloride and xylazine hydrochloride or with telazol via a jab stick or blowdart. For all bears, we recorded date and capture location, weight, sex, morphological measurements, body condition, and reproductive condition, and we put a uniquely numbered ear-tag in each ear, applied a tattoo inside of the upper lip and in the groin, and removed an upper first premolar to estimate age. We fitted bears that would not

outgrow collars with a VHF transmitter-collar (Telonics, Mesa Arizona; SirTrack, Havelock North, New Zealand; Lotek, New Market, Ontario Canada) that did not exceed 2% of the bear's weight. We reversed the effects of xylazine hydrochloride with yohimbine hydrochloride within approximately 45 minutes of immobilization.

We captured black bears on the Virginia study sites in 1994-2002 using culvert traps and spring-activated Aldrich leg-hold snares. We immobilized bears with a 2:1 mixture of ketamine hydrochloride and xylazine hydrochloride (concentration of 300mg/ml) at a dosage of 1cc/45.4 kg (100 lbs.), using dart pistol, jab stick, or blowgun. For all bears, we recorded date and capture location, temperature, weight, sex, morphological measurements, body condition, and reproductive condition, and we applied a uniquely numbered ear-tag, applied a tattoo inside of the upper lip, removed an upper first premolar to estimate age, and collected blood and hair samples for genetic and nutritional analyses. Select bears received a VHF radiocollar, cub collar, or eartag transmitter. We reversed the effects of xylazine hydrochloride with yohimbine hydrochloride (0.15 mg/kg) within approximately 60 minutes of immobilization.

At all sites, we located female bears with active transmitter collars at their den sites between October and February. We entered dens from mid-January through mid-March to conduct physical examinations of the females and to change collars if necessary. We documented reproduction by the presence of cubs and, during spring and summer trapping, documented reproduction by the presence of cubs in culvert traps or in trees above the trap site when a female was captured.

Mast Surveys

For the two study sites in North Carolina, the Wildlife Commission surveyed hard mast annually from August through September and based indices on visual estimates of the percentage

of oak crowns with acorns (Greenberg and Warburton 2007). Predetermined hard mast

categories were: failure (0-19.4% with acorns), poor (19.5-39.4%), average (39.5-59.4%), good

(59.5-79.4%), and bumper (79.5-100%). For the two study sites in Virginia, the Virginia

Department of Game and Inland Fisheries used the average number of acorns per 10 limbs on

each tree to index annual hard mast production from August to September (Fearer et al. 2002;

Bridges 2005). Due to small sample sizes in some mast categories and to increase power, we

combined the "failure" and "poor" categories and the "good" and "bumper" categories for all

study areas.

Weight Comparisons: Urban Versus Rural Bears

We used the *lsmeans* package (Lenth 2016) in R (v. 3.3.1) and a factorial ANOVA to detect

differences in yearling weights at capture by study area and by the hard mast index for the

autumn before each bear was weighed, and we included an interaction term between study area

and hard mast index to determine if the effect of hard mast index varied by study area. We made

post hoc multiple comparisons using the Tukey HSD method. We examined the QQ plots and

the Shapiro-Wilk test for normality prior to analysis and found evidence of skewness and non-

normality. We therefore log transformed the data to meet the assumptions of normality

associated with ANOVA in the distribution of yearling weights prior to our analyses.

We tested whether average weights of non-reproducing yearling females differed among

the 4 study sites using the statistical methods described above with the lsmeans package in

program R. The sample size for the urban site was reduced to 4 yearling females for this

comparison. Finally, we used a t-test to detect whether the reproducing yearling females in

Asheville were heavier than the urban yearling females that did not reproduce.

RESULTS

We obtained data on 133 yearling female black bears, one of which was not weighed until she was 2 years old. Mean weights of yearling female black bears differed significantly among the 4 study sites, with urban bears being heaviest ($F_{3,115} = 44.1$, $P < 0.001$), but with no differences among the rural study sites (Pisgah and Virginia; Fig. 1.2).

Summer weights for yearling female bears did not differ by hard mast index recorded during the previous fall (when they were cubs; $F_{2,115} = 0.57$, $P = 0.567$; Fig. 1.3). The interaction term between study area and hard mast index was significant ($F_{4,115} = 2.73$, $P = 0.033$), indicating that the effect of hard mast index on weights of yearling female bears varied by study area.

Urban, non-reproducing yearling females ($n = 5$) were heavier than non-reproducing rural females ($n = 107$, combined Pisgah and Virginia; $F_{1,89} = 27.7$, $P < 0.001$). Lastly, weights of yearling urban females that reproduced ($n = 6$) and those that did not reproduce did not differ (mean $= 50.4 \pm 14.0$ [1 sd]; $n = 5$; $t_9 = -0.476$, $P = 0.646$).

None of the 89 yearlings handled on the Pisgah and the Virginia study sites produced cubs on their second birthdays. Out of 12 yearling female black bears in the urban site, seven produced a total of 11 cubs on their second birthdays (mean litter size $= 1.6 \pm 0.8$). The cubs were observed at five urban dens and during two urban captures in culvert traps while trapping the following spring and summer. Two of the seven mother bears weighed less than 50 kg and all cubs were born following autumns with mast indices of average or poor.

DISCUSSION

We demonstrated that heavy yearling, female black bears do come into estrus and breed as yearlings and then produce cubs on their 2nd birthdays. We hypothesize that, being heavy, they have the nutritional reserves to sustain pregnancy and parturition (see Table 1.1). The six 2-year old bears (excluding the one bear captured and weighed as a 2-year old) that produced and raised cubs had mean weights of 53 kg ($\pm$2) when captured as yearlings. The flexibility to breed as yearlings pre-adapts black bears in food rich environments, including some urban areas.

Summer weights of yearlings at all four of our study sites were unaffected by the mast crops during the previous autumn, suggesting that spring and summer foods and their mothers' condition may be as important for growth of cubs as autumn foods. Female yearlings at the urban site weighed about double the weights of yearlings from the rural sites, suggesting the hypothesis that anthropogenic foods provide important nutrition for urban bears. Further, the results suggest that abundant hard mast in autumn may not be required for young urban bears to grow rapidly, even rapidly enough to enter estrus as yearlings. Thus, foods other than hard mast contribute to the weight gain and early reproduction of urban female bears. Quantifying urban food sources and possibly even urban refuse would have enabled us to identify the foods responsible for rapid weight gain and early reproduction by bears in Asheville.

As often is the case, black bears are at the center of human-wildlife interactions (Merkle et al. 2013, Baruch-Mordo et al. 2014) and urban bears may suffer high mortality if they ignore the dangers of humans, such as vehicle collisions. We suggest that researchers document the effects of quantified urban food sources on black bear life history. Our results

beg the question of whether cubs produced by young bears survive and are recruited into the population more or less than cubs born to females of older age classes. Efforts to reduce bear population sizes in urban areas may require refined focus on educating residents to use best practices for living responsibly with bears, and becoming "Bearwise" (see https://bearwise.org/).

Lastly, researchers and state agencies that monitor parturition in urban bear populations need to identify environmental conditions that contribute to source or sink dynamics. If urban bears produce cubs as 2- and 3-year olds, contributing to high population fecundity, and their populations can sustain relatively high mortality rates, then urban bear populations may be source populations for surrounding, rural areas. Alternately, if reproduction in urban populations cannot match high time specific or age specific urban mortality rates (Beckman and Berger 2003), then urban populations may be sinks for the surrounding areas.

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Table 1.1. Age of primiparity and reproduction events for 12 urban American black bears in North Carolina, USA, April 2014 through March 2018.

Bear ID	Age at Primiparity	Den Year	Capture Date	No. Cubs	Mast (previous fall)	Weight at First Capture / Age at first capture
N042[a]	2.5	2014	7/1//2014	1	Failure	127 / 2.5
N016	2.5	2015	7/10/2015	2	Average	122 / 1.5
N035	2.25	2015	3/25/2015	3	Average	95 / 1.5
N057	2.25	2015	3/16/2015	0	Average	125 / 1.5
N073	2.25	2016	3/9/2016	1	Poor	115 / 1.5
N077	2.25	2016	3/4/2016	1	Poor	132 / 1.5
N083	2	2016	N/A	0	Poor	88 / 1.5
N150	2	2017	N/A	0	Poor	110 / 1.5
N139	2.25	2017	3/8/2017	0	Poor	117 / 1.5
N143	2.25	2017	3/7/2017	2	Poor	117 / 1.5
N148	2	2017	N/A	0	Poor	116 / 1.5
N170[b]	2	2018	N/A	1	Average	109 / 1.5

[a] Study began April 2014; this was the only 2-year old female we captured with a cub present and that showed signs of lactation.
[b] Recon on the location of the exact substrate for this den caused the bear to flush from den; upon inspection there was one dead cub inside nest bowl. Bear made no attempt to return to den and remained 300 – 500 m away for duration of den season.
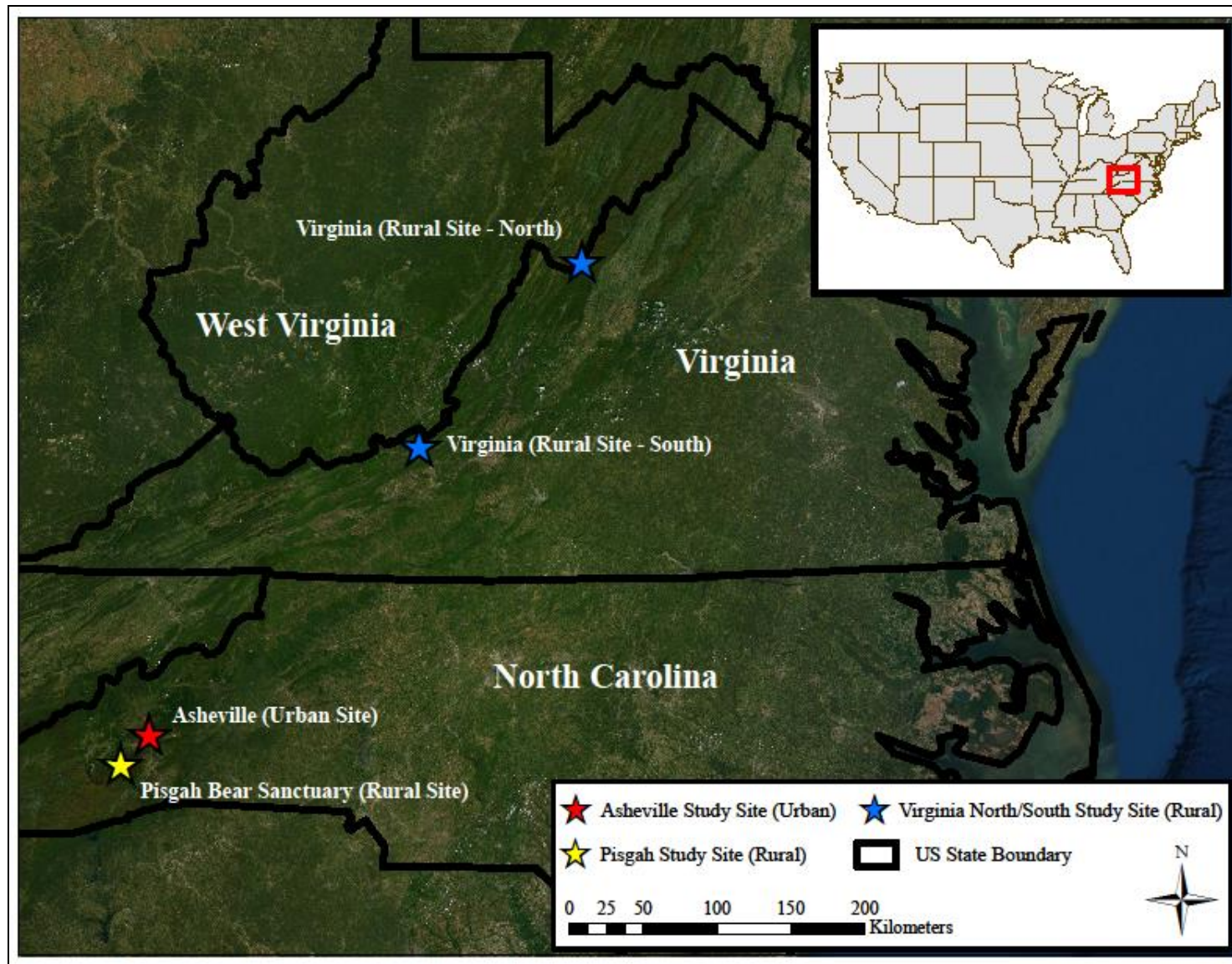
Figure 1.1. Locations of captures for yearling urban and rural black bears (*Ursus americanus*) at four study sites across in North Carolina and Virginia, USA.
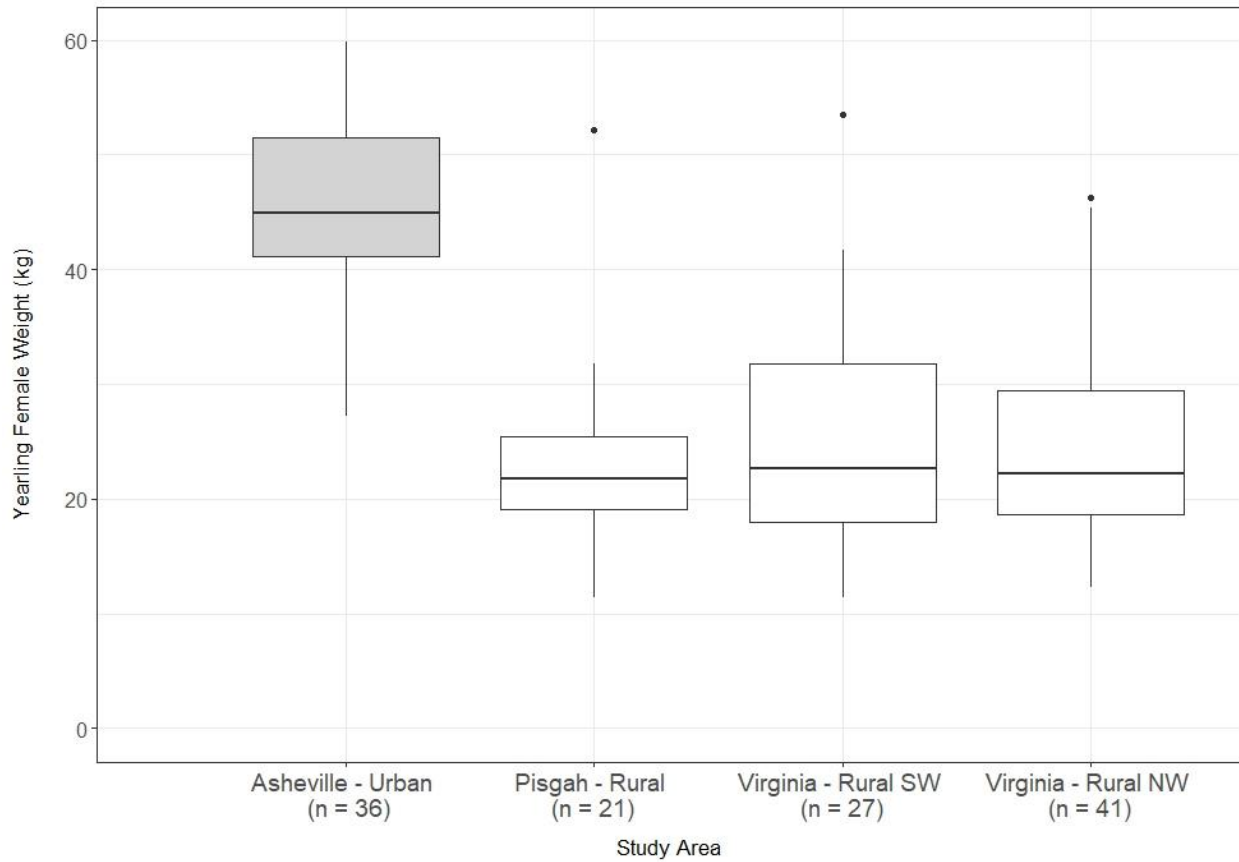
Figure 1.2. Average weights (kg) of yearling female black bears (*Ursus americanus*) in one urban (Asheville) and one rural (Pisgah Bear Sanctuary) study site in North Carolina, and two rural study sites in Virginia, USA. The horizontal line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the highest and lowest values.
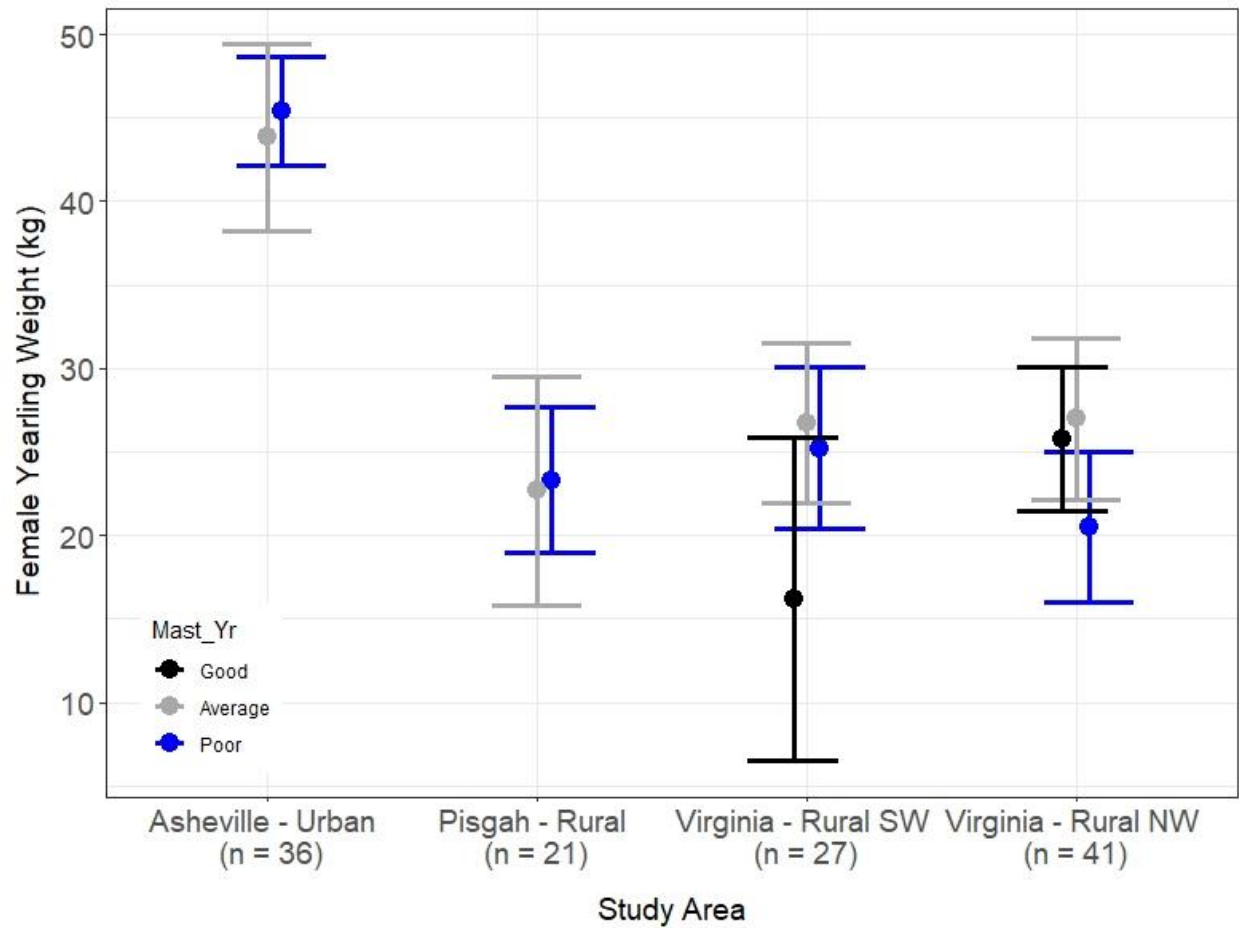
Figure 1.3. The effect of mast year (natural food production) on average weights (kg) of yearling female black bears (*Ursus americanus*) in one urban (Asheville) and one rural (Pisgah Bear Sanctuary) study site in North Carolina, and two rural study sites in Virginia, USA. The circle indicates the mean, and the vertical arms indicate the error associated with the estimates.

CHAPTER 2: Comparison of home range sizes for urban and rural black bears: effects of production of natural foods and housing density

ABSTRACT

As urbanization and development expand worldwide, human land use has fragmented natural land cover with interspersed urban and rural environments. Although populations of black bears (*Ursus americanus*) in rural areas shift their spatial distribution in response to available resources, information is limited on how bears navigate urban environments beyond the bears' use of urban areas in years of poor natural food production. To understand how urbanization and associated habitat fragmentation may affect the persistence and adaptation of wildlife populations, we compared the spatial ecology of urban and rural American black bears in North Carolina. We used continuous time movement models to quantify annual and seasonal home range sizes to make empirical comparisons between bears occupying developed areas (urban bears) and those in undeveloped areas (rural bears). We used generalized linear mixed effects modelling to evaluate relationships between bear home range size and five biologically important *a priori* covariates: study area (urban or rural), housing density, sex, reproductive class, and natural food production (i.e., indices of hard and soft mast) on black bear home range size. Urban bears had consistently smaller home ranges than rural bears regardless of variation in the production of natural food. Furthermore, home range sizes of urban bears did not vary in size with respect to housing density or natural food production. These results indicate that urban areas may be good habitat for bears where they can meet their metabolic requirements and secure adequate resources across a range of housing development.

INTRODUCTION

Currently, greater than 10% of the earth's land surface is categorized as 'urban cover' and that area is continually growing (McGrannahan 2005). By the year 2050, 67% of the human population is expected to live in cities (UNPD 2014). Cities now constitute one of the 'newest and fastest growing' ecosystems in the world (Magle et al. 2019). Conversion of wildlife habitat into landscapes developed by humans, and the concomitant habitat fragmentation (McCleery et al. 2014; Mills 2013), affects wildlife diversity (Lawler et al. 2014; McIntyre 2014; Mckee et al. 2003, McKinney 2002) and population dynamics (Rodewald and Gehrt 2014; Gehrt and Riley 2010). Hence, the focus on wildlife in 'natural' systems is now sharing importance with a focus on urban systems (McCleery et al. 2014), providing important research opportunities in urban ecology and conservation (Magle et al. 2019).

Wildlife often alter their behaviors in plastic responses to urbanization (Zeller et al. 2019; Parsons et al. 2018; Fehlmann et al. 2017; Ghalambor et al. 2010; Sih et al. 2011), with avoidance of developed areas by some species and the exploitation of urban resources by others (Riley and Gehrt 2014; McKinney 2002; Blair 1996). The intentional (e.g., bird feeders) and unintentional (e.g., fruits and seeds from native and non-native vegetation, or municipal garbage) feeding of wildlife can induce changes to reproductive ecology (Chapter 1), foraging behaviors and diets in response to the foods available in urban areas (Lowry et al. 2013). The year-round availability of foods in urban areas increases breeding season length for some wildlife (Shochat et al. 2004; Lowry et al. 2013; McIntyre 2014). Many wildlife species, such as black bears (*Ursus americanus*), coyotes (*Canis latrans*), and raccoons (*Procyon lotor*), face risks in urban environments, such as collision with vehicles and because of the trade-off between risk of mortality and access to food (Laundre et al. 2001; Preisser et al. 2005), wildlife may occupy

areas where urban development and the presence of humans influence their spatial ecology. Further, urban wildlife can damage property (Raithel 2017; Conover 2002), destroy fruit trees and gardens (Raithel 2017; Witmer and Whittaker 2001) and, potentially, transmit zoonotic diseases (Parsons et al. 2019; Stephenson et al. 2015; Bronson et al., 2014). Therefore, managing wildlife in urban areas often is a necessity but there are no legal hunting opportunities inside city limits (Treves et al. 2018). Thus, understanding animal space use may provide critical insight into providing opportunity for unique hunting opportunities in urban areas, via public land acquisition adjacent to development.

Understanding how wildlife use urban spaces can help managers develop management plans by identifying wildlife distributions, corridor use, foraging areas, and areas of overlap with other taxa, including humans (Kays et al. 2015; Nathan et al. 2008; Powell 2012). Specifically, an animal's home range size represents one characteristic of the area with which it is intimately familiar. This area contains food, escape routes, cover, and potential mates, all of which affect fitness (Powell 2012; Burt 1943). Many urban mammals maintain home ranges that are smaller than those of their rural counterparts (Harris 1981; Frost 2005; Riley 2006; Baker et al. 2007; Gehrt et al. 2009; Gehrt and Riley 2010; Gosselink et al. 2010; Gould and Andelt 2013; Beckmann and Berger 2003, Baruch-Mordo et al. 2014, Karelus et al. 2016, but see Mitchell and Powell 2008), and alter their activity patterns to become more nocturnal to avoid people (Baruch-Mordo et al. 2014). Typically, mammals have small home ranges in productive habitats, and that is the case for rural bears (Koehler and Pierce 2003; Oli et al. 2002; Powell et al.1997, Smith and Pelton 1990). Although ideal methods for quantifying home ranges would account for how an animal perceives its own home (Powell 2000), we can instead use spatial

records of where an animal actually spends its time to statistically describe the size of an area it needs.

The limited literature on space use by urban bears suggests they likely respond to resources similarly to rural bears (Tri 2013). Black bears can have highly variable home range sizes that generally correlate with seasons as well as natural food production. Rural bear populations, without access to urban areas, respond to natural food shortages by increasing their home range size and by making long-distance movements to secure adequate food (Olfenbuttel 2005; Powell et al. 1997; Garshelis and Pelton 1981; Amstrup and Beechum 1976). Alternatively, in years of good natural food production, bears will exhibit reduced home range sizes, both annually and seasonally, as less area is needed to meet metabolic requirements (Olfenbuttel 2005; Powell et al. 1997), but may exhibit large home range sizes in the autumn season during hyperphagia. Black bears occupying the rural to urban interface may supplement their food intake with anthropogenic resources. Baruch-Mordo (2012) reported that black bears exhibited a fluid or dynamic response to suboptimal natural food production by increasing their use of foods within the city limits of Aspen, Colorado, but returning to adjacent rural areas during optimal years. Similarly, black bears may become nocturnal and increase their activity around urban areas at times when human disturbance is likely to be low (Zeller et al. 2019; Evans 2016). Black bears may respond to the urban environment by generally maintaining large home ranges (Mori 2017) or maintaining seasonal home ranges away from developed areas (Palmer et al. 2017), if natural food production is good. Conversely, bears may solely occupy the periphery of urban areas and not shift their home ranges closer to urban areas during natural food shortages (Tri et al. 2016). Nonetheless, a threshold may exist in which bears may avoid areas with increasing housing density in developed areas, indicative of 'urban tolerance' rather than

habituation or adaptation (Evans 2016). Beyond reduced home range sizes, bears that can regularly obtain resources in urban areas may benefit from increased weight gain due to the predictability of year-round anthropogenic food sources (e.g., garbage; Baruch-Mordo 2012; Beckmann and Berger 2003), which in turn may influence reproduction by bears (Chapter 1). Regardless, to gain a better understanding of potential differences between urban and rural bears both populations should be compared under the same study using source data (i.e., not estimates from the literature) and the same home range methodology (Klip 2018; Karelus et al. 2016; Börger et al. 2006; Seaman and Powell 1996).

Our objectives were to compare space use by urban and rural black bears while also considering the effects of study area, housing density, sex, reproductive class and yearly variation in natural food production on black bear home range size. We hypothesized that food is the primary driver of home range size for bears and, thus, 1) that urban bears have smaller home ranges than do their rural counterparts; 2) that urban bears expand use into areas with dense housing when natural food production is low and, thus, have larger home range sizes in these years; 3) seasonal home ranges for all bears are small during years of good natural food production; and 4) females have smaller home ranges than males in urban and rural landscapes.

STUDY AREAS

We studied bears in two study areas in the southern Appalachian Mountains of western North Carolina (Fig. 2.1) with heterogeneous topography (500–1800 m elevation), mild winters, cool summers, and high annual precipitation (130–200 cm/year). The dominant forest types included mixed deciduous hardwoods with scattered pines (*Pinus spp*.; Kirk et al. 2012) and pine-hardwood mixes (Mitchell et al. 2002; Powell et al. 1997).

We collected data from 2014 to 2018 in the urban study, which was centered on the city

of Asheville. Located in a valley bottom, the city-limits of Asheville encompassed 117 km² with

approximately 92,000 people; with the surrounding urban, suburban, and exurban areas, the

human population totaled approximately 200,000 people. Asheville was divided roughly into

four quadrants separated by two four-lane, interstate highways, while a third interstate highway

looped in a semi-circle around Asheville's downtown district (Fig. 2.1).

We collected data from 1981 through 2002 in the Pisgah Bear Sanctuary, located

approximately 8 km southwest of Asheville and located entirely within the Pisgah District of the

Pisgah National Forest (Powell et al. 1997; Fig. 2.1). Bear hunting was not allowed in the

Sanctuary (marked with signs), although all other legal hunting was allowed. The study area was

bisected by the Blue Ridge Parkway, a two-lane highway with an approximate 400 m

right-of-way managed by the National Park Service. This study area had no human residences,

though some residences did border the study area.

METHODS

Bear Capture and Handling

We used homeowner reports of black bears on private property to identify trap sites in

Asheville. We deployed culvert traps, baited with commercial pastries, within and adjacent to

Asheville city limits. We trapped solely on private properties and checked traps twice

daily. We immobilized captured bears with a drug combination of telazol hydrochloride (11

mg/kg estimated weight), ketamine hydrochloride (9 mg/kg) and xylazine hydrochloride (2

mg/kg) delivered via a CO_2 powered dart pistol. We placed a uniquely numbered ear-tag in each

ear, applied a tattoo to the inside of the upper lip, removed an upper first premolar from all bears

≥12 months old to estimate age (Wiley 1974), and inserted a Passive Integrated Transponder tag (PIT tag) between the scapulae. We recorded weight, sex, reproductive status, morphometric measurements, date, and capture location for each bear. Additionally, we collected blood for serum from the femoral artery, collected any ectoparasites present, and obtained tissue and hair samples including follicles. We fitted bears with global positioning system (GPS) radiocollars (Vectronic, Berlin, Germany) that did not exceed ~ 4% of any bear's weight (Samuel and Fuller 1996; Cattet 2011). We administered a long-lasting analgesic and an antibiotic and reversed xylazine hydrochloride with yohimbine hydrochloride (0.15 mg/kg) within approximately 60 minutes of immobilization. We released all bears at their capture sites. We used the virtual fence application on the GPS collars to obtain locational data every 15 minutes for bears within Asheville city limits and every hour for bears outside the city limits.

We captured black bears on the Pisgah study site using home-made barrel traps and leg-hold snares modified for bear safety (Powell 2005), and baited with sardines, day-old pastries or left unbaited and checked daily. We immobilized bears with ketamine hydrochloride (4 mg/kg) and xylazine hydrochloride (4 mg/kg) or with telazol (4 mg/kg) delivered via jab stick or blow dart. For all bears, we placed a uniquely numbered ear-tag in each ear, applied a tattoo inside of the upper lip and in the groin, and removed an upper first premolar to estimate age (Wiley 1974; ages estimated by Matson's Laboratory, Milltown, Montana). We recorded weight, sex, morphology, date, and capture location, and we fitted bears that would not outgrow collars with VHS transmitter-collars (Telonics, Mesa Arizona; SirTrack, Havelock North, New Zealand; Lotek, Newmarket, Canada) that did not exceed 2% of a bear's weight. We reversed the effects of xylazine with yohimbine hydrochloride (100 mg) within approximately 45 minutes of immobilization at the capture site. We located bears via triangulation every 2 hours for 8, 12 or

24 consecutive hours each day (depending on changing research goals during the 2 decades of research) while bears were not in winter dens. Sampling intervals were repeated every 32 hours to standardize bias from autocorrelation within the sampling periods (Powell 1987).

All animal handling techniques for both sites were approved by the Institutional Animal Care and Use Committee at North Carolina State University and were consistent with guidelines provided by the American Society of Mammalogists (Sikes et al. 2016)

Data Handling and Home Range Estimates

To avoid bias associated with behavioral effects from the chemical immobilization, we excluded data collected 7 days after the capture and release of each bear (Cattett et al. 2008). We removed GPS locations that did not meet the positional dilution of precision criteria of ≤ 10 for 3D and ≤ 5 for 2D-fixes (Lewis et al. 2007) or that had erroneous elevation or temperature values. We defined three seasons for calculating home ranges based on dates of food production and bear biology: Annual = den emergence to den entrance, or den emergence to 31 December, or 1 January to den entrance; Spring = den emergence to 15 June; Summer = 16 June to 31 August; and Fall = 1 September to den entry or 31 December (Olfenbuttel 2005; Tri 2013). We included bears with ≥ 4.5 months of data in the analyses for annual home ranges while bears with >1.5 months of data during the specified season were included in the seasonal home range analyses.

We estimated annual and seasonal home ranges using Autocorrelated Kernel Density Estimation (AKDE) and the *ctmm* package (Calabrese et al. 2016; Fleming et al. 2015; Fleming and Calabrese 2017) in R (v. 3.3.1) for both datasets. The *ctmm* package uses empirical variograms, or plots of the semi-variance in positions that represent the average squared distance moved over some time lag, and provide good visual diagnostics for evaluating range residency for animal space use (Calabrese et al. 2016; Fig. 2.2). Home range residency is indicated by an

asymptotic behavior in the semi-variance shortly after data collection begins (Fig 2.2A) whereas a lack of home range residency is illustrated by an increasing semi-variance (Fig 2.2B). When autocorrelation is limited (i.e., some VHF datasets), the AKDE defaults to KDE, thus increasing the efficacy of this method to make comparisons between datasets with differing methodologies. The methods in the *ctmm* package perform well with small effective sample sizes and there is no need to subsample or otherwise "match" the data to make direct comparisons (Fleming et al. 2019).

To ensure sufficient sample sizes further, we included only those annual or seasonal home ranges that had at least 30 locations, which was a concern for only the rural dataset. Additionally, if any home range lacked asymptotic behavior in the plots of the semi-variance, we split the dataset for each bear into a first half and second half and used the overlap () function in the *ctmm* package to further ascertain range residency. If the two halves of the relocation data overlapped less than 75%, we considered that bear not to be range resident for this analysis. For each annual and seasonal period, we defined a bear home range as the 95% contour resulting from the utilization distribution. We excluded dispersing bears from home range analysis.

Covariates Associated with Use of Space by Black Bears

We examined five covariates on bear home range size: study site, the degree of human housing development, natural food production, and individual bear attributes (sex and age group). Female bears were categorized as barren, having cubs of the year, or having yearlings. Males were classified as juvenile (<3) or adult ($\geq$3 years). To estimate the effect of housing development and human foods on black bears, we used a housing footprint layer for Buncombe County (www.buncombecounty.org). We verified (via aerial photography 2013) the housing footprint layer by removing any addresses that did not have a physical structure. We then

calculated the house density (per km^2) in each individual bear's annual and seasonal home ranges. Housing density within a bear's annual and seasonal home range became our metric of their human food use, as we assumed that bears using human development were foraging on anthropogenic resources (Johnson et al. 2015; Lewis et al. 2015).

The North Carolina Wildlife Resources Commission surveyed hard mast annually from August through September, summer soft mast (blueberry, huckleberry, blackberry, and pokeberry) in odd years (i.e., 2015, 2017, etc.), and autumn soft mast (pokeberry, cherry, grapes, and blackgum) during the annual hard mast surveys (NCWRC). Hard mast indices were based on visual estimates of the percentage of oak crowns with acorns (Greenberg and Warburton 2007). Predetermined hard mast categories included: failure (0-19.4% with acorns), poor (19.5-39.4%), average (39.5-59.4%), good (59.5-79.4%), and bumper (79.5-100%). During summer and fall soft mast surveys, the overall abundance of berries for each species was estimated as the percentage of plants with little to no mast as 0.0 to 2.0 (Poor), scarce to moderate mast as 2.1 to 4.0 (Fair), good to abundant berry production as 4.1 to 6.0 (Good), or a bumper crop as 6.1 to 8.0 (Excellent). This numerical rating (0.0 - 8.0) is equivalent to the crop quality for that season. The numerical rating was averaged across all transects for each soft mast species. We used the categorical estimates of hard and soft mast production (e.g., failure, poor, average, etc.) as covariates in our models representing the quality of natural foods for each year/season.

Modeling space use

We first developed a model to ascertain the effects of study area (urban vs rural) on home range size while also including annual hard mast production, sex, and reproductive class. Second, we considered only the bears in the urban site to examine the effects of housing density, in addition to natural food production, sex, and reproductive class, on home range size. We ran

these models with annual home range size as well as with seasonal home range size, with the additional covariate of season (spring, summer, and fall) included in the models. Because summer and fall seasonal food production had similar annual values from 1994 through 2001 and between 2014 and 2017, we created an interaction variable, 'Summer*Autumn', for these two seasonal food indices to increase parsimony in modeling efforts and are confident that we minimized information loss because of the similarity in numerical scores for seasonal food production across the years of both studies. We removed observations that had missing data for seasonal natural food production, mostly due to the NCWRC surveying for summer seasonal foods in odd years.

We examined residuals and, due to inhomogeneity of variances, we used a natural log-transformation on the 95% AKDE as the response variable in each of the four model sets. This reduced skewness and increased normality in the distribution of home ranges prior to our analyses. We used the *lme4* package (Bates et al. 2015) in R (R Development Core Team 2015) and constructed linear mixed effects models for all four model sets. The candidate model sets included additive models with interactions as well as a random intercept for each bear to account for multiple observations on the same bear across years. We used Akaike's information criterion corrected for small sample size (AICc) to assess model weights and ranked candidate models using ΔAICc (Anderson 2008; Burnham and Anderson 2002), and we used Akaike weights to determine the relative support for each model. If any model contained ≥ 60% of the AICc weight, we chose the top model as opposed to model averaging. Lastly, we used the *emmeans* (Lenth 2016) package in R to develop post-hoc contrasts using estimated marginal means for comparisons of interest.

RESULTS

We obtained an average of 7,265 locations/bear/year for the urban bear study area and 136 for

the rural bear study area. Combining the urban and rural datasets, we were able to construct and

use 202 annual home ranges (100 urban, 102 rural) and 234 seasonal home ranges (119 urban,

113 rural).

Annual Home Range: Urban vs Rural

Annual home range size for urban bears averaged 10.7 (sd = 13.9) and 67.3 km^2 (sd = 60.1) for

females and males, while annual home range size for rural bears averaged 19.9 (sd = 13.2) and

89.0 km^2 (sd = 49.5) for females and males. Housing density within home ranges for urban bears

averaged 135.9 (sd = 111.2; range: 0 - 394) and 121.8 km^2 (sd = 91.3; range: 20 - 300) for

females and males. The top model (Study + Sex + Hard Mast; Table 2.1) for annual home range

size was supported with 60% of the overall Akaike model weight. Female and male urban bears

had significantly smaller annual home range sizes than rural bears, regardless of the quality of

natural food production, though urban bears in 'Poor' food years had significantly smaller home

range sizes than rural bears in either the observed hard mast categories ('Average' or 'Poor';

Table 2.2; Fig. 2.3).

Annual Home Range: Effect of human development

The top model including main effects and interaction terms (HD*Sex*Hard Mast; Table

2.3) for the effect of housing density on urban black bear home range size was supported with

60% of the overall Akaike model weight. Contrary to our hypotheses, home range size did not

correlate positively with housing density for either females or males (Table 2.4). We detected

significant differences between annual male and female home range sizes at low to intermediate

levels of housing density (0 – 200 houses/km^2) during years when natural food production was

average, with females having significantly smaller home ranges than males at these levels (Fig. 2.4; Fig. 2.5). Lastly, home range size did not increase significantly with increasing housing density for either females or males in years of poor quality hard mast production (Table 2.5; Fig. 2.5).

Seasonal home ranges: urban vs rural

The top seasonal model (Sex*Season*Study; Table 2.6) for comparisons of home range size between urban and rural bears was supported with 100% of the overall Akaike model weight. There was no support for our hypothesis that urban bears had smaller seasonal home range sizes than rural bears for males and females (Fig. 2.6). Because seasonal home range sizes were similar within and among urban and rural bears, we averaged over 'Study Area' to examine the effects of Sex on seasonal home range size. Female urban bears had smaller averaged seasonal home range sizes than rural female bears, but there was no difference in averaged seasonal home range between urban and rural male bears (Fig. 2.7; Table 2.7). Lastly, female bears in both study areas had smaller averaged seasonal home ranges than male bears, respectively (Fig. 2.7). Natural food production (Hard Mast) and seasonal mast production were not included in the top model, nor was reproductive class.

Seasonal home range: effect of human development

The top model (HD*Sex*Season + Summer*Autumn; Table 2.8) was supported with 78% of the overall Akaike model weight. We did not detect support for our hypothesis that urban bears had larger home range size in the fall (Fig. 2.8; Table 2.9). Nonetheless, males in the spring used larger home ranges as housing density increased (Fig. 2.8). Seasonal home ranges of males and females differed in size during all three seasons and at nearly all levels of housing density, with females having smaller home ranges than males (Fig. 2.8).

DISCUSSION

That we did not detect an increase in annual or seasonal home range sizes with increasing levels of housing density (i.e., human disturbance), partnered with our result that urban bears had significantly smaller annual and seasonal home ranges than rural bears, suggests that bears used highly developed areas permanently (not just in bad years) and that urban areas (at least Asheville) function as high quality habitat with sufficient food resources. Further, our results contrast with recent results indicating that bears generally use urban areas primarily in times of food shortages or poor mast production (Zeller et al. 2019; Baruch-Mordo et al. 2014).

We detected no support for our hypothesis that home range sizes would be larger in years of poor natural food production (i.e., shortages) for either urban or rural bears. Although both study sites appear to have high quality habitat, urban bears had consistently smaller annual home range sizes compared to rural bears, regardless of the quality of the regional natural food production (e.g., 'average' versus 'poor' hard mast production). This result was surprising because other studies have shown that rural black bears typically respond to food shortages by increasing travel distances and home range size (Olfenbuttel 2005; Powell et al. 1997; Garshelis and Pelton 1981; Amstrup and Beechum 1976). However, the smaller home range sizes for urban bears may be a consequence of the population not being at carrying capacity, as has been observed in brown bears (*Ursus arctos*) in Slovenia (Krofel et al. 2010), coyotes in southern California (Riley et al. 2003), and red deer (*Cervus elaphus*) populations inhabiting urban areas or otherwise fragmented habitats (Klemen 2012). The fact that urban bears did not respond to poor mast production by increasing their home range sizes suggests that bears in Asheville are decoupled from these natural fluctuations due to the availability of anthropogenic food. This is contrary to Baruch-Mordo et al. (2014) that determined that bears used the city of Aspen,

Colorado, primarily during years with poor natural food quality. One reason for the difference may be that Asheville comprises an area 10 times larger (117.2 km² versus 10.1 km²) than the urban area in Aspen and, thus, the amount of plentiful high-calorie urban foods (e.g., bird seed, pet food, ornamental fruit trees, etc.) may be more abundant in Asheville due to the size of the community alone. Regardless, because we can only hypothesize that urban food sources were driving the differences in our study, it appears important to collect and quantify data on both natural food production and anthropogenic food availability when examining space use for urban black bears.

We did not detect a consistent increase in annual or seasonal home range size with increasing levels of housing density (excepting for male bears in the spring season). The lack of increased home range size with increased level of development occurred regardless of sex and natural mast production for annual home range and regardless of sex and most seasons (summer or fall), both of which were counter to our hypotheses that bears would expand their range in times of poor food production. Our results contradict other urban bear studies that have suggested the use of development by black bears is 'temporarily dynamic' (Zeller et al. 2019; Evans et al. 2018; Baruch-Mordo et al. 2014) and restricted to times when natural food production is poor or when human activity is reduced (e.g., nighttime).

In concert with our previous results, we detected evidence of a sex effect with home range size and increasing levels of housing density. Specifically, females had significantly smaller annual home range sizes than males at low to intermediate levels of housing density and significantly smaller seasonal home range sizes at nearly all levels of housing density. Although not surprising, provided that females have smaller home ranges than males, it is possible female bears in Asheville have learned that occupying areas with development rewards them with high

calorie foods, and that may extend to educating their female young to take advantage of those same resources. Lowry et al. (2013) suggested that urban individuals may become habituated to development and its associated disturbance through learning, and thus individuals may increase in their boldness, or willingness to take up residence in urban areas, over time. Also, the absence of an age class effect in any top models may be due to the fact that young female bears in Asheville are heavier and may be reproducing earlier in life than their rural counterparts (Chapter 1), thereby suggesting that younger female bears may be using space similarly to other reproductive classes in our study.

 Home range sizes were not larger in fall season due to the onset of hyperphagia, when bears typically face increased energetic demands and seasonal home range size was similar between urban and rural bears. A lack of seasonal differences in home range sizes suggests stability across seasons and likely indicates that food resources are sufficient enough that alteration of home range size is not required (Ryan and Partan 2013; Prange 2004). Nevertheless, differences between seasonal home range sizes for black bears is variable with some studies reporting a lack of difference in the size of seasonal home ranges (Karelus et al. 2016; Tri 2013), whereas others report significant differences, with the fall season generally being largest in size due to increased search effort associated with increased caloric intake during hyperphagia (Moyer et al. 2007; Powell et al. 1997; Hellgren and Vaughan 1990), and in years of poor natural food production (Powell et al. 1997). Nonetheless, urban male bears had significantly larger home ranges as housing density increased only in the spring season which is likely due to males increasing their home range size to locate females for the onset of breeding season and possibly because homeowners had not established bird feeders yet, and thus males may need to increase their search area for food as well. Similarly, Klip (2018) determined that male bears around Lake

Tahoe, California had greater overlap with urban areas in the spring season. There is difficulty with comparing seasonal home ranges between studies because seasons are intuitively defined and unique based on geography because food production varies with latitude and longitude. Combined with our larger samples sizes, our ability to compare urban and rural bear space use in the same geographic area make our study a good benchmark for future research on urban and rural bear space use.

Both urban and rural female bears had significantly smaller annual and seasonal home range sizes than did male bears, which was expected, and consistent with nearly all other studies examining differences between male and female black bear space use (Klip 2018; Karelus et al. 2016; Baruch-Mordo et al. 2014; Tri et al. 2013; Olfenbuttel 2004; Fersterer et al. 2001; Powell et al. 1997; Smith and Pelton 1990; Reynolds and Beecham 1980). It is well established that the larger physical size and metabolic requirements for male bears influences males having significantly larger home sizes than females (Powell et al. 1997). Similarly, male black bears are polygynous, and thus, use more space to locate potential mates; and females select areas with abundant resources, which is generally influenced by having cubs of the year, or potentially dependent yearlings, leading to smaller home range sizes (Powell et al. 1997).

Recent investigations of urban black bears have reported smaller sample sizes than our study, some have had samples of bears in areas with lower levels of housing density (i.e., exurban) (Zeller et al. 2019; Evans et al. 2018; Tri et al 2016), and have lacked the empirical comparisons to rural bear space use. Some authors only reported home range size for urban bears and relied on comparisons to published literature for home range size on rural bears. Future research should focus on collecting data on natural and anthropogenic food sources in or near urban areas as well as making attempts to compare urban and rural bears simultaneously

using a continuous time movement modeling approach (Calabrese et al. 2016; Fleming et al. 2015; Fleming and Calabrese 2017).

Future studies should attempt to identify whether there are differences in levels of boldness/shyness, stress levels, and body condition between urban and rural black bears which will further advance our understanding of the landscape of fear hypothesis as it pertains to black bears in urban habitats. Furthermore, if some populations of urban bears are synanthropic and are less temporally dynamic with regard to the timing of use of urban areas than previous studies report, then steps to increase Bearwise community involvement are imperative to reduce and remove negative human-bear interactions and develop strong urban bear management plans.

Our primary goal was to make empirical comparisons of space use between bears from the same population, separated into an urban and rural study area. This comparison using the AKDE estimator eliminated the need to compare home range results to previous estimates from the literature as well as the commonplace practice of constructing home ranges using multiple different estimation methods (e.g., minimum convex polygons and standard KDEs). Estimating animal home ranges using methodology that account for the autocorrelation structure that occurs in nearly all radio-telemetry and GPS collar movement data, but specifically allows for comparisons between studies that have different data collection methods (e.g., VHF versus GPS collars, fix schedules, etc.; Fleming et al. 2015) will make comparison of space use results more standardized in the future. Further, under this approach, it is not necessary to use the ad hoc fix to remove any bias via subsampling (Calabrese et al. 2016; Fleming et al. 2015). Our results establish a baseline for future comparisons of space use between populations of urban and rural animals using empirical data and a single, superior home range estimator and address

suggestions raised from recent black bear studies (Klip 2018; Tri 2013, and Baruch-Mordo

2012).

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Table 2.1. Model selection results for the effect of study area (urban vs. rural), sex, reproductive class, and natural food production on annual home range size of urban and rural black bears, North Carolina, USA, 1981-2001; 2014-2017.

	ΔAIC_c	AIC_c weight	Model Likelihood	K	Log Likelihood
Study + Sex + Hard Mast	0	0.60	1	7	-221.1
Study + Sex + Hard Mast + Repro class	1.9	0.24	0.40	8	-220.9
Study + Sex	2.7	0.16	0.26	5	-224.6
Null	111.7	0.00	0.00	3	-281.2

Table 2.2. Estimated marginal mean Tukey pairwise comparisons for the effect of study area, sex, and natural food production on annual home range size for urban and rural black bears, North Carolina, USA, 1981-2001; 2014-2017, respectively. The 'emmean' is the least-squares means (estimated marginal means) from the model.

Hard Mast = 'Average':

Study	Sex	emmean	SE	df	LCL	UCL	Tukey Group
Urban	F	2.01	0.107	172	1.80	2.22	1
Rural	F	2.76	0.128	191	2.51	3.02	2
Urban	M	3.56	0.157	159	3.25	3.87	3
Rural	M	4.31	0.150	179	4.01	4.60	4

Hard Mast = 'Poor':

Study	Sex	emmean	SE	df	LCL	UCL	Tukey group
Urban	F	1.92	0.110	175	1.71	2.14	1
Rural	F	2.68	0.115	164	2.45	2.90	2
Urban	M	3.47	0.163	170	3.15	3.79	3
Rural	M	4.22	0.144	170	3.94	4.51	4

Table 2.3. Model selection results including main effects and interaction terms for the effect of housing density, sex, reproductive class, and natural food production on annual home range size for urban bears, North Carolina, USA, 2014-2017.

	ΔAIC_c	AIC_c weight	Model Likelihood	K	Log Likelihood
HD*Sex*Hard Mast	0	0.60	1	10	-115.79
HD + Sex + Hard Mast	2.98	0.13	0.22	6	-122.07
HD + Sex + Repro class	3.29	0.11	0.19	6	-122.22
HD*Sex*Repro class	3.74	0.09	0.15	10	-117.66
HD + Sex + Hard Mast + Repro class	4.28	0.07	0.12	7	-121.56
HD*Sex*Hard Mast*Repro class	9.87	0.00	0.01	18	-109.74
Null Model	28.84	0.00	0.00	3	-138.32

Table 2.4. Results for the effect of housing density trend (positive or negative) with increasing housing density within the individual home range, sex, and natural food production on annual home range size for urban black bears, North Carolina, USA, 2014-2017.

Hard Mast Yr	Sex	HD trend	SE	df	95 LCL	95 UCL	Tukey group
Poor	F	-0.000044	0.00115	108.5	-0.002318	0.00223	1
Average	M	0.000641	0.00352	93.3	-0.006349	0.00763	1
Average	F	0.002521	0.00120	107.7	0.000134	0.00491	1
Poor	M	0.003898	0.00345	104.5	-0.002934	0.01073	1

Table 2.5. Results for the Tukey pairwise comparisons between the effect of sex and natural food production ('Average' or 'Poor' food year) on annual home range size for urban black bears, North Carolina, USA, 2014-2017.

Contrast	estimate	SE	df	*t* ratio	*P*
F (Average) – M (Average)	0.001880	0.00372	95.4	0.505	0.9576
F (Average) – F (Poor)	0.002565	0.00131	60.2	1.964	0.2130
F (Average) – M (Poor)	-0.001376	0.00365	104.9	-0.377	0.9816
M (Average) – F (Poor)	0.000685	0.00370	96.0	0.185	0.9977
M (Average) – M (Poor)	-0.003257	0.00468	107.2	-0.695	0.8987
F (Poor) – M (Poor)	-0.003942	0.00363	105.4	-1.085	0.6992

*P value adjustment: Tukey method for comparing a family of 4 estimates

Table 2.6. Model selection results including main effects and interaction terms for the effect of study area, sex, reproductive class, and natural food production on seasonal home range size of urban and rural bears, North Carolina, USA, 1981-2001; 2014-2017, respectively.

	ΔAIC$_c$	AIC$_c$ weight	Model Likelihood	K	Log Likelihood
Sex*Season*Study	0	1	1.00	14	-245.24
Repro class+ Sex + Season + Study + Hard Mast	17.10	0.00	0.00	9	-259.35
Repro class+ Sex*Season + Study + summer*autumn	17.72	0.00	0.00	12	-256.36
Repro class+ Sex + Season*Study + summer*autumn	19.13	0.00	0.00	12	-257.06
Null	101.11	0.00	0.00	3	-307.70

Table 2.7. Results for the Tukey pairwise comparisons between the effect of sex and study area on average seasonal home range size for urban and rural black bears, North Carolina, USA, 1981-2001; 2014-2017, respectively. The 'emmean' is the least-squares means (estimated marginal means) from the model.

Sex = F:

Study	emmean	SE	df	95 LCL	95 UCL	Tukey group
Urban	1.78	0.116	96.3	1.55	2.01	1
Rural	2.40	0.138	125.7	2.13	2.68	2

Sex = M:

Study	emmean	SE	df	95 LCL	95 UCL	Tukey group
Rural	3.61	0.273	242.9	3.07	4.15	1
Urban	4.17	0.219	153.9	3.74	4.61	1

*Results are averaged over the levels of "Season".

Table 2.8. Model selection results including main effects and interaction terms for the effect of housing density (per km²), sex, reproductive class, and natural food production on seasonal home range size for urban bears, North Carolina, USA, 2014-2017.

	ΔAIC_c	AIC_c weight	Model Likelihood	K	Log Likelihood
HD*Sex*Season + summer*autumn	0	0.78	1	15	-123.54
Sex*Season + HD*Season + summer*autumn	3.74	0.12	0.15	12	-129.27
Sex*Season + HD*Season + summer*autumn *HD	4.46	0.08	0.11	13	-128.37
HD + Sex + Hard Mast	7.98	0.01	0.02	6	-138.49
Sex + Hard Mast + Repro class*HD	16.74	0.00	0.00	10	-138.22
Null	65.46	0.00	0.00	3	-170.50

Table 2.9. Results for the effect of housing density trend (positive or negative) with increasing housing density within the individual seasonal home range by sex and season for urban black bears, North Carolina, USA, 2014-2017.

Season = Fall:

Sex	HD trend	SE	df	95 LCL	95 UCL	Tukey group
M	0.00245	0.00309	113.2	-0.003668	0.00856	1
F	0.00415	0.00115	127.2	0.001883	0.00642	1

Season = Spring:

Sex	HD trend	SE	df	95 LCL	95 UCL	Tukey group
F	0.00268	0.00125	133.5	0.000220	0.00515	1
M	0.03383	0.01042	107.4	0.013178	0.05448	2

Season = Summer:

Sex	HD trend	SE	df	95 LCL	95 UCL	Tukey group
F	0.00279	0.00106	121.8	0.000681	0.00489	1
M	0.00647	0.00433	94.9	-0.002122	0.01506	1

*Results are averaged over the levels of "summer*autumn".
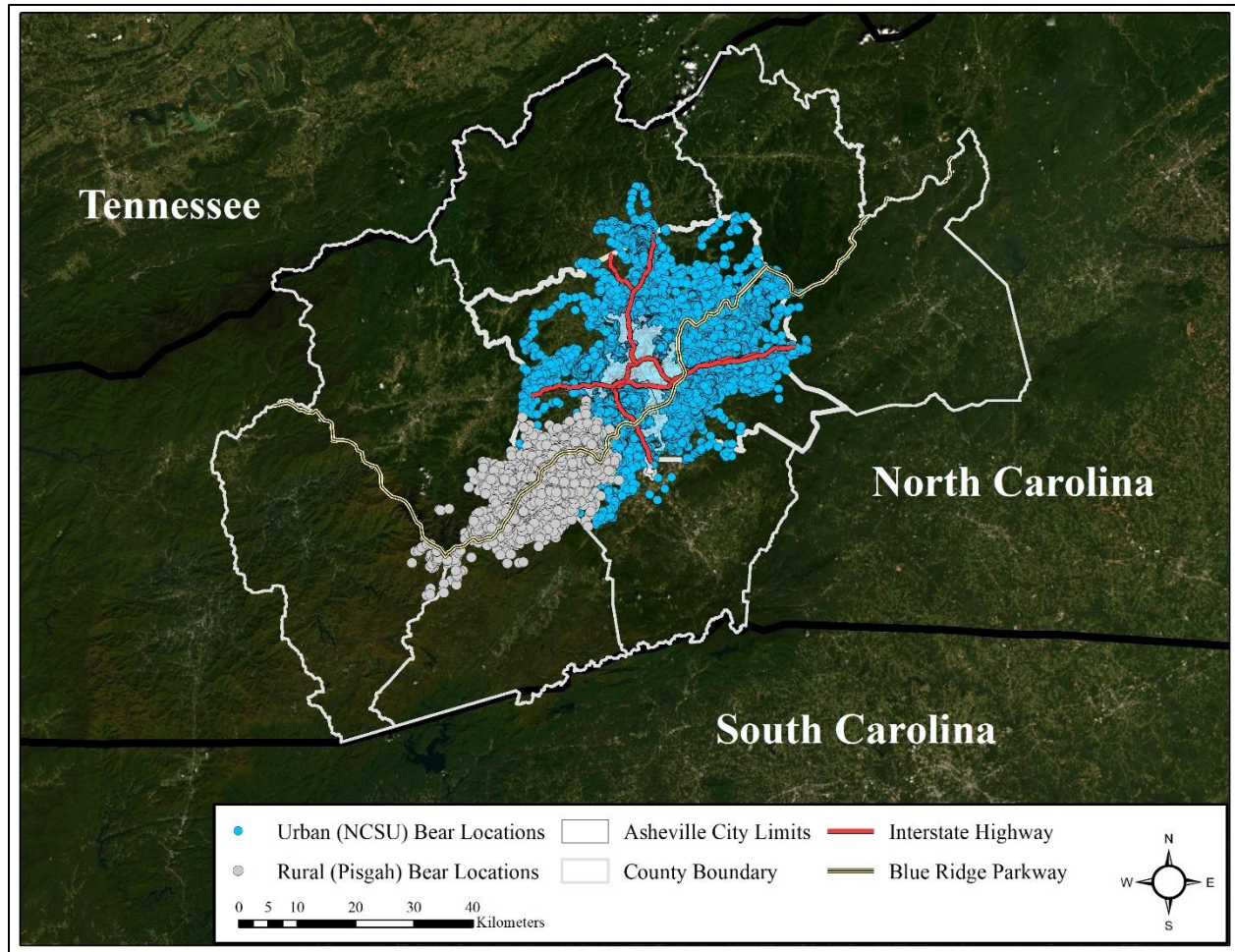
Figure 2.1. Study areas for rural and urban black bears (*Ursus americanus*) in North Carolina, USA.

A.
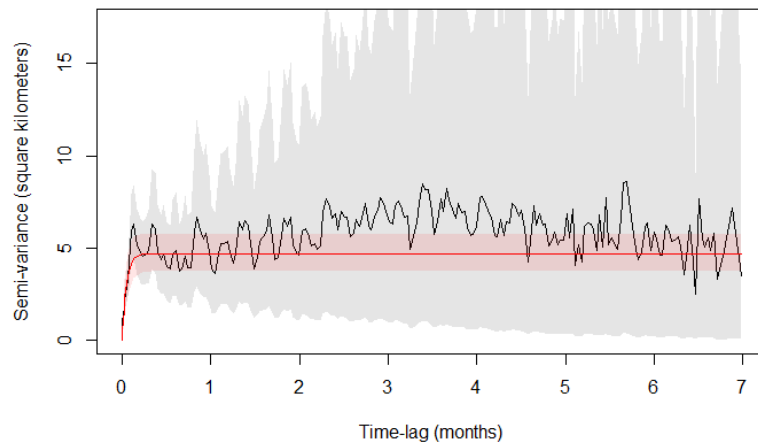
B.
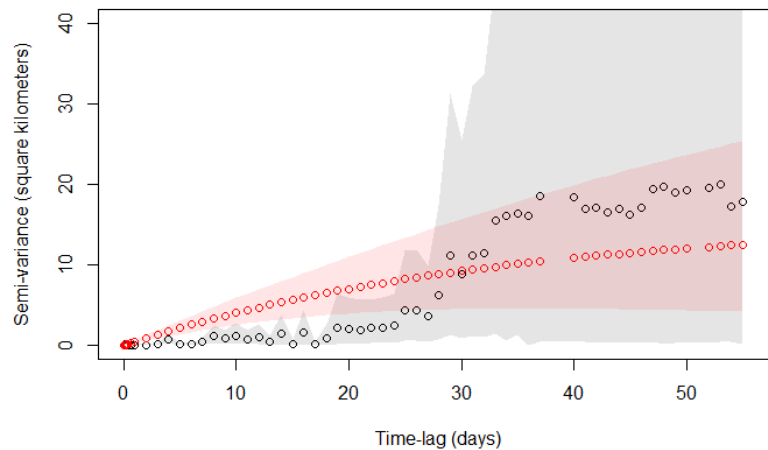
Figure 2.2. (A)**.** Example plot for an annual (7 months) semi-variogram for range resident black
bear. The semi variogram reaches an asymptote within the first couple of weeks of data
collection. The black line represents the actual data input into model and the red line is
the top model (based on AICc) fit with 95% confidence intervals. (B). Example plot for
seasonal (50+ days) semi-variogram for a black bear that did NOT represent range
residency. The semi variogram does not reach an asymptote due to the behavior of the
individual bear.
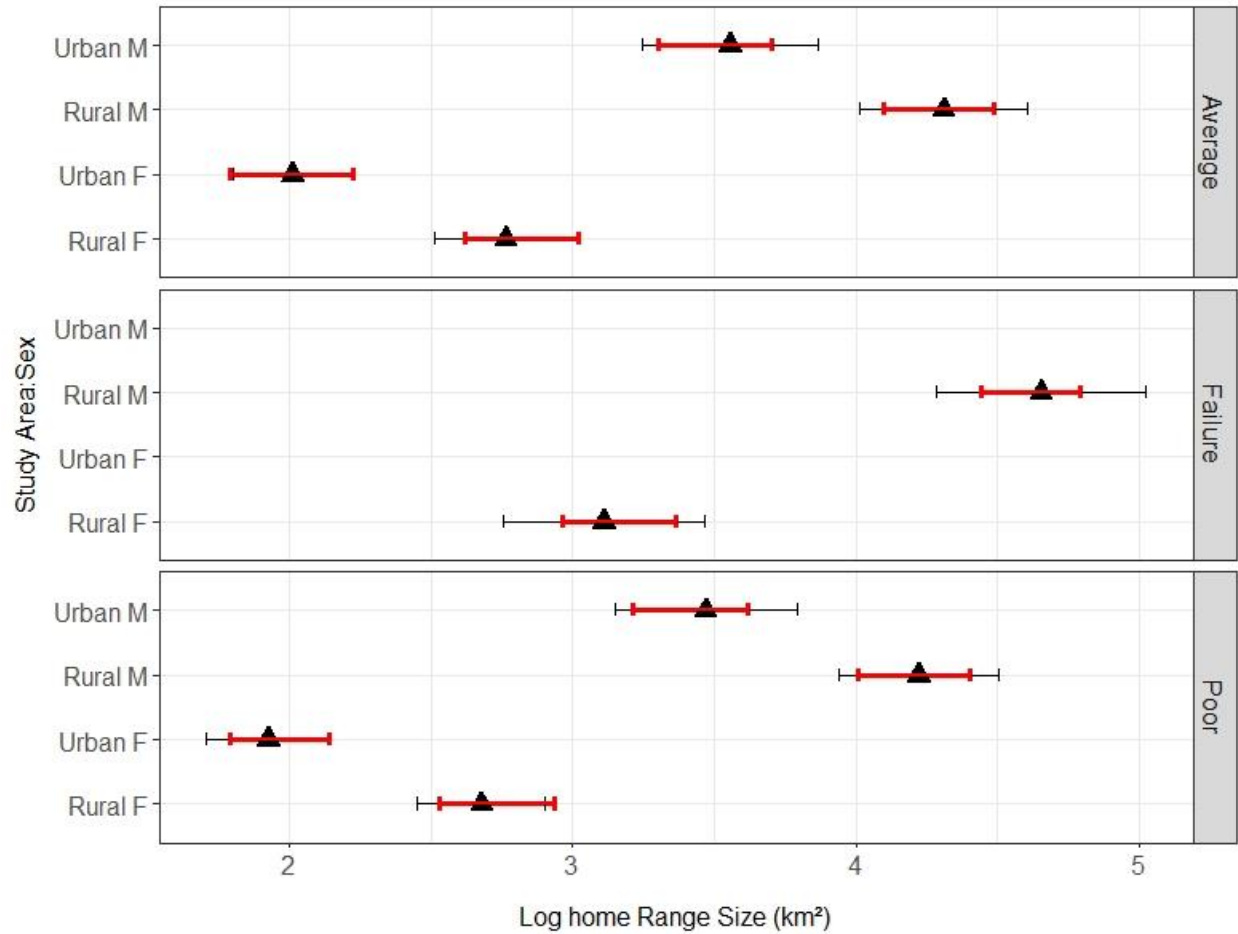
Figure 2.3. Effect of three observed indices of natural annual food production (failure, poor, and average) on average annual home range size comparisons between rural and urban black bears, North Carolina, USA. Black triangles represent the estimated marginal mean from the top model, the black bars are confidence intervals for the estimated marginal mean, and the red bars are for the comparisons among them. If a red bar from one mean overlaps a red bar from another group (i.e., mast year for females and males), the difference is not significant.
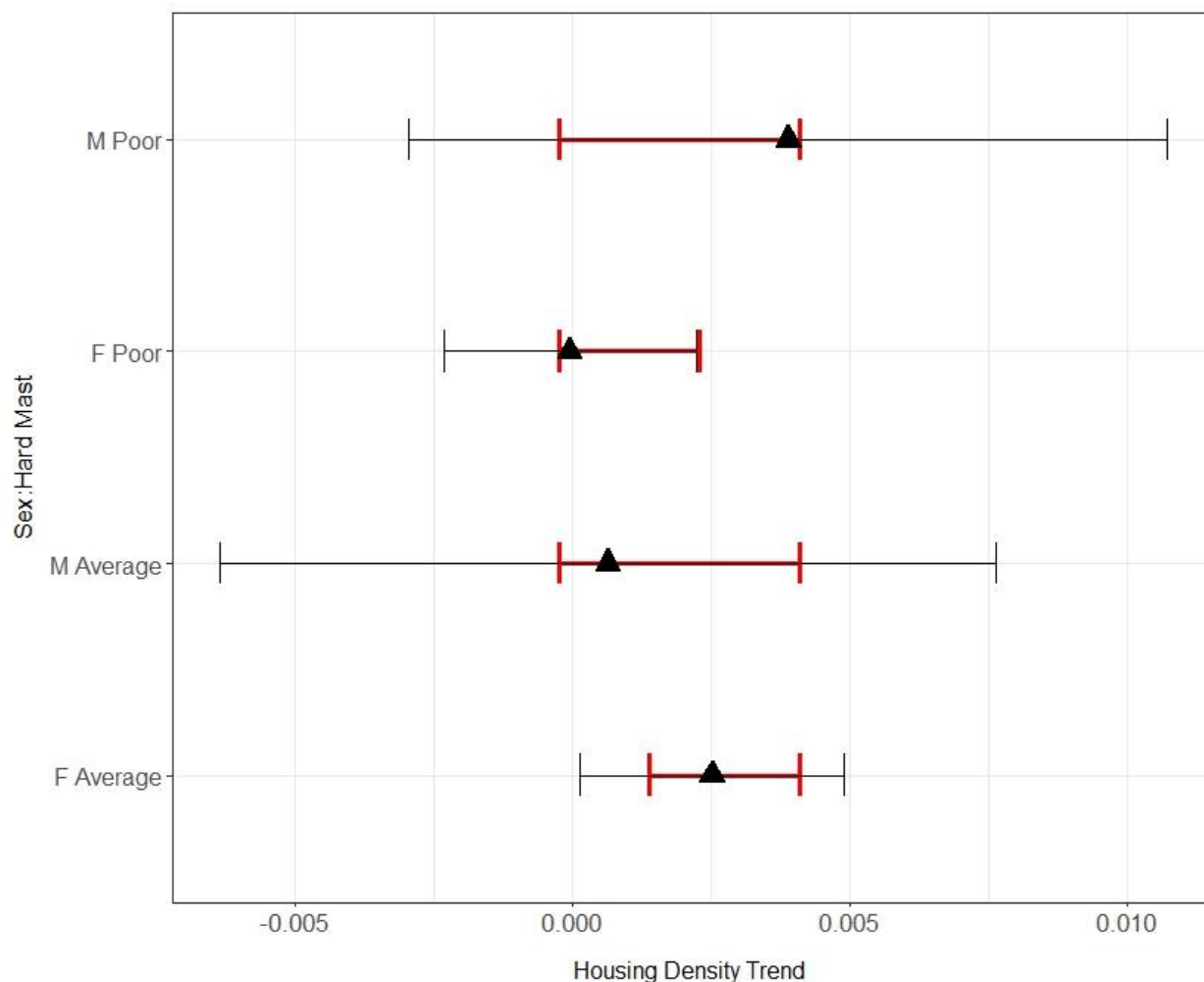
Figure 2.4. Representation of housing density trend (centered on zero) on annual home range size for female and male urban black bears across different observations of annual natural food production. Positive means home range size increases with increasing housing density; negative indicates home range size decreases with increasing housing density. Black triangles represent the estimated marginal mean from the top model, the black bars are confidence intervals for the estimated marginal mean, and the red bars are for the comparisons among them. If a red bar from one mean overlaps a red bar from another group (i.e., mast year for females and males), the difference is not significant.
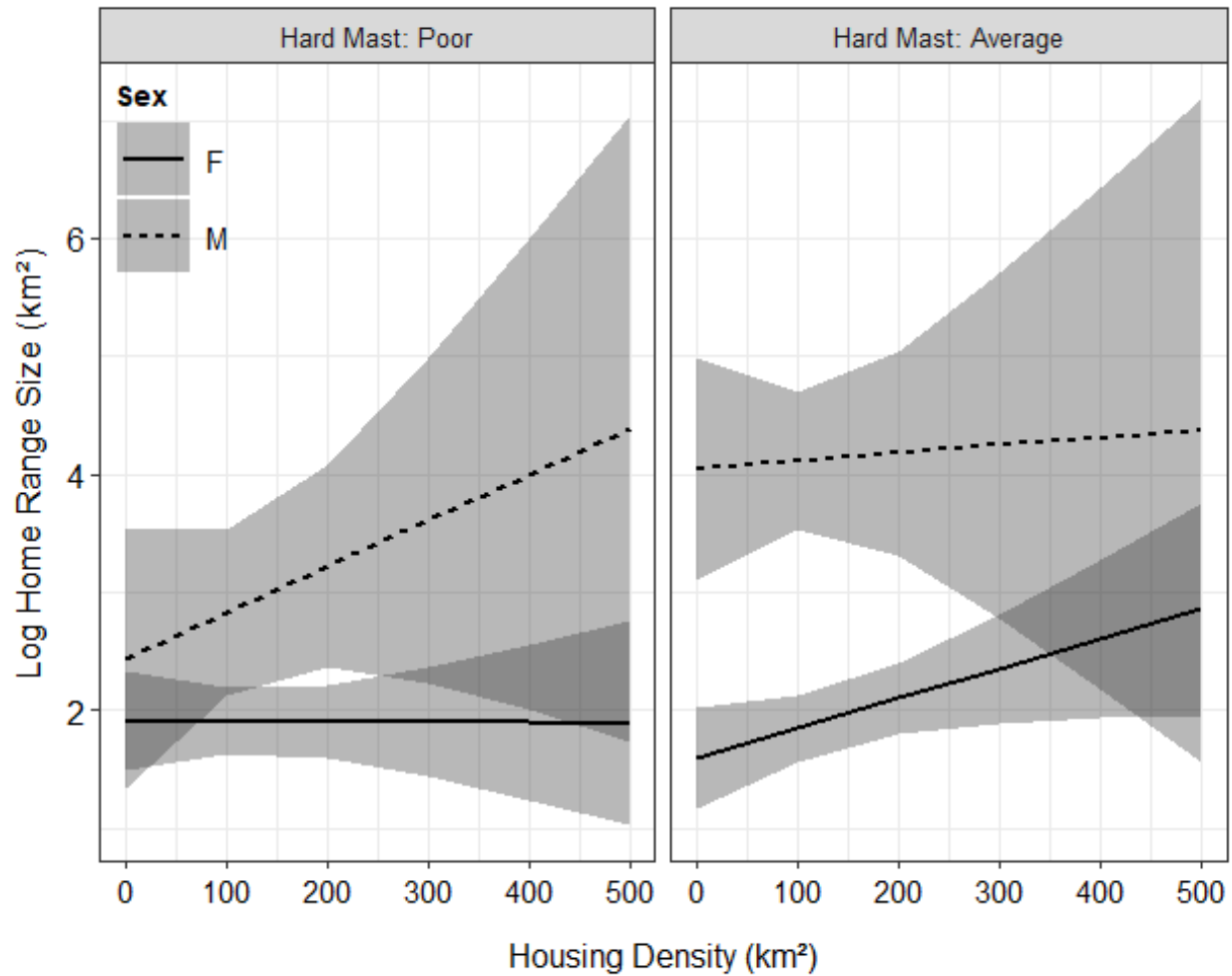
Figure 2.5. Effect of different levels of housing density on annual home range size for both female and male urban black bears across different levels of annual natural food production (Poor and Average). Black trend lines indicate home range sizes with shading representing the 95% confidence interval around the estimates.
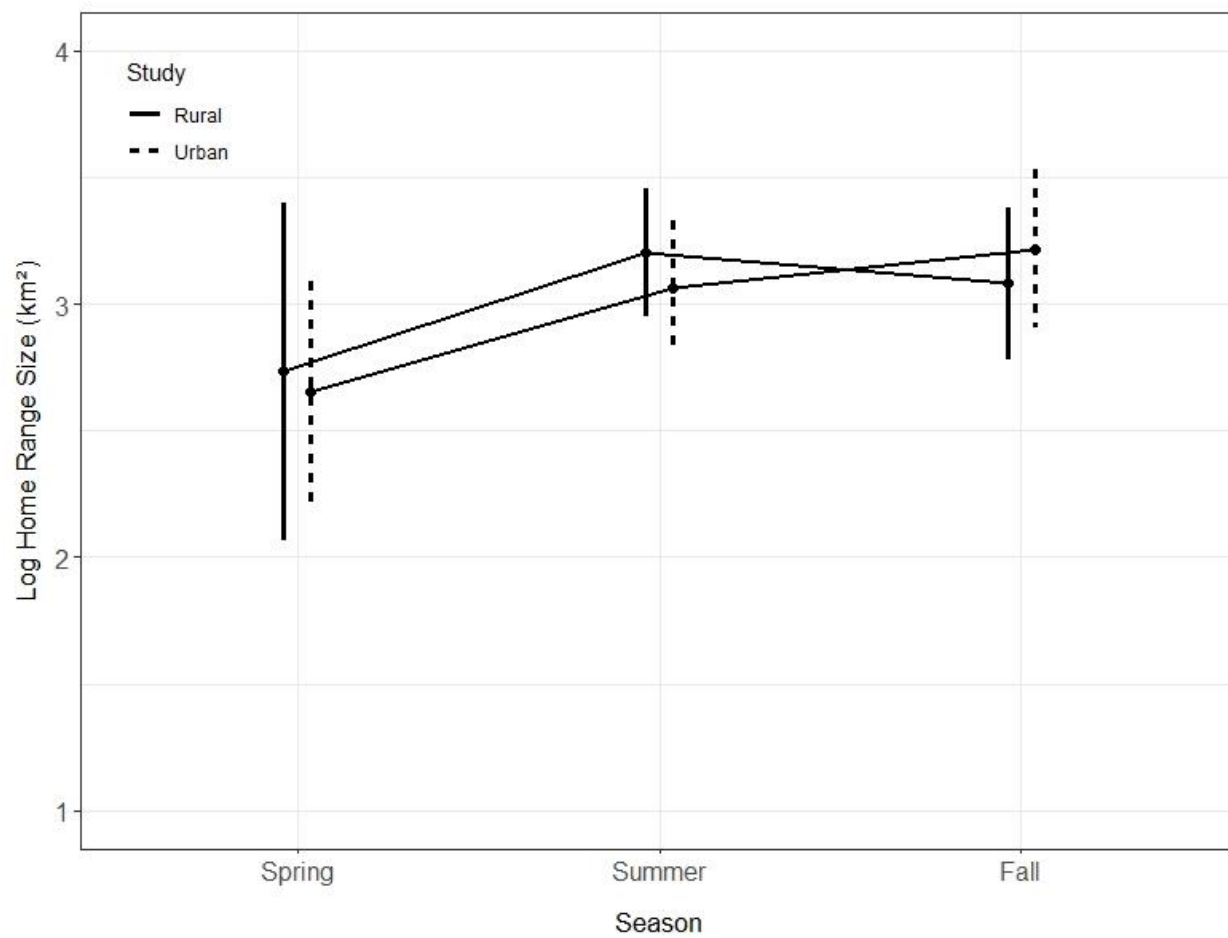
Figure 2.6. Seasonal (spring, summer, and fall) home range size comparisons between rural and urban black bears, North Carolina, USA.
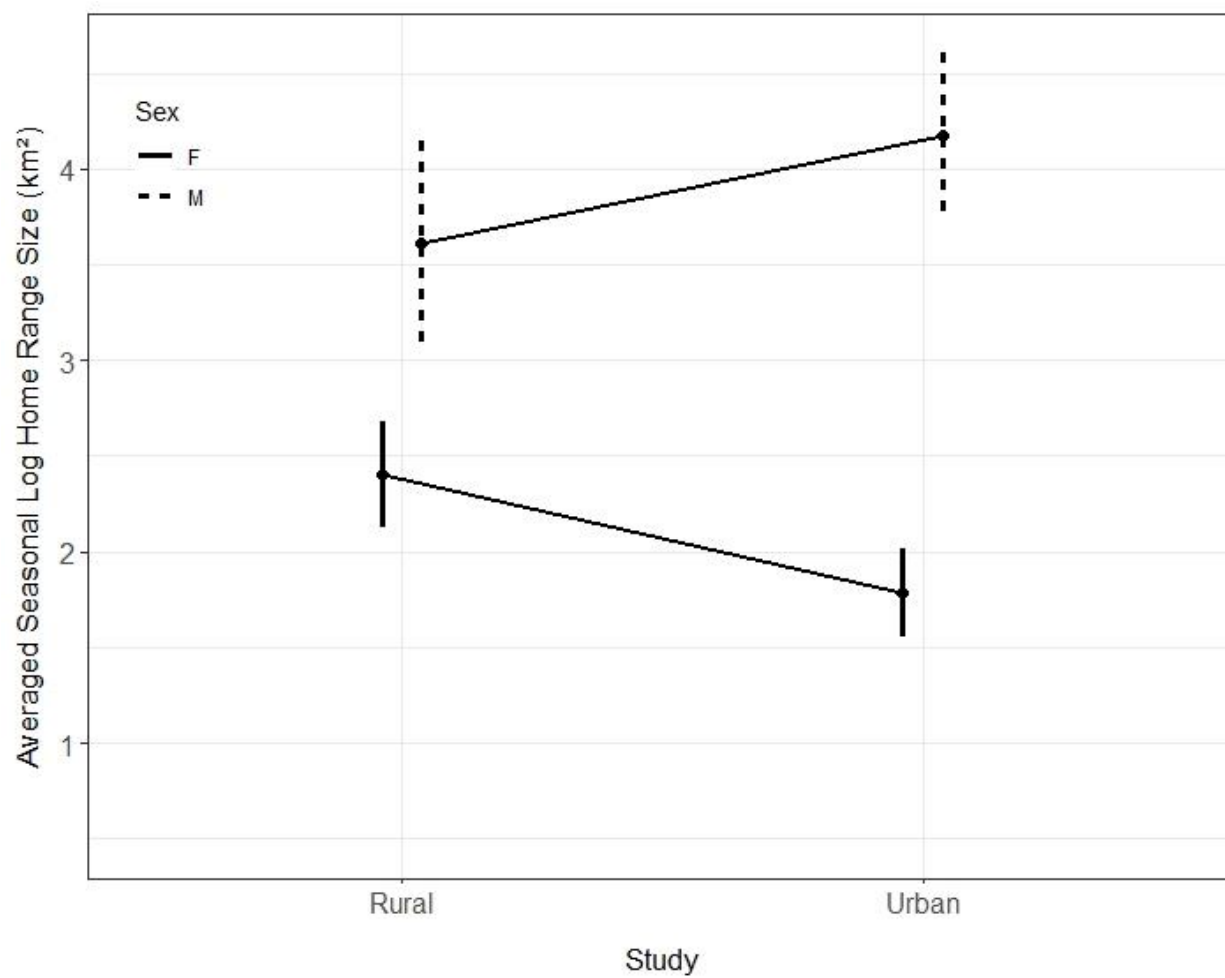
Figure 2.7. Differences in averaged seasonal home range sizes between rural and urban black bears, North Carolina, USA.
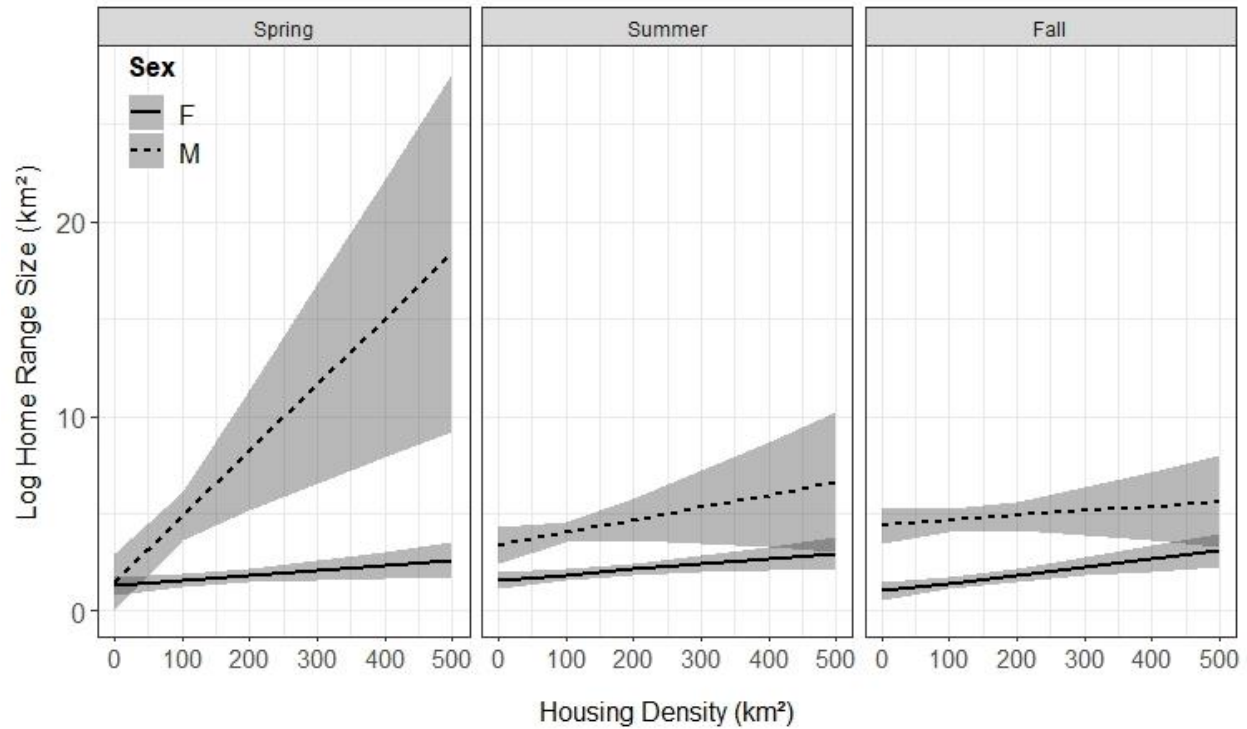
Figure 2.8. Effect of housing density (number of house per km^2 of home range) on average seasonal home range sizes for urban black bears across variable levels of housing density in Asheville, North Carolina, USA. Black trend lines indicate home range sizes with shading representing the 95% confidence interval around the estimates.

CHAPTER 3: Den site selection, denning chronology and den reuse by American black bears in an urban environment

ABSTRACT

Hibernation is an evolutionary strategy that enables wildlife to survive during seasons of harsh environmental conditions and few resources, and the selection of den sites are generally considered a crucial component of an individual's fitness. For black bears (*Ursus americanus*) den sites provide protection from predators and disturbance, a suitable environment for parturition, and proximity to resources upon emergence. Our objective was to determine the effects of development (i.e., housing density and road density) on the selection of den sites by black bears. Additionally, we describe den chronology and re-use by urban bears. We detected no selection or avoidance of housing or road density, elevation, slope, or any land cover type at the 2nd order (study area) of selection. At a finer scale (3rd order), we determined that bears selected to den on steeper slopes, but there was no relationship between proximity to houses or roads, indicating that bears were not avoiding or selecting for areas of development at a finer scale. Median den entry was the third week in December and emergence dates for bears was the third week in March. Den reuse was low ($\bar{x} = 8.2\%$, sd $= 5.7$), suggesting that dens are not a limiting factor in Asheville. Collectively, our results indicate that selection of den sites by black bears in urban areas may not be as critical to their fitness compared to their rural counterparts.

INTRODUCTION

Many animals are faced with seasonal environments that require adaptation to food shortages and severe weather (Ruf and Geiser 2015). Although some terrestrial animals migrate between summer and winter ranges in search of foods and breeding opportunities, most animals are not

capable of long distance migration (Fryxell et al. 1988), and instead are predisposed to undergo long periods of dormancy or hibernation (Humphries et al. 2003). Hibernation is as an evolutionary strategy that enables many terrestrial mammals to survive seasonal food shortages and is characterized by reduced body temperature and respiration as well as a general reduction in metabolic activity (Ruf and Geiser 2015; Watts et al. 1981; Johnson and Pelton 1981).

For black bears (*Ursus americanus*), careful selection of a high quality den site for hibernation, or winter lethargy, provides parturient females with a secure place to give birth to cubs (Oli et al. 1997), an aspect of the life history of bears that is important to their survival. Winter den sites provide bears with security from inclement weather and predation (Libal et al. 2011; Hellgren and Vaughan 1989; Johnson and Pelton 1981). Geiser (2004) suggested that by hibernating, mammals may reduce their energy expenditure to nearly 15% of what would be used by maintaining normal activity throughout the winter season. Unlike 'classic' hibernators (e.g., small mammals) however, bears can be awakened easily while hibernating (Boyles and Brack 2009; Nelson and Beck 1984), which places them at risk to disturbances that can have negative effects on their physiology, behavior, and fitness (Linnell et al. 2000).

The effects of human disturbance (primarily in the form of roads) have previously been identified as likely one of the most significant forces impacting selection of den sites by black bears (Reynolds-Hogland et al. 2007; Rogers 1987). Many studies have documented bears selecting den sites that are far from human activity and disturbances, such as roads (Pigeon et al. 2014; Linnell et al. 2000), and selecting locations at high elevations (Pigeon et al. 2014; Ciarniello et al. 2005), on steep slopes (Baldwin and Bender 2008; Libal et al. 2012; Shafer et al. 2018), with dense vegetation cover (e.g., forest canopy cover; Pigeon et al. 2016; Waller et al.

2013; Libal et al. 2012), all of which generally correlate negatively with human activity and development.

Some studies of rural black bears have reported relationships with no differences in selection between males and females (Pigeon et al. 2014), in particular with regard to distance from disturbances, primarily in the form of roads (Reynolds-Hogland et al. 2007; Gaines 2003). Difference of den site selection amongst reproductive classes for rural bears have been documented, with females with cubs of the year denning in areas farther from roads than barren females (Reynolds-Hogland et al. 2007). Yet, limited information exists as to whether these relationships hold in urban environments. It is reasonable to posit that urban female bears will select for den sites farther from human disturbances than male bears due to the risk of anthropogenic mortality to cubs and possibly from male bears directly, as male bears have been documented using urban areas more than females (Merkle et al. 2013).

Understanding den site selection within an urban landscape is critical for understanding how black bears use urban environments (Pigeon et al. 2014; Reynolds-Hogland et al. 2007). Bears are attracted to urban areas likely because of the availability and permanence of anthropogenic foods (Baruch-Mordo et al. 2014; Merkle et al. 2013; Beckmann and Berger 2003), especially in years of poor natural food production (Zeller et al. 2019; but see Chapter 1). Residential neighborhoods provide garbage cans, bird feeders, ornamental fruit trees, and pet food as year round sources of high calorie foods that are easily obtained by bears. Bears may use these urban foods prior to den entry and upon den emergence if their dens are in urban areas. Nonetheless, urban development poses inherent risks for bears from increased road densities, traffic, and human activity. Bears that use urban environments may be restricted by the number of potential den sites available due to the

amount of roads, infrastructure, and concrete. Thus, understanding to what extent, if any, development affects den site selection by black bears is an important aspect of the biology of urban bears that warrants investigation (Schafer et al. 2018), and may have implications for human-bear interactions (Evans 2016).

Re-use of winter dens by black bears is variable and ranges from low (15%; Crook and Chamberlain 2010) to high (71%; Davis et al. 2012), depending on the geographic location and the available substrate in the study area. High level of den reuse indicate a scarcity of available den sites, which affects reproductive success by black bears adversely (Oli et al. 1997). The timing of den entry and emergence varies by geographic location (Gaines 2003; Linnell et al. 2000), wild and anthropogenic food abundance (Fowler et al. 2019; Johnson and Pelton 1980), temperature and precipitation (Johnson et al. 2017; Oli et al. 1997), and the condition of the individual bears (Fowler et al. 2019). Den chronology has been used to establish legal harvest seasons for bears (Immell et al. 2013). Use of urban foods and warmer temperatures may reduce the overall duration of black bear hibernation (Johnson et al. 2015; Beckmann and Berger 2003), thereby increasing the duration of human-bear interactions.

We investigated the den sites of black bears in and around Asheville, North Carolina. Our objectives were to characterize den site selection and to document den chronology and den reuse by bears using an urban environment. Specifically, we hypothesized that 1) bears select den sites in areas with low housing and road density, with limited human access, or in forest or shrub land cover; 2) male bears select den sites with more 'human disturbance' and at lower elevations than female bears because females are likely to attempt to minimize the risks associated with development for the protection of their cubs; and 3) den sites for bears will

include areas in close proximity to houses in years of poor natural food production where anthropogenic food sources are likely abundant.

STUDY AREA

The study was centered on the city of Asheville, North Carolina (Fig. 3.1). Located in a valley bottom, the city-limits of Asheville encompasses 117 km² with approximately 92,000 people, with the surrounding urban, suburban, and exurban population approximating 200,000 people.

The area around Asheville, North Carolina is characteristic of the southern Appalachian mountain range (Kirk et al. 2012) with a heterogeneous topography (500–1800 m elevation), mild winters, cool summers, and high annual precipitation that is primarily rainfall (130–250 cm/year). The dominant forest types include mixed deciduous hardwoods with pine-hardwood mix (Mitchell et al. 2002; Powell et al. 1997).

Asheville is roughly divided into four quadrants separated by two four-lane highways (Fig. 3.1); Interstate 40, runs east to west, and Interstate 26, runs north to south. Interstate 240 is a 9.1-mile (14.6 km) long Interstate Highway loop that serves as an urban connector for Asheville and runs in a semi-circle around Asheville's downtown district.

METHODS

Bear capture and handling

From April 2014 through September 2017, we used homeowner reports of non-nuisance black bears on private property to identify trap sites. We attempted to follow a spatially balanced design to deploy culvert traps evenly within or adjacent to Asheville city limits. We set traps solely on private properties and checked them twice daily.

We immobilized captured bears with the drug combination telazol hydrochloride -

ketamine hydrochloride-xylazine that included a 5 cc bottle of telazol (100 mg/ml) combined

with 4.0 cc of ketamine hydrochloride (100mg/ml) and 1.0 cc of xylazine hydrochloride

(100mg/ml) at a dose of 1cc per 45 kgs, delivered by a CO_2 powered dart pistol. We placed a

uniquely numbered ear-tag in each ear, applied a tattoo to the inside of the upper lip, removed an

upper first premolar to estimate age from all bears ≥12 months old (Wiley 1974), and inserted a

Passive Integrated Transponder tag (PIT tag) between the scapulae. We recorded weight, sex,

reproductive class, date, and capture location for each bear. We fitted bears with a GPS tracking

collars (Vectronic, Berlin, Germany) that did not exceed ~4% of the animal's body weight

(Samuel and Fuller 1996; Cattet 2011). We administered a long-lasting analgesic, an antibiotic

and yohimbine hydrochloride (0.15 mg/kg) to reverse the xylazine hydrochloride within

approximately 60 minutes of immobilization. Handling of bears was approved by the

Institutional Animal Care and Use Committee at North Carolina State University (14-019-O) and

was consistent with the guidelines of the American Society of Mammalogists (Sikes et al. 2016).

Identifying den locations

We used telemetry to locate bears at their den sites between October and February 2014 - 2018.

We identified a bear as "denning" if its GPS locations became clustered for ≥ 2 weeks after 1

October. For bears with collars only emitting a VHF signal, we located them every three days

until locations remained clustered. In late December and January, we ground-truthed dens

identified by clustered GPS or telemetry data points to identify ground versus tree dens and to

obtain permission to access private property. We entered dens from mid-January through

early-March to assess reproduction, to conduct physical examinations of the females, and to

change collars if necessary. Female bears were categorized as barren, having cubs of the year, or

having yearlings. Males were classified as juvenile (<3) or adult (≥3 years).

Covariates associated with black bear den site selection

We examined several environmental covariates associated with individual bear den sites to test

our hypotheses. We accessed and obtained land cover data from the 2013 National Land Cover

Database at a resolution of 30 m x 30 m. We combined and reduced the number of land cover

types to 8 cover-type categories (Table 3.1). To estimate the effect of development on den site

selection, we used a housing footprint layer for Buncombe County (www.buncombecounty.org).

We verified (via aerial photography 2013) the housing footprint layer by removing any addresses

that did not have a physical structure. We calculated the mean number of houses (per km^2)

inside each of the individual 100 m radius buffers. The number of houses within the buffers was

used as a metric for the bears' potential to use of human foods, as we assumed that bears using

human development took advantage of the availability of anthropogenic foods (Johnson et al.

2015; Lewis et al. 2015).

To account for the annual variation in natural food availability during our study, we

assessed the abundance of annual hard mast and seasonal summer and fall soft mast. The North

Carolina Wildlife Resources Commission surveyed hard mast annually from August through

September. Seasonal summer soft mast (blueberry, huckleberry, blackberry, and pokeberry) was

surveyed in odd years (i.e., 2015, 2017, etc.), and seasonal fall soft mast (pokeberry, cherry,

grapes, and blackgum) surveys were conducted during the annual hard mast surveys (NCWRC).

Hard mast indices were based on visual estimates of the percentage of oak crowns with acorns

(Greenberg and Warburton 2007). Predetermined hard mast categories included: failure (0-

19.4% with acorns), poor (19.5-39.4%), average (39.5-59.4%), good (59.5-79.4%), and bumper

(79.5-100%). During summer and fall soft mast surveys the overall abundance of berries for each species was indexed as Poor mast production (little to no berries = 0.0 to 2.0), Fair (scarce to moderate = 2.1 to 4.0, Good (abundant = 4.1 to 6.0, or Excellent (6.1 to 8.0). The numerical rating was averaged between summer and fall survey results, as well as across all transects for each soft mast species. We used the categorical estimates of hard and soft mast production as covariates representing the quality of natural foods for each year.

Identifying sex differences

We used univariate logistic regression with a logit link and individual bears as repeated subjects in program R to investigate potential differences in the selection of den factors (predictor variables) by males and females (binary response variable) while accounting for the correlation among different dens from the same individuals.

Den site selection: 2nd order selection

We modeled second order resource selection (den site availability within the entire study area; Johnson 1980) using mixed-effects logistic regression (glmer) in the lmer package in Program R to compare used den sites with available sites, where individual bear was a random effect to account for the dependency of multiple observations per bear. We defined our study area by creating a minimum convex polygon around the used den sites buffered by 3.2 km, which represented the majority of area covered by bears. Available sites were drawn at random from within the study area, using ArcGIS 10.5.1 (ESRI, Inc., Redlands, California, USA). We generated two different sets of available points to determine if the results remained consistent: one set with 250 available points and one set with 500 available points, respectively. Both the den sites and available random points were buffered by a circular polygon with a 100 m radius to describe the area around the den. We used ArcGIS to calculate mean elevation, slope, aspect,

road density, and housing density within the 100 m buffers. Also, we summed the total number

of pixels per land cover type and calculated percent land cover within each of the used and

available buffers. We used a Pearson correlation matrix in R to check for relationships between

covariates and used estimates $\geq$ 0.60 as the threshold for collinearity. Numerous variables were

correlated; housing density was correlated with road density, and forest cover type; elevation was

correlated with slope, road density and forest cover type, and slope was correlated with

elevation, and forest cover type. Thus, we did not include collinear variables in the same models,

and we scaled all continuous variables prior to analyses.

Den site selection: 3rd order selection

To assess third order resource selection (availability within the home range scale; Johnson 1980),

we used conditional logistic regression (function clogit) in the survival package in Program R,

where we conditioned on bear identification number to compare the used and available locations

for each bear. We generated a 500 m radius buffer around the den sites, and available sites were

drawn at random from within the 500 m buffer around each known den site using a geographic

information system. We generated two different sets of available points to determine if the

results remained consistent: one set with 10 available points and one set with 50 available points,

within each of the individual 500 m radius buffers. We selected 500 m as the buffer, as opposed

to individual home ranges because we did not have annual home ranges for all the bears that

denned in our study. Also, the den sites were heavily clumped and using the 95% home range

isopleth (which was considerably larger than our 500m radii buffer) likely would have provided

a more substantial amount of overlap between the areas of comparisons (i.e., the large home

range overlap would have caused us to sample available points from a ubiquitous/homogenous

area). We did not want the majority of the randomly sampled points to come from within a

cluster of home ranges that overlapped considerably. We used ArcGIS to extract raster values

for elevation, slope, aspect, and land cover type for each used/available point. Also, we

calculated linear distances to the nearest road and nearest house for each used and available

point. We used a Pearson correlation matrix in R and used estimates ≥ 0.60 as the threshold for

collinearity where we did not include collinear variables in the same model. Only slope and

elevation were highly correlated, so we did not use them in the same models. We scaled all

continuous variables prior to analyses. Lastly, the use of conditional logistic regression does not

allow incorporation of categorical predictor variables such as sex, age class, or hard and soft

mast. Conditioning on the individual bear ID number, which only has one value for variables

such as sex, age class, or hard and soft mast, makes it impossible to estimate covariate effects for

these variables (Schafer et al. 2018). Thus, we used the *lsmeans* package (Lenth 2016) in R (v.

3.3.1) and a factorial ANOVA to summarize the effect of housing density on male and female

bears by hard mast and soft mast indices, and we included an interaction term between sex and

both the hard and soft mast indices. We log transformed housing density to meet the assumptions

of normality associated with ANOVA.

Modeling factors associated with den site selection

We selected a set of *a priori* models using the covariates that were biologically important to

black bears to examine den site selection at both the 2nd and 3rd orders of selection. Specifically,

we examined multiple covariates on bear den site selection: housing density, natural food

production, forest and shrub cover types, elevation, slope, and individual bear attributes (sex and

age group). The model set included univariate and additive combinations of covariates that

represented difficult human access, high potential for food availability and cover, and avoidance

of people. We removed wetlands, barren, and crop/agriculture because too few used and

available points were represented by these cover types. Lastly, we elected to use housing density as the metric for development, and not the 'developed' land cover type because that would have restricted our inference to areas close to downtown Asheville, and would likely underrepresent areas of increased housing density that are not near downtown. We used Akaike's information criterion corrected for small sample size (AICc) to assess model weights, and ranked candidate models using ΔAICc (Anderson 2008; Burnham and Anderson 2002), and we used Akaike weights to determine the relative support for each model.

Den entrance, emergence, duration of denning

We used telemetry data to establish timing of den entry, den emergence, and duration of time spent in the den. Entry date was defined as the first date that telemetry locations became clustered in one location for ≥ 2 weeks. For bears with functioning GPS collars, den entry was determined to a single day. For bears with collars emitting a VHF signal only, we calculated den entry as the midpoint between the date the bear was first identified at the den site and the date of the previous location. Den emergence was the date a bear left its den. We refrained from ground-truthing dens during the fall and early winter to avoid den abandonment. If either a bear's pre-den (entrance) or post-den (emergence) location was > 14 days from the identified den entrance or emergence date, we did not include that bear in the analysis. Den duration was calculated as the number of days between the den entry and emergence dates annually.

Den reuse

We monitored black bears for up to 3 consecutive den seasons, which allowed us to estimate an annual rate of reuse of dens. In late January and February of each year, when the majority of bears were likely to be denned, we used binoculars to inspect each years' previous den sites to

determine occupancy for the current year. We did this for all previous den sites, provided that they still existed.

RESULTS

Sex Differences

From October 2014 through March 2018, we identified 82 den sites (67 female, 15 male) used by the marked population of black bears in our study. In our univariate analysis, we detected no differences between male and female bears in the selection of den sites based on slope (β_{Slope} = -0.472, se = 0.560, P = 0.400), elevation ($\beta_{Elevation}$ = 0.643, se = 1.535, P = 0.675), housing density ($\beta_{Housing\ Density}$ = 0.143, se = 0.355, P = 0.686), road density ($\beta_{Road\ Density}$ = 0.388, se = 0.615, P = 0.528) or forest cover type (β_{Forest} = 0.086, se = 0.526, P = 0.871).

Den Site Selection 2nd Order

The analyses of den site selection at the 2nd order indicated the null model was the top performing model, supported with 20.9% (500 available points; Table 3.2) of the overall Akaike model weight suggesting that bears were not selecting den sites based on any of the covariates in our model sets at the level of the study area. Although the univariate housing density and road density models showed some support (both models were within ~2 ΔAIC_c), the 95% confidence intervals overlapped zero, suggesting no evidence that levels of disturbance associated with either housing or road density influenced den site selection (Table 3.2, Table 3.3).

Den Site Selection 3rd Order

The analyses of den site selection at the 3rd order of scale indicated that slope was the primary environmental covariate best able to describe the probability of a den site (Table 3.4; Table 3.5, respectively), supported with 53.0% (50 available points) of the overall Akaike model weight.

We documented a positive relationship between the site use and slope ($\beta_{\text{Slope 50 PTS}}$ = 1.006, CI =

0.459 - 1.554), with every one standard deviation increase in slope, the odds of a site being used

rose by 1.01%. No models containing distance to house were within ΔAIC_c < 2, and the 95%

confidence interval overlapped zero ($\beta_{\text{Dist to House 50 PTS}}$ = 0.084, CI = -0.328 - 0.497), suggesting

little support that distance to house influenced den site selection at the 3$^{\text{rd}}$ order. Two models

were within 2 ΔAIC_c, Slope + Forest (21.6% of overall Akaike model weight) and Slope +

Distance to Road (19.9% of overall Akaike model weight), but the 95% confidence intervals for

Forest Cover ($\beta_{\text{Forest 50 PTS}}$ = -0.159, CI = -0.725 - 0.408) and Distance to Road ($\beta_{\text{Dist to Road 50 PTS}}$ =

0.013, CI = -0.362 - 0.388) overlapped zero, suggesting little support that these covariates

influenced den site selection at the 3$^{\text{rd}}$ order.

The effect of housing density did not differ by sex ($F_{1,76}$ = 0.56, P = 0.46), hard mast

index ($F_{1,76}$ = 0.35, P = 0.56), soft mast index ($F_{1,76}$ = 0.55, P = 0.46), or the interaction between

sex and hard mast index ($F_{1,76}$ = 0.01, P = 0.92) and sex and soft mast index ($F_{1,76}$ = 0.35, P =

0.56; Table 3.6).

Den distribution, chronology, and reuse

Locations of the 82 dens were distributed across the study area and across the city of Asheville,

including two dens within 1 km of downtown Asheville. Sixty percent (49/82) of dens were

located on the ground and associated with a downed tree or fallen log. Twelve percent (10/82) of

dens were located in tree cavities (Fig. 3.2). Median den entrance was the third week in

December and median den emergence was the third week in March. Average den duration was

84 days (sd = 13.0; range: 74 - 108 days). Duration was longest in 2015, a year with the second

best mast year on record (Table 3.7). Lastly, the annual estimates of den reuse for 2016, 2017,

and 2018 were 13.6% (3/22), 2.3% (1/44), and 8.8% (5/57), respectively ($\bar{x}$ = 8.2, sd = 5.7).

DISCUSSION

We found no evidence that black bears selected or avoided areas with increased housing density, suggesting the level of housing density, or proximity to housing, was not a factor in how or where bears selected den sites. Our results are similar to those of Shafer et al. (2018), who found no evidence that black bear den site selection in Aspen, Colorado was affected by housing density. This result consistent across studies with such different habitats suggests that black bears are able to adapt to 'consistent' disturbance in the form of vehicular traffic, noises, and overall human activity on a daily basis. Some authors have suggested that bears may in fact be likely to tolerate fixed or predictable sources of disturbance near dens (Linnell et al. 2000; McDonald and Fuller 1998). Other studies investigating the effects of disturbance on den site selection for rural bears have focused on distance to roads or road density as a proxy for human disturbance, with many of those studies showing that bears avoid den sites located near roads (Pigeon et al. 2014; Reynolds-Hogland et al. 2007; Linnell et al. 2000). Our study was able to incorporate both the effects of housing and road development. Interestingly, the lack of selection may be a result of the ubiquitous nature of housing and roads in our study area and an indication that black bears in some urban areas have become accustomed to these mostly 'fixed' levels of disturbances, and thus proximity to roads and houses may not be a factor for bears when selecting a den site.

Similarly, bears did not select den sites in areas with extensive development during times of food stress, providing no support for our hypothesis that bears would be more likely to den closer to development in years categorized as poor natural food years. The lack of a relationship between den site selection and housing density in urban areas is corroborated by our result (Chapter 2) that bears did not respond to high levels of housing density by increasing their

seasonal and annual home range sizes. Although virtually no information exists for den site selection by large carnivores in urban areas, many studies have suggested that use of urban areas is largely governed by production of natural or wild foods, with increased use of urban areas during times of food stress (Johnson et al. 2015; Baruch-Mordo et al. 2014). Our results are counter to this idea, and generally suggest that bears may not factor the level of housing density into their 'denning decisions'. Regarding the indices used to assess the quality of natural food production in our study, we acknowledge it is possible that the broad scale at which natural food production was collected needs to be conducted at a much finer scale.

Our result that black bears selected steep slopes when choosing den sites at a finer scale is well supported by past research (Schafer et al. 2018; Libal et al. 2012; Baldwin and Bender 2008; Reynolds-Hogland et al. 2007). Selecting den sites on steep slopes provides support for risk avoidance associated with disturbance because they are difficult to access (Linnell et al. 2000), and residences are seldom constructed on steep slopes. Steep slopes may provide additional den locations with better stability because they allow access to dig underneath root masses and increase the probability of trees falling. Black bears commonly select den sites in dense shrub or forested cover (Immell et al. 2013; Hellgren and Vaughan 1989; Tietje and Ruff 1983). We suspect that because the landscape within our study area included predominantly forested land cover with residential houses interspersed, forest cover type did not predict selection of dens by black bears. Similarly, we were surprised that only one environmental covariate was associated with den sites, steep slopes, and suspect that den site selection by black bears in urban areas may be more strongly governed by fine-scale environmental variables rather than broad scale variables.

Contrary to our hypothesis that females would select den sites with less housing development than males, female bears in our study did not select for or avoid development more than males. Further, elevation, slope, land cover type, and effects of roads for dens of male and female bears did not differ, consistent with the results of Pigeon et al. (2014), Elfstrom et al. (2008) and Reynolds-Hogland et al. (2007). Provided that our urban study site likely included more houses and roads than did these other studies adds support to the idea that female and male black bears do not differ in their selection of den sites with regard to roads and houses.

Our den chronology results were within the range of those reported for black bear populations inhabiting rural areas (Baldwin and Bender 2010; Gaines 2003). Nonetheless, our documented dates of den entrance and emergence were later and earlier, respectively, than other published works for black bears across North America (Immell et al. 2013; Schooley et al. 1994; Schwartz et al. 1987). It is possible that our later entrance dates and earlier emergence dates is due to the mild climate in the Southeast (Hellgren and Vaughan 1987; Johnson and Pelton 1980). Another plausible reason for later entry and earlier emergence may be the presence of natural and anthropogenic foods. Johnson et al. (2017) reported that den chronology for black bears in Durango, Colorado was driven by climatic variables as well as the presence of natural and anthropogenic food sources, with bears entering later and emerging earlier if foods were more readily available. Of course, the opposite may be true (earlier entrance, later emergence) if food sources are limiting or reduced (e.g., in poor natural food years; Johnson and Pelton 1981). We suggest that managers working with urban bear populations monitor den chronology as a way to inform residents about how and when to bear-proof their properties, thereby potentially reducing human-bear interactions.

The reuse of dens by bears in our study was low ($\bar{x} = 8.2\%$), suggesting that dens were not a limiting factor, which helps explain the lack of environmental predictors of den site selection. We suspect that den reuse is low in our study area because the majority of dens were located on the ground and associated with downed or fallen logs (Fig. 2), which appeared to be numerous (N. Gould, personal observation). Also, we posit that resident's tolerance for bears denning near homes is fairly high in Asheville, and thus bears are not readily discouraged from denning close to people. Educating residents that bears will den in areas with downed or fallen logs may be a useful tool to encourage residents to remove downed woody debris.

Collectively, our results indicate that selection of den sites by black bears in urban areas may not be as critical to their fitness as it is to their rural counterparts. Partnered with our observation that black bears selected den sites regardless of housing development at broad or fine scales and did not differ in their use of housing development in years of "good" (Average and Fair categories) or "bad" (Poor categories) food years provides an example of a large carnivore not avoiding highly developed landscapes and adds support for the idea some urban areas can be beneficial to large carnivores. Furthermore, the use of den sites by females in urban areas indicate that developed environments are not avoided by bears for reproduction. We suggest that future research focus on whether our results are applicable to other highly developed urban areas with year round resident bears. Lastly, large carnivores occupying areas of development, such as Asheville, North Carolina are surprising and not without cause for alarm. If bears, and potentially other large carnivores, can occupy these developed landscapes there is likely to be a rise is human-bear interactions that managers will need to address.

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Table 3.1. Environmental covariates developed for American black bear den site resource selection functions.

Variable	Data Type	Details (2nd Order)	Details (3rd Order)
Elevation	Continuous	meters; mean elevation within 100m buffer	meters
Slope	Continuous	mean degrees (0 - 90) within 100m buffer	Degrees (0 - 90)
Housing Density (2nd order)	Continuous	mean density per km² within 100m buffer	n/a
Road Density (2nd order)	Continuous	density raster	n/a
Landcover	Categorical	Transformed into percentage of 100m buffer	30 x 30m grid cells
Forest			
Shrub			
Barren			
Wetland			
Open water			
Crop/Agriculture			
Distance to House (3rd order)	Continuous	n/a	meters
Distance to Road (3rd order)	Continuous	n/a	meters

Table 3.2. Model selection results, coefficient estimates (±1 SE) and fit statistics (AICc, ΔAICc, AICc Weight, and K [number of estimable parameters]) for modeling American black bear den-site selection in the urban environment of Asheville, North Carolina, USA, 2015-2018 using mixed-effects logistic regression at the second order of selection and 250 available points. Forest combines evergreen, mixed deciduous, and deciduous forests.

Model (coeff. ± 1SE)	K	AICc	Δ AICc	AICc Weight
Null	**2**	**7.54**	**0**	**0.207**
Road Density (0.556 ± 8.717)	3	9.57	2.03	0.075
Slope (0.343 ± 8.567)	3	9.57	2.04	0.075
Forest (-0.153 ± 8.519)	3	9.57	2.04	0.075
Elevation (-0.271 ± 16.285)	3	9.57	2.04	0.075
Housing Density (-0.015 ± 5.690)	3	9.57	2.04	0.075
Shrub (-0.012 ± 5.249)	3	9.57	2.04	0.075
Wetlands (0.002 ± 5.387)	3	9.57	2.04	0.075

Table 3.3. Model selection results, coefficient estimates (±1 SE) and fit statistics (AICc, ΔAICc, AICc Weight, and K [number of estimable parameters]) for modeling American black bear den-site selection in the urban environment of Asheville, North Carolina, USA, 2015-2018 using mixed-effects logistic regression at the second order of selection and 500 available points. Forest combines evergreen, mixed deciduous, and deciduous forests.

Model (coeff. ± 1SE)	*K*	AIC*c*	Δ AIC*c*	AIC*c* Weight
Null	**2**	**7.55**	**0**	**0.209**
Road Density (0.639 ± 8.053)	3	9.56	2.02	0.076
Slope (0.262 ± 8.982)	3	9.57	2.02	0.076
Elevation (-0.511 ± 19.136)	3	9.57	2.02	0.076
Forest (-0.199 ± 7.967)	3	9.57	2.02	0.076
Housing Density (0.072 ± 4.926)	3	9.57	2.02	0.076
Wetlands (0.037 ± 4.104)	3	9.57	2.02	0.076
Shrub (-0.045 ± 6.377)	3	9.57	2.02	0.076

Table 3.4. Model selection results, coefficient estimates (±1 SE) and fit statistics (AICc, ΔAICc, AICc Weight, and K [number of estimable parameters], and cumulative AICc weight) for modeling American black bear den-site selection in the urban environment of Asheville, North Carolina, USA, 2015-2018 using conditional logistic regression at the third order of selection and 10 available points within the 500m buffer. Forest combines evergreen, mixed deciduous, and deciduous forests.

Model (coeff. ± 1SE)	K	AICc	Δ AICc	AICc Weight	Cum Weight
Slope (1.027 ± 0.278)	1	424.14	0	0.54	0.54
Slope (1.059 ± 0.289) + Forest (-0.117 ± 0.286)	2	425.98	1.84	0.21	0.75
Slope (1.025 ± 0.281) + Distance to Road (0.012 ± 0.185)	2	426.15	2.00	0.20	0.95

Table 3.5. Model selection results, coefficient estimates (±1 SE) and fit statistics (AICc, ΔAICc, AICc Weight, and K [number of estimable parameters], and cumulative AICc weight) for modeling American black bear den-site selection in the urban environment of Asheville, North Carolina, USA, 2015-2018 using conditional logistic regression at the third order of selection and 50 available points within the 500m buffer. Forest combines evergreen, mixed deciduous, and deciduous forests.

Model (coeff. ± 1SE)	*K*	AIC*c*	Δ AIC*c*	AIC*c* Weight	Cum. Weight
Slope (1.006 ± 0.279)	1	678.77	0	0.53	0.53
Slope (1.043 ± 0.287) + Forest (-0.159 ± 0.289)	2	680.48	1.70	0.23	0.76
Slope (1.004 ± 0.282) + Distance to Road (0.013 ± 0.191)	2	680.77	2.00	0.20	0.95

Table 3.6. Mean housing density (per km²) for den sites selected by female and male American black bears during years of variable natural food production (hard mast and soft mast), winter 2015 through winter 2018 in Asheville, North Carolina, USA.

Hard Mast Year	Sex	N	Housing Density ($\bar{x}$)	Housing Density (SD)
Average	Female	38	144.1	292.1
Poor	Female	29	154.8	555.5
Average	Male	7	150.0	155.8
Poor	Male	8	238.8	560.5

Soft Mast Year	Sex	N	Housing Density ($\bar{x}$)	Housing Density (SD)
Fair	Female	50	146.4	478.5
Poor	Female	17	155.4	190.4
Fair	Male	9	222.8	526.5
Poor	Male	6	159.2	168.6

Table 3.7. Median den entrance and emergence dates for both female and male GPS-collared bears in Asheville, North Carolina, USA, October 2014 - May 2018.

Year	*n*	Den Entrance	Den Emergence	Previous Year's Hard Mast Index	Duration (Days) in Den
2015	15	12/6/2014	4/2/2015	Average (4.1)	103
2016	16	12/30/2015	3/10/2016	Poor (2.1)	78
2017	12	12/30/2016	3/23/2017	Poor (2.7)	81
2018	21	12/26/2017	3/18/2018	Average (3.4)	74
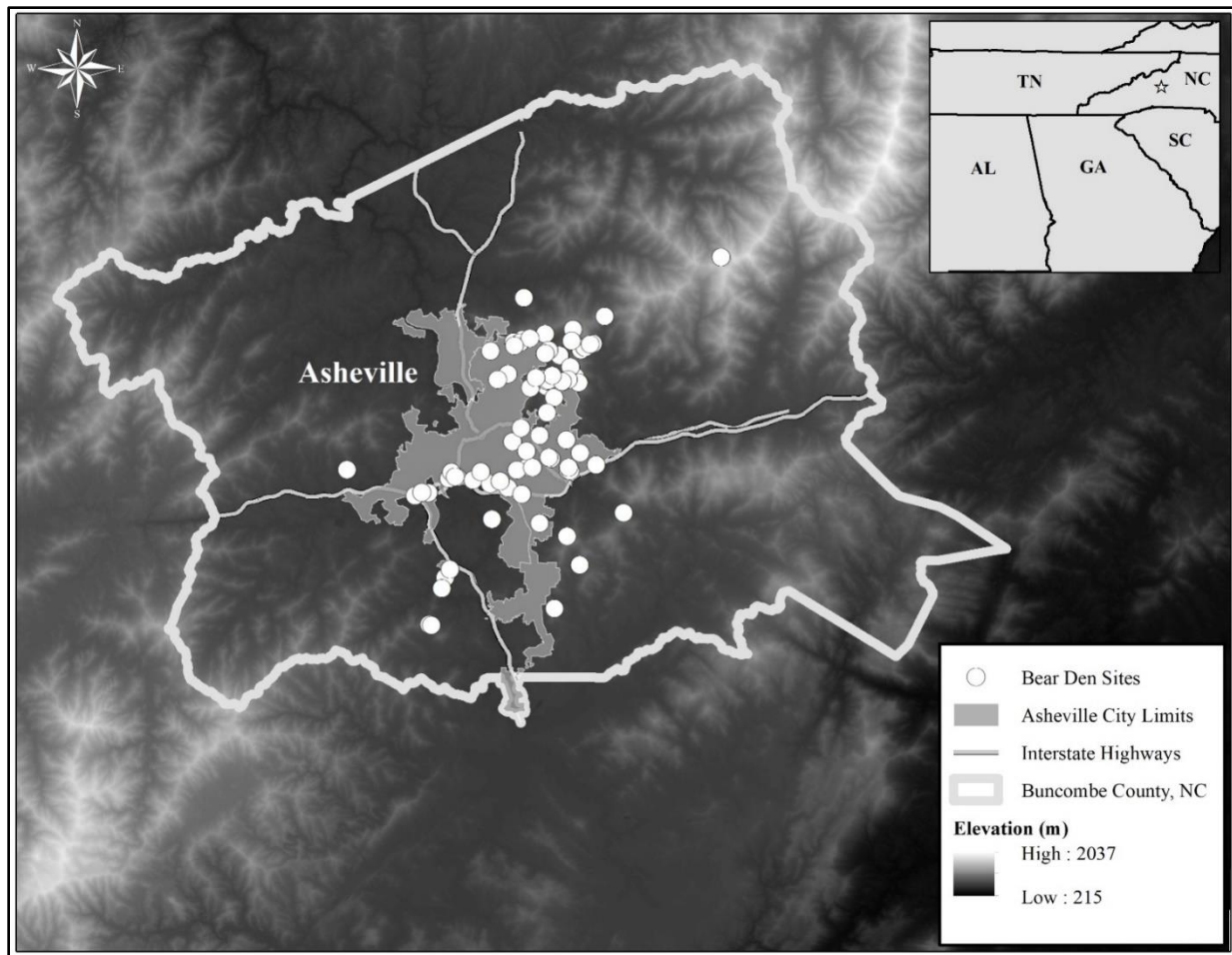
Figure 3.1. Study area and locations of American black bear (*Ursus americanus*) den sites in Asheville, North Carolina, USA, 2015 - 2018.
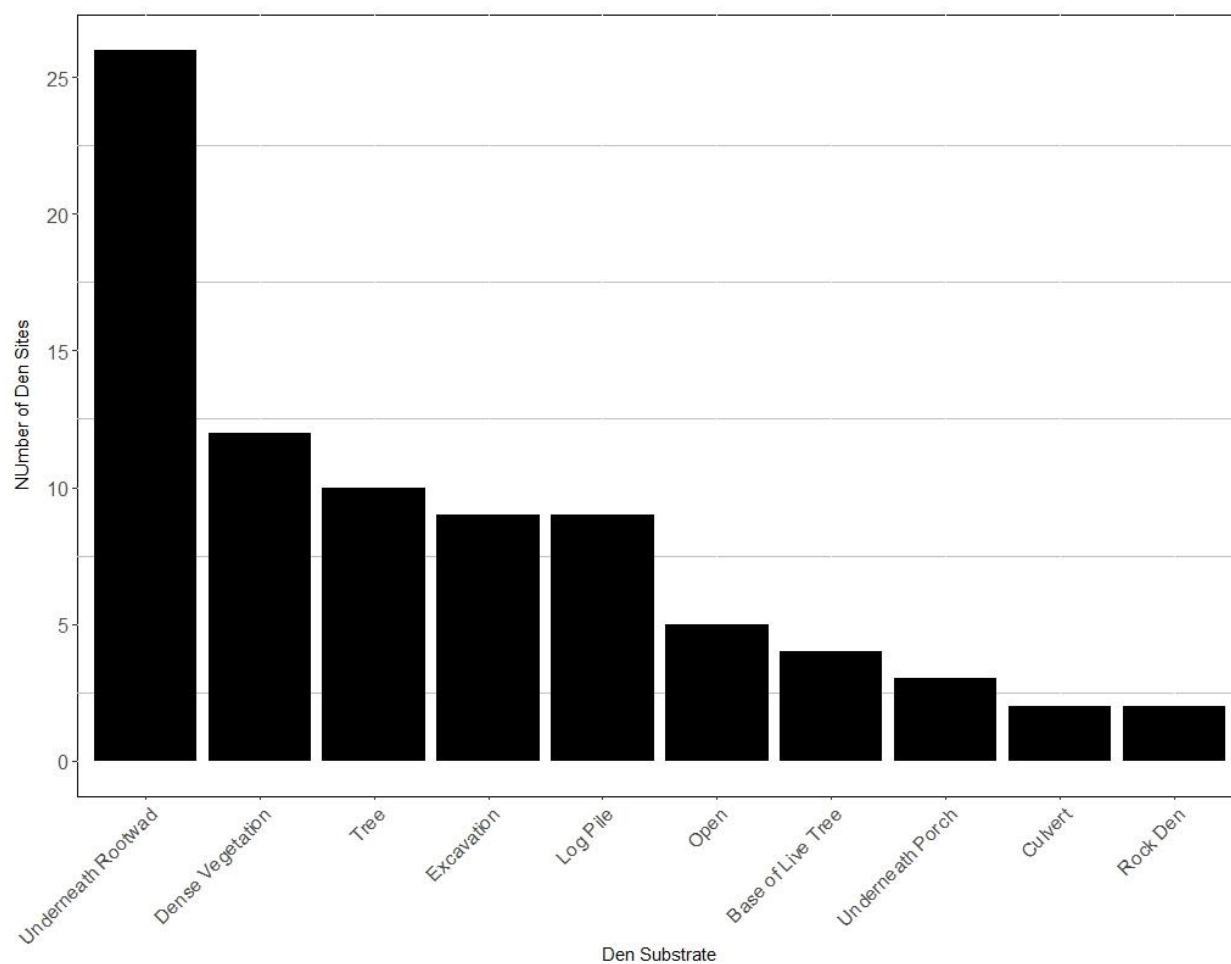
Figure 3.2. Frequency distribution of den site substrate by American black bears in Asheville, North Carolina, USA, 2015 - 2018.

APPENDICES

Appendix A

Captures of American black bears April 2014 - March 2018, Asheville, North Carolina, USA.

Date	Location	Sex	Age	Capture	Eartag	Weight (lbs)
17-Apr	Trailridge Road	Female	Adult	Original	N001	223
22-Apr	Big Springs Drive	Female	Adult	Original	N003	237
22-Apr	Peach Knob Drive	Male	Adult	Original	N004	185.5
23-Apr	Bull Creek Road	Male	Adult	Original	N005	309*
23-Apr	Peach Knob Drive	Female	Adult	Original	N006	194
23-Apr	Peach Knob Drive	Male	Yearling	Original	N007	91
23-Apr	Peach Knob Drive	Male	Yearling	Original	N008	100
24-Apr	Chunns Cove Road	Female	Subadult	Original	N011	144
24-Apr	Bull Creek Road	Male	Adult	Original	N010	439
25-Apr	Peach Knob Drive	Male	Yearling	Recapture	N008	n/a
25-Apr	Bull Creek Road	Male	Adult	Original	N013	572
26-Apr	Peach Knob Drive	Male	Yearling	Recapture	N008	n/a
28-Apr	Swanger Road	Female	Adult	Original	N014	297.5
1-May	Lakewood Avenue	Female	Adult	Original	N015	258.5
1-May	Lakewood Avenue	Male	Yearling	Original	N016	122
1-May	Lakewood Avenue	Male	Yearling	Original	N017	163
1-May	Big Springs Drive	Female	Adult	Original	N019	234
2-May	Swanger Road	Female	Yearling	Original	N018	64.5
5-May	Hampden Road	Female	Adult	Original	N020	251.5

8-May	Chunn's Cove Road	Female	Adult	Original	N021	140.5
9-May	Merrimon Avenue	Female	Adult	Original	N022	183.5
15-May	Robin Lane	Male	Yearling	Original	N023	82.5
23-May	Beechwood Road	Female	Adult	Original	N024	246
23-May	Cisco Road	Female	Yearling	Original	N025	106.5
23-May	Redwood Avenue	Female	Adult	Original	N026	184.5
28-May	Highland Place	Female	Adult	Recapture	N015	258.5
28-May	Robin Lane	Female	Adult	Original	N027	258
29-May	Bull Creek Road	Female	Adult	Original	N028	133.5
29-May	Day Spring Drive	Female	Adult	Original	N031	156
31-May	Highland Place	Male	Adult	Original	N032	327.5
2-Jun	Highland Place	Male	Yearling	Recapture	N016	122
6-Jun	Ranger Road (NPS)	Male	Subadult	Original	N033	136
10-Jun	Christ School Road	Female	Yearling	Original	N034	96
23-Jun	Brevard Road	Female	Yearling	Original	N035	94.5
25-Jun	Redwood Avenue	Unk	Cub	Original	N/A	~10 lbs
26-Jun	Ratt Mann Drive	Male	Subadult	Original	N036	180
2-Jul	Brevard Road	Female	Adult	Original	N037	140
8-Jul	Rattman Drive	Female	Adult	Original	N038	229
10-Jul	Blue Ridge Parkway	Male	Adult	Original	N039	245.5
13-Jul	Rattman Drive	Female	Adult	Original	N040	180
18-Jul	Mirehouse Run	Female	Adult	Original	N042	127
20-Jul	Ramble Drive	Male	Adult	Original	N043	293.5

28-Jul	Woodland Drive (Swannanoa)	Male	Yearling	Original	N044	126
29-Jul	Woodland Drive (Swannanoa)	Male	Adult	Original	N045	263
30-Jul	Brevard Road	Female	Adult	Original	N047	132
4-Aug	Ramble Way	Male	Yearling	Original	N046	114
6-Aug	Brevard Road	Male	Yearling	Original	N048	110.5
7-Aug	Amber Lane	Male	Yearling	Original	N049	105.5
12-Aug	Brevard Road	Female	Adult	Original	N050	191
14-Aug	Mirehouse Way	Female	Adult	Original	N051	267
14-Aug	Carter Cove Road	Female	Adult	Original	N052	228.5
14-Aug	Cove Road	Female	Yearling	Original	N053	132
18-Aug	Brevard Road	Male	Yearling	Original	N054	139
19-Aug	Carter Cove Road	Male	Adult	Original	N055	291.5
23-Aug	Ramble Way	Male	Adult	Recapture	N043	N/A
23-Aug	Brevard Road	Female	Adult	Recapture	N037	N/A
30-Aug	Cove Road	Female	Adult	Original	N056	194
2-Sep	Meadow Ridge	Female	Subadult	Original	N057	125
8-Sep	Carter Cove Road	Male	Adult	Original	N058	236.5
9-Sep	Peach Knob Drive	Female	Adult	Original	N059	150
2015						
3-Feb	Shawnee Trail	Male	Adult	Original	N060	~275.0
4-Feb	Shawnee Trail	Male	Yearling	Original	N061	183
4-Feb	Shawnee Trail	Female	Adult	Recapture	N0024	264.5

13-Feb	Shawnee Trail	Male	Yearling	Original	N062	207
19-Mar	Shawnee Trail	Male	Yearling	Original	N065	208.5
11-Mar	Blue Ridge Parkway	Male	Yearling	Original	N063	~60.0
14-Apr	Woodland Drive (Swannanoa)	Male	Yearling	Original	N066	155
22-Apr	Sheep Farm Road	Male	Adult	Recapture	N043	433
23-Apr	Highland Place	Male	Adult	Original	N068	273
25-Apr	Big Level Drive	Female	Adult	Original	N069	123
25-Apr	Highland Place	Male	Subadult	Original	N070	280
30-Apr	Sheep Farm Road	Male	Subadult	Recapture	N048	195
1-May	Woodland Drive (Swannanoa)	Male	Yearling	Original	N071	133
1-May	Highland Drive	Male	Yearling	Original	N072	120
1-May	Big Level Drive	Female	Yearling	Original	N073	115
7-May	Big Level Drive	Male	Yearling	Recapture	N063	~70.0
8-May	Big Level Drive	Female	Adult	Recapture	N006	202
9-May	Sheep Farm Road	Male	Subadult	Recapture	N046	163.5
11-May	Big Level Drive	Male	Yearling	Recapture	N063	78
15-May	Big Level Drive	Female	Adult	Recapture	N059	~185.0
15-May	Woodland Drive (Swannanoa)	Male	Subadult	Original	N074	140
16-May	Carter Cove Road	Female	Adult	Original	N075	196
19-May	Carter Cove Road	Female	Adult	Original	N076	233
19-May	Carter Cove Road	Female	Yearling	Original	N077	132
19-May	Carter Cove Road	Male	Yearling	Original	N078	184
28-May	Covewood Road	Male	Adult	Original	N079	209

30-May	Covewood Road	Male	Yearling	Original	N080	145
3-Jun	Lucky Lane	Female	Adult	Original	N081	165.5
3-Jun	Riverside Drive	Female	Adult	Original	N082	184
3-Jun	Covewood Road	Female	Yearling	Original	N083	88
3-Jun	Carter Cove Road	Male	Adult	Original	N084	225
9-Jun	Lucky Lane	Male	Adult	Original	N085	314.5
9-Jun	Highland Drive	Female	Yearling	Original	N086	113
9-Jun	Chunn's View Drive	Female	Yearling	Original	N087	142
15-Jun	Haw Creek Circle	Male	Subadult	Original	N088	186
16-Jun	Covewood Road	Female	Adult	Recapture	N057	177
18-Jun	Haw Creek Circle	Female	Adult	Original	N089	162
25-Jun	Riverside Drive	Female	Subadult	Original	N090	113
26-Jun	Haw Creek Circle	Female	Subadult	Recapture	N018/N091	181.5
27-Jun	Windswept Drive	Female	Adult	Recapture	N015	241
1-Jul	Schenk Parkway	Male	Subadult	Original	N092	165.5
8-Jul	Haw Creek Circle	Female	Subadult	Original	N093	151.5
10-Jul	Windswept Drive	Female	Subadult	Recapture	N016	183
13-Jul	Brevard Road	Unk	Cub	Original	N/A	~15.0
22-Jul	Haw Creek Circle	Male	Adult	Original	N094	350
28-Jul	Haw Creek Circle	Unk	Cub	Original	N/A	~30.0
28-Jul	Haw Creek Circle	Unk	Cub	Original	N/A	~30.0
28-Jul	Haw Creek Circle	Unk	Cub	Original	N/A	~30.0
28-Jul	Haw Creek Circle	Unk	Cub	Original	N/A	~20.0

28-Jul	Haw Creek Circle	Female	Adult	Recapture	N014	225.5
29-Jul	Sheep Farm Road	Female	Adult	Original	N095	186
5-Aug	Lucky Lane	Female	Adult	Original	N096	257
6-Aug	Schenck Parkway	Male	Subadult	Original	N097	152
24-Aug	Schenck Parkway	Male	Subadult	Original	N098	130
25-Aug	Lucky Lane	Female	Adult	Original	N099	300
2-Sep	Honeysuckle Drive	Unk	Cub	Original	N/A	Unk
6-Sep	Sheep Farm Road	Unk	Cub	Original	N/A	Unk
9-Sep	Sheep Farm Road	Unk	Cub	Recapture	N/A	Unk
16-Sep	Sheep Farm Road	Unk	Cub	Recapture	N097	162
16-Sep	Sheep Farm Road	Male	Subadult	Recapture	N/A	Unk
16-Sep	Schenck Parkway	Unk	Cub	Original	N/A	Unk
16-Sep	Schenck Parkway	Unk	Cub	Original	N/A	Unk
2016						
8-Mar	Vanderbilt Road	Female	Yearling	Original	N101	76
29-Mar	Piney Mountain Drive	Male	Yearling	Original	N102	86
29-Mar	Piney Mountain Drive	Male	Yearling	Original	N103	104
7-Apr	Carter Cove Road	Unk	Yearling	Original	N/A	N/A
7-Apr	Carter Cove Road	Female	Adult	Recapture	N075	205
7-Apr	Carter Cove Road	Female	Yearling	Original	N104	77
7-Apr	Carter Cove Road	Female	Yearling	Original	N105	68
8-Apr	Windswept Drive	Male	Yearling	Original	N106	158.5

8-Apr	Windswept Drive	Female	Yearling	Original	N107	125.5
8-Apr	Windswept Drive	Female	Yearling	Original	N108	91.5
8-Apr	Windswept Drive	Female	Yearling	Original	N109	99.5
13-Apr	Spring Park Drive	Female	Subadult	Original	N110	100
14-Apr	Piney Mountain Drive	Female	Yearling	Original	N111	90
14-Apr	Piney Mountain Drive	Male	Yearling	Recapture	N102	N/A
14-Apr	Piney Mountain Drive	Male	Yearling	Recapture	N103	N/A
15-Apr	Vance Gap Road	Female	Yearling	Original	N112	103.5
15-Apr	Vance Gap Road	Female	Yearling	Original	N113	96
19-Apr	Piney Mountain Drive	Male	Yearling	Recapture	N102	N/A
19-Apr	Piney Mountain Drive	Female	Yearling	Recapture	N111	N/A
21-Apr	Piney Mountain Drive	Male	Yearling	Recapture	N102	N/A
21-Apr	Piney Mountain Drive	Male	Yearling	Recapture	N103	N/A
24-Apr	Vance Gap Road	Female	Y/SA	Original	N114	101.5
25-Apr	Piney Mountain Drive	Male	Adult	Recapture	N079	301.5
26-Apr	Piney Mountain Drive	Male	Yearling	Recapture	N102	N/A
26-Apr	Crockett Avenue	Female	Yearling	Original	N115	97.5
26-Apr	Vance Gap Road	Female	Yearling	Recapture	N112	~110.0
28-Apr	Vance Gap Road	Female	Yearling	Recapture	N113	N/A
28-Apr	Sheep Farm Road	Male	Adult	Recapture	N043	480
29-Apr	Spring Park Drive	Male	Adult	Recapture	N092	302.5
3-May	Windswept Drive	Female	Yearling	Recapture	N109	99.5
3-May	Piney Mountain Drive	Female	Yearling	Recapture	N111	N/A

5-May	Piney Mountain Drive	Female	Yearling	Recapture	N110	100
9-May	Sheep Farm Road	Male	Subadult	Recapture	N061	299
10-May	Sheep Farm Road	Male	Subadult	Original	N116	186
10-May	Riverside Drive	Female	Yearling	Original	N117	109.5
11-May	Windswept Drive	Male	Yearling	Recapture	N106	192
11-May	Vance Gap Road	Female	Yearling	Recapture	N114	N/A
12-May	Piney Mountain Drive	Male	Yearling	Recapture	N102	N/A
12-May	Piney Mountain Drive	Female	Yearling	Recapture	N112	N/A
14-May	Sheep Farm Road	Male	Yearling	Original	N118	110
14-May	Piney Mountain Drive	Female	Yearling	Recapture	N110	107
15-May	Vance Gap Road	Female	Yearling	Recapture	N112	N/A
16-May	Piney Mountain Drive	Female	Adult	Original	N119	203
17-May	Sheep Farm Road	Male	Yearling	Original	N120	117
17-May	Sheep Farm Road	Female	Yearling	Original	N121	81.5
18-May	Sheep Farm Road	Male	Subadult	Recapture	N116	185
20-May	Windswept Drive	Female	Yearling	Recapture	N110	N/A
22-May	Sheep Farm Road	Female	Adult	Recapture	N050/N122	189.5
24-May	Windswept Drive	Female	Yearling	Recapture	N108	N/A
31-May	Winding Road	Female	Yearling	Original	N123	99.5
7-Jun	Dale Street	Female	Yearling	Original	N124	83
8-Jun	Winding Road	Female	Adult	Original	N125	238
8-Jun	Riverside Drive	Female	Yearling	Original	N126	91
9-Jun	Delano Road	Female	Yearling	Recapture	N108	N/A

25-Jun	Dale Street	Female	Adult	Recapture	N051	259
26-Jun	Cozy Mountain Road	Male	Subadult	Original	N127	193
27-Jun	Winding Road	Male	Adult	Original	N128	296.5
1-Jul	Winding Road	Male	Yearling	Original	N129	104.5
1-Jul	Riverside Drive	Male	Yearling	Original	N130	131
6-Jul	Sheep Farm Road	Female	Yearling	Recapture	N121	93
7-Jul	Winding Road	Female	Adult	Original	N131	157.5
12-Jul	Chunn's Cove Road	Female	Adult	Original	N132	126
12-Jul	Piney Mountain Drive	Male	Adult	Original	N134	400
17-Jul	Delano Road	Female	Yearling	Recapture	N109	N/A
17-Jul	Sheep Farm Road West	Male	Subadult	Original	N134	175
21-Jul	Bear Left Road	Female	Adult	Recapture	N132	N/A
24-Jul	Piney Mountain Drive	Female	Adult	Recapture	N087	150
24-Jul	Crockett Avenue	Male	Adult	Original	N135	463.5
24-Jul	Wolfe Cove Road	Female	Yearling	Original	N136	91
25-Jul	Sheep Farm Road West	Male	Subadult	Original	N137	181.5
26-Jul	Sheep Farm Road	Male	Subadult	Recapture	N061	285
29-Jul	Sheep Farm Road	Male	Adult	Original	N138	268.5
29-Jul	Wolfe Cove Road	Female	Yearling	Recapture	N139	116.5
31-Jul	Piney Mountain Drive	Female	Yearling	Recapture	N111	N/A
31-Jul	Spring Park Drive	Female	Yearling	Recapture	N107	N/A
8-Aug	Old Toll Road	Female	Yearling	Recapture	N113	N/A
8-Aug	The Ramble	Female	Adult	Original	N140	150

8-Aug	Old Toll Road	Female	Adult	Recapture	N132	N/A
9-Aug	The Ramble	Male	Yearling	Original	N141	80
10-Aug	Piney Mountain Drive	Male	Adult	Recapture	N032	360
14-Aug	Sweeten Creek Road	Male	Adult	Original	N142	207
14-Aug	Shawnee Trail	Unk	Cub	Original	N/A	N/A
14-Aug	Shawnee Trail	Unk	Cub	Original	N/A	N/A
18-Aug	Bear Left Drive	Male	Adult	Recapture	N133	N/A
5-Sep	Old Toll Road	Female	Yearling	Original	N143	117
6-Sep	Kalmia Drive	Female	Yearling	Recapture	N144	77
12-Sep	Old Toll Road	Female	Adult	Recapture	N132	155
15-Sep	Shawnee Trail	Unk	Cub	Recapture	N/A	Unk
16-Sep	Kalmia Drive	Female	Yearling	Recapture	N123	Unk
18-Sep	Aiken Road	Male	Adult	Original	N145	172
19-Sep	Old Charlotte Hwy	Female	Adult	Original	N146	167
19-Sep	Old Charlotte Hwy	Unk	Cub	Original	N/A	Unk
19-Sep	Old Charlotte Hwy	Unk	Cub	Original	N/A	Unk
20-Sep	Piney Mountain Road	Male	Yearling	Original	N147	116
22-Sep	Dale Street	Female	Yearling	Recapture	N148	116
23-Sep	Kalmia Drive	Male	Yearling	Original	N149	105
23-Sep	Sheep Farm Road	Male	Adult	Recapture	N092	Unk
25-Sep	Kalmia Drive	Female	Yearling	Recapture	N150	110
25-Sep	Sheep Farm Road	Male	Adult	Recapture	N138	281

2017						
8-Mar	Spring Park Drive	Male	Subadult	Original	N151	200
16-Mar	Highland Place	Female	Adult	Original	N152	180
30-Mar	Windswept Drive	Male	Subadult	Recapture	N151/N153	185
4-Apr	Highland Place	Male	Subadult	Recapture	N154	198
12-Apr	Woodland Drive	Male	Adult	Original	N155	189
2-May	Highland Place	Male	Subadult	Original	N156	152
3-May	Old Charlotte Highway	Male	Yearling	Original	N157	109
18-May	Spring Park Drive	Female	Subadult	Recapture	N158/N108	174
24-May	Carter Cove Road	Male	Subadult	Original	N159	217
26-May	Carter Cove Road	Female	Adult	Original	N160	171
1-Jun	Sheep Farm Road	Female	Adult	Recapture	N037	172
1-Jun	Carter Cove Road	Male	Yearling	Original	N161	154
8-Jun	Piney Mountain	Female	Yearling	Original	N162	91
22-Jun	Sheep Farm Road	Male	Yearling	Original	N163	93
26-Jun	Piney Mountain	Female	Adult	Recapture	N114/N164	200
27-Jun	Sheep Farm Road	Male	Subadult	Original	N165	136
28-Jun	Country Club Road	Female	Subadult	Recapture	N143	216
29-Jun	Piney Mountain Road	Female	Yearling	Recapture	N162	93
6-Jul	Town Mountain Road	Male	Adult	Recapture	N135	456
9-Jul	Town Mountain Road	Female	Adult	Recapture	N056	234
9-Jul	Town Mountain Road	Male	Adult	Recapture	N128	307
25-Jul	Piney Mountain Road	Female	Adult	Original	N166	180

26-Jul	Piney Mountain Road	Male	Yearling	Original	N167	143
27-Jul	Town Mountain Road	Female	Adult	Recapture	N089	206
27-Jul	Country Club Road	Female	Subadult	Recapture	N139/N168	171
28-Jul	Town Mountain Road	Female	Yearling	Recapture	N169/C037	90
31-Jul	Town Mountain Road	Female	Subadult	Recapture	N073	209
9-Aug	Walnut Valley Parkway	Female	Yearling	Original	N170	109
9-Aug	Walnut Valley Parkway	Male	Subadult	Original	N171	194
11-Aug	Walnut Valley Parkway	Male	Subadult	Original	N172	279

Appendix B

Summary statistics and output for home range sizes and continuous time movement models for urban (Asheville) and rural (Pisgah) American black bears, North Carolina, USA.

Bear ID	Study	Age	Sex	Year	No. Locs	95% HR	No. Houses	Housing Density	Model	95% LCL HR	95% UCL HR	HR X-ing Time (hrs)	Velocity (mins)	Dist. Travel (km)
N001	Asheville	4.5	F	2014	7289	5.3	1114	210.2	OUF anis	4.7	5.9	11.2	15.4	13.5
N003	Asheville	7.5	F	2014	6610	5.4	540	100	OUF anis	4.7	6	14.9	24.4	9.4
N004	Asheville	3.5	M	2014	3604	31.6	3397	107.5	OUF anis	27	36.6	20.3	40.2	14.5
N005	Asheville	6.5	M	2014	4826	193.2	9004	46.6	OUF anis	81.8	351.7	1.1 mo	33.7	9.8
N006	Asheville	4.5	F	2014	4898	5.4	175	32.4	OUF anis	4.8	6	15.6	49.6	5.9
N014	Asheville	9.5	F	2014	6190	4.5	549	122	OUF anis	4.1	5	10	20.2	11.1
N015	Asheville	6.5	F	2014	7694	17.5	6019	343.9	OUF anis	14.6	20.6	1.6 days	13.5	14.5
N016	Asheville	1.5	F	2014	2461	14.4	4063	282.2	OUF anis	11.6	17.5	1.1 days	53	8.6
N019	Asheville	5.5	F	2014	6555	7.7	353	45.8	OUF anis	6.6	8.8	1.3 days	23.3	7.3
N021	Asheville	2.5	F	2014	5300	3.8	286	75.3	OUF anis	3.4	4.1	13.6	21.9	6.8
N025	Asheville	1.5	F	2014	7537	8.6	2552	296.7	OUF anis	7	10.4	1.8 days	14.8	9.6
N026	Asheville	3.5	F	2014	8679	5.7	1224	214.7	OUF anis	4.9	6.6	17.5	17.1	11.5
N028	Asheville	7.5	F	2014	4102	4.1	140	34.1	OUF anis	3.6	4.5	11.5	42.9	7.2

N030	Asheville	1.5	F	2014	4794	4.7	53	11.3	OUF anis	4	5.4	1.2 days	27.3	8.4
N031	Asheville	2.5	F	2014	4876	12.5	1331	106.5	OUF anis	10.4	14.7	1.6 days	46.1	7.1
N033	Asheville	1.5	M	2014	6740	42	12594	299.9	OUF anis	30	56.1	5.6 days	20.4	9.9
N035	Asheville	1.5	F	2014	5367	19.8	1339	67.6	OUF anis	15.6	24.5	2.4 days	31.9	8.3
N037	Asheville	3.5	F	2014	5735	23.7	5123	216.2	OUF anis	16.6	32.2	3.2 days	25.3	9.6
N038	Asheville	4.5	F	2014	3742	32.6	6740	206.7	OUF anis	21.9	45.3	3.9 days	16.6	20.4
N039	Asheville		M	2014	4044	107.5	11367	105.7	OUF anis	75.7	144.9	4.6 days	56.8	10.8
N040	Asheville	2.5	F	2014	3882	21.5	2466	114.7	OUF anis	16.7	26.8	2.3 days	58.3	6.6
N043	Asheville	3.5	M	2014	4270	85.5	3037	35.5	OUF anis	62.8	111.5	3.3 days	45.9	13.2
N045	Asheville	5.5	M	2014	3440	24	782	32.6	OUF anis	19.1	29.6	1.8 days	59.2	7.8
N047	Asheville	3.5	F	2014	4949	22.4	4409	196.8	OUF anis	14.9	31.4	4.1 days	28.1	8.3
N052	Asheville	4.5	F	2014	5442	2.5	187	74.8	OUF anis	2.1	2.9	19	19.6	6.4
N006	Asheville	5.5	F	2015	6515	8.2	623	76	OUF anis	6.9	9.5	1.5 days	26	7.5
N014	Asheville	10.5	F	2015	6986	3.4	543	159.7	OUF anis	3	3.8	13.3	14.3	9.9
N015	Asheville	7.5	F	2015	5400	9.3	3665	394.1	OUF anis	7	12	2.7 days	17.5	7.4
N016	Asheville	2.5	F	2015	7522	10	3173	317.3	OUF anis	7.8	12.5	2.3 days	6.7	16.4
N021	Asheville	3.5	F	2015	6515	3	331	110.3	OUF anis	2.5	3.6	1.4 days	13.2	5.3
N024	Asheville	8.5	F	2015	21858	9	2921	324.6	OUF anis	7.4	10.8	2.4 days	19.8	7.4

N031	Asheville	3.5	F	2015	2725	12.5	1981	158.5	OUF anis	10.4	14.7	1.3 days	44.7	7.7
N035	Asheville	2.5	F	2015	3684	13	195	15	OUF.iso	6.8	21.2	8.4 days	17.4	5.3
N037	Asheville	4.5	F	2015	658	50.8	10645	209.5	OUF.anis	37.9	65.5	5.2 days	2.8 hours	3.1
N040	Asheville	3.5	F	2015	3308	17.6	2615	148.6	OUF.anis	11.3	25.2	5.3 days	36.8	4.7
N045	Asheville	6.5	M	2015	3932	25.2	1118	44.4	OUF.anis	18.6	32.8	4.5 days	1.4 hours	5.2
N050	Asheville	7.5	F	2015	545	11.4	39	3.4	OUF.anis	8.2	15.2	2.7 days	26.1	6.7
N051	Asheville	14.5	F	2015	9533	10.8	1142	105.7	OUF.anis	7.2	15.2	6.1 days	22.6	6.5
N056	Asheville	4.5	F	2015	3092	1.4	54	38.6	OUF.anis	1.3	1.5	13.3	1.1	3
N057	Asheville	2.5	F	2015	10965	4.9	453	92.4	OUF.anis	4.4	5.4	17.5	26.5	8.5
N059	Asheville	4.5	F	2015	5502	2.6	52	20	OUF.anis	2.4	2.8	9.7	36.8	6.3
N060	Asheville		M	2015	12285	113.3	23251	205.2	OUF.anis	63.6	177	9.8 days	50.7	9.8
N063	Asheville	1.5	M	2015	6097	4.6	93	20.2	OUF.anis	3.7	5.6	3.0 days	33.3	6.3
N069	Asheville	3.5	F	2015	4822	5.6	156	27.9	OUF.anis	4.9	6.4	21.9	25.5	8
N070	Asheville	2.5	M	2015	3005	23.6	6057	256.7	OUF.anis	14.8	34.5	4.0 days	28.1	9.6
N073	Asheville	1.5	F	2015	5263	5.3	149	28.1	OUF.anis	4.7	5.9	19	24.5	8.2
N075	Asheville	3.5	F	2015	10218	2.7	309	114.4	OUF.anis	2.4	3	18.9	17.8	6.6
N077	Asheville	1.5	F	2015	8507	2.8	181	64.6	OUF.anis	2.6	3.1	9.9	20.4	8.7
N081	Asheville	4.5	F	2015	4210	6.9	437	63.3	OUF.anis	5.7	8.2	1.5 days	44.7	5.3

N082	Asheville	2.5	F	2015	4049	35.8	5810	162.3	OUF.anis	24.1	49.6	4.2 days	38.2	9.7
N083	Asheville	1.5	F	2015	12098	4.3	718	167	OUF.anis	3.7	4.9	23.2	20.9	8
N089	Asheville	2.5	F	2015	5642	2		0	OUF.anis	1.8	2.2	8.4	18.8	8.8
N094	Asheville	5.5	M	2015	5691	2.7	118	43.7	OUF.anis	1.7	4	6.9 days	19.1	5.1
N006	Asheville	6.5	F	2016	6332	8.1	600	74.1	OUF.anis	7	9.2	1.1 days	37.3	6.8
N024	Asheville	9.5	F	2016	11409	6.7	2420	361.2	OUF.anis	5.3	8.3	3.5 days	11.9	8
N050	Asheville	8.5	F	2016	4090	10.7	61	5.7	OUF.anis	9.2	12.4	1.1 days	1.3 hours	6.2
N056	Asheville	5.5	F	2016	10221	3.7	385	104.1	OUF.anis	3.2	4.2	1.2	8.9	8.8
N057	Asheville	3.5	F	2016	13205	4.2	517	123.1	OUF.anis	3.7	4.6	17.3	23.4	7.8
N059	Asheville	5.5	F	2016	753	2.2	31	14.1	OUF.anis	2	2.5	3.8	3.8 hours	3.8
N060	Asheville		M	2016	6995	80.5	11265	139.9	OUF.anis	62.9	100.3	2.4 days	40.6	16.2
N075	Asheville	4.5	F	2016	14586	2.2	261	118.6	OUF.anis	2	2.5	21.5	18.6	6
N083	Asheville	2.5	F	2016	5724	96.8	119	1.2	OUF.anis	73.1	123.9	2.0 days	7.3	5.6
N087	Asheville	3.5	F	2016	10785	1.5	178	118.7	OUF.anis	1.3	1.7	17.9	15.7	7.4
N089	Asheville	3.5	F	2016	3088	1.3	105	80.8	OUF.anis	1.2	1.4	9.8	8.7	9.3
N107	Asheville	1	F	2016	13965	12.4	4632	373.5	OUF.anis	10.2	14.9	1.4 days	17.8	12.8
N110	Asheville	1.5	F	2016	12146	3.4	1078	317.1	OUF.anis	2.8	4.1	1.1 days	14.3	8.2
N115	Asheville	1	F	2016	8807	10.7	3702	346	OUF.anis	8	13.8	2.0 days	14.5	10.2

N117	Asheville	2.5	F	2016	7285	25.7	5615	218.5	OUF.anis	16.4	37	4.6 days	17.6	10.4
N121	Asheville	1	F	2016	2861	22.2	616	27.7	OUF.anis	17	28.2	1.3 days	17.1	21.7
N125	Asheville	5.5	F	2016	3064	10.7	391	36.5	OUF.anis	9.3	12.3	15.2	49.9	9
N131	Asheville	3.5	F	2016	3065	8	155	19.4	OUF.anis	7	9.2	15.9	47.5	7.9
N132	Asheville	1.5	F	2016	11061	3.3	602	182.4	OUF.anis	2.9	3.7	12.8	15.8	9.3
N133	Asheville	6.5	M	2016	10390	10.9	2646	242.8	OUF.anis	7.5	14.8	4.7 days	17.3	7.2
N139	Asheville	1.5	F	2016	6574	4.7	562	119.6	OUF.iso	4	5.5	20.9	17.3	9.1
N006	Asheville	7.5	F	2017	7318	5.9	490	83.1	OUF.anis	5.2	6.6	1.0 days	36.2	5.6
N020	Asheville	9.5	F	2017	24205	16.8	4998	297.5	OUF.anis	13.3	20.8	3.8 days	14.3	8
N024	Asheville	10.5	F	2017	31650	13.7	4838	353.1	OUF.anis	11	16.8	3.9 days	15.6	6.8
N037	Asheville	6.5	F	2017	7903	60.4	10193	168.8	OUF.anis	39.6	85.6	6.6 days	19.4	8.4
N050	Asheville	9.5	F	2017	3683	16.2	69	4.3	OUF.anis	13	19.6	1.7 days	45	6.6
N051	Asheville	16.5	F	2017	16774	12.7	2010	158.3	OUF.anis	10.4	15.3	2.8 days	14.7	7.8
N056	Asheville	6.5	F	2017	6394	2	103	51.5	OUF.anis	1.8	2.2	1.1 days	30.4	3.7
N057	Asheville	4.5	F	2017	7928	3.5	347	99.1	OUF.anis	3	4	20.2	16.5	6.6
N073	Asheville	3.5	F	2017	3085	2.3	93	40.4	OUF.anis	1.9	2.6	19.5	17.7	5.7
N075	Asheville	5.5	F	2017	1323	2.3	248	107.8	OUF.anis	2	2.6	14.4	1.2 hours	3.2
N087	Asheville	4.5	F	2017	15466	2.5	371	148.4	OUF.anis	2.1	2.9	1.3 days	10	6.4

N089	Asheville	4.5	F	2017	2731	1.6	118	73.8	OUF.anis	1.4	1.7	7.6	24	6.3
N108-158	Asheville	2.5	F	2017	17430	13.8	5240	379.7	OUF.anis	11.6	16.2	1.5 days	14.7	11.2
N114-164	Asheville	2.5	F	2017	14063	4.5	1560	346.7	OUF.anis	3.8	5.2	1 day	9.8	9.6
N128	Asheville	6.5	M	2017	6151	189.8	20563	108.3	OUF.anis	118.3	277.8	7.5 days	34	12.3
N132	Asheville	2.5	F	2017	4047	6.3	1466	232.7	OUF.anis	5.3	7.4	1 day	17.1	7.6
N139-168	Asheville	2.5	F	2017	3593	3.9	460	117.9	OUF.anis	3.5	4.3	11.7	46.8	5.4
N143	Asheville	2.5	F	2017	4816	7	96	13.7	OUF.anis	5	9.4	3.6 days	20.5	5
N146	Asheville	3.5	F	2017	19348	7	799	114.1	OUF.anis	6.2	7.8	1 day	19.7	7.8
N152	Asheville		F	2017	10648	3.5	945	270	OUF.anis	3.1	4	16.4	16.8	7.8
N159	Asheville		M	2017	14080	83.9	16503	196.7	OUF.iso	59.6	112.4	5.2 days	19	13.5
N160	Asheville		F	2017	7160	3.5	134	38.3	OUF.anis	3.2	3.8	11.4	21.7	8.4
N163	Asheville		M	2017	3658	58.6	3658	62.4	OUF.anis	40.9	79.5	4 days	26.2	10.5
N166	Asheville		F	2017	5165	1.9	43	22.6	OUF.anis	1.6	2.2	17	11.2	8.2
N169	Asheville		F	2017	1657	9.8	851	86.8	OUF.anis	8	11.7	1.4 days	57.5	4.9
N170	Asheville		F	2017	3191	3.5	38	10.9	OUF.anis	3.1	4	13	40.4	6.3
11	Pisgah	4.5	F	1981	91	12.2	0	0	OU.anis	9.3	15.5	3.9	-	-
5	Pisgah	2.5	F	1982	211	25.4	0	0	OU.anis	19	32.7	1.3 days	-	-
12	Pisgah	5.5	M	1982	182	110.7	0	0	OU.anis	71.4	158.5	3.6 days	-	-

21	Pisgah	3.5	M	1982	76	96.1	0	0	OU.anis	62.7	136.5	1.2 days	-	-
29	Pisgah	1.5	F	1982	200	5.3	0	0	OU.anis	4.2	6.6	11.8	-	-
31	Pisgah	1.5	M	1982	177	62.8	0	0	OU.anis	45	83.7	1.7 days	-	-
44	Pisgah	4.5	M	1982	61	241	0	0	OU.anis	137	373.6	1.1 days	-	-
5	Pisgah	3.5	F	1983	65	38.1	0	0	OU.anis	26.5	51.8	1.3 days	-	-
61	Pisgah	9.5	F	1983	168	12.9	0	0	OU.anis	9.6	16.7	1.8 days	-	-
66	Pisgah	2.5	F	1983	90	6.6	0	0	OU.anis	4.9	8.4	4.8	-	-
68	Pisgah	5.5	M	1983	171	33.9	0	0	OU.anis	26.4	42.3	1.3 days	-	-
70	Pisgah	3.5	F	1983	132	15.2	0	0	OU.anis	11.4	19.6	8.5	-	-
1	Pisgah	8.5	F	1984	333	60.6	0	0	OU.anis	42.5	81.7	4.5 days	-	-
61	Pisgah	10.5	F	1984	453	9.7	0	0	OUF.anis	8	11.6	1.6 days	30.7	6.4
68	Pisgah	6.5	M	1984	356	45.3	0	0	OU.anis	34.4	57.7	4.1 days	-	-
78	Pisgah	2.5	F	1984	338	12.9	0	0	OUF.anis	10.6	15.4	16.2	1.4 hours	7.4
83	Pisgah	3.5	M	1984	299	59.9	0	0	OUF.anis	47	74.4	1.4 days	37.2	16
87	Pisgah	7.5	F	1984	349	31.4	0	0	OU.anis	24.4	39.3	2.1 days	-	-
96	Pisgah	2.5	F	1984	268	12.7	0	0	OU.anis	10	15.7	20.1	-	-
98	Pisgah	3.5	F	1984	249	9.6	0	0	OU.anis	7.8	11.5	10.8	-	-
106	Pisgah	8.5	F	1984	130	24.1	0	0	OU.anis	16.1	33.6	1.9 days	-	-

1	Pisgah	9.5	F	1985	210	12.4	0	0	OU.anis	10.1	14.9	10.4	-	-
12	Pisgah	8.5	M	1985	150	135.3	0	0	OU.anis	97.5	179.2	1.9 days	-	-
61	Pisgah	11	F	1985	205	17.1	0	0	OU.anis	12.9	21.9	1.5 days	-	-
68	Pisgah	7	M	1985	197	105.5	0	0	OU.anis	71.7	145.7	5.3 days	-	-
83	Pisgah	4.5	M	1985	71	77.3	0	0	OU.anis	48.6	112.6	5.6 days	-	-
85	Pisgah	2.5	M	1985	126	88.9	0	0	OU.anis	61.4	121.6	1.7 days	-	-
87	Pisgah	8	F	1985	233	19.8	0	0	OU.anis	15.5	24.6	1.3 days	-	-
98	Pisgah	4	F	1985	168	35	0	0	OU.anis	27.4	43.4	20.1	-	-
101	Pisgah	2.5	M	1985	133	83.5	0	0	OU.anis	57.6	114.1	3 days	-	-
109	Pisgah	3.5	M	1985	167	50.6	0	0	OU.anis	32.6	72.5	4.7 days	-	-
122	Pisgah	8.5	F	1985	179	24.3	0	0	OU.anis	18.8	30.3	15.1	-	-
126	Pisgah	2.5	M	1985	118	138.1	0	0	OU.iso	94.9	189.2	2.6 days	-	-
68	Pisgah	8	M	1986	140	57.7	0	0	OU.anis	41.4	76.8	2 days	-	-
83	Pisgah	5.5	M	1986	180	150.1	0	0	OUF.anis	102.6	206.5	3.7 days	30.6	16.9
85	Pisgah	3.5	M	1986	173	127.4	0	0	OU.anis	92.7	167.5	1.7 days	-	-
87	Pisgah	9	F	1986	253	35.8	0	0	OU.anis	27.5	45.2	1.9 days	-	-
91	Pisgah	3.5	M	1986	73	114.1	0	0	OU.anis	78.4	156.4	1.3 days	-	-
101	Pisgah	3.5	M	1986	137	108	0	0	OU.anis	77.4	143.6	1.4 days	-	-

109	Pisgah	4.5	M	1986	172	63.6	0	0	OU.anis	41.4	90.5	5 days	-	-
142	Pisgah	1.5	M	1986	112	91.4	0	0	OU.anis	57.7	132.8	3.6 days	-	-
143	Pisgah	1.5	M	1986	176	46.6	0	0	OU.anis	34.7	60.3	1.2 days	-	-
152	Pisgah	1.5	F	1986	152	37.5	0	0	OU.iso	29.1	46.9	22	-	-
156	Pisgah	2.5	M	1986	101	219.4	0	0	OU.anis	141.5	314.3	3.8 days	-	-
163	Pisgah	2.5	F	1986	131	13.9	0	0	OU.anis	10.7	17.5	10.1	-	-
12	Pisgah	10.5	M	1987	82	146.7	0	0	OU.anis	109.1	189.8	2 days	-	-
119	Pisgah	3.5	F	1987	109	59.1	0	0	OUF.anis	48	71.4	n/a	-	-
180	Pisgah	3.5	M	1989	112	85.5	0	0	OUF.anis	58.5	117.6	2.2 days	51.3	15.8
208	Pisgah	1.5	F	1989	124	8.7	0	0	OU.anis	5.9	12	2.6 days	-	-
96	Pisgah	8.5	F	1990	70	17.5	0	0	OU.anis	13	22.6	7.4	-	-
178	Pisgah	5.5	F	1990	151	13.2	0	0	OU.anis	10.5	16.2	5.7	-	-
208	Pisgah	2.5	F	1990	242	19.5	0	0	OU.iso	16.1	23.2	13.6	-	-
214	Pisgah	2.5	F	1990	137	37.8	0	0	OU.anis	28.9	47.9	16.4	-	-
256	Pisgah	2.5	M	1993	193	34.8	0	0	OU.anis	28.5	41.8	13.4	-	-
260	Pisgah	5.5	F	1993	257	23.7	0	0	OU.anis	19.3	28.5	1.1 days	-	-
262	Pisgah	2.5	F	1993	224	25.4	0	0	OU.iso	21.3	29.9	8.6	-	-
266	Pisgah	4.5	F	1993	245	21.1	0	0	OUF.anis	17.6	25.1	8.6	39.3	17.1

268	Pisgah	3.5	F	1993	206	11.9	0	0	OU.anis	10	14	5.6	-	-
274	Pisgah	3.5	F	1993	263	11.5	0	0	OU.anis	9.9	13.3	4.5	-	-
229	Pisgah	7.5	M	1994	110	54.1	0	0	OU.anis	41.2	68.8	1.2 days	-	-
245	Pisgah	6.5	M	1994	73	87.2	0	0	OU.anis	59.9	119.5	2.1 days	-	-
258	Pisgah	2.5	F	1994	151	9.2	0	0	OU.anis	7.5	11.1	10.1	-	-
260	Pisgah	6.5	F	1994	200	15.6	0	0	OU.anis	12.1	19.5	1.6 days	-	-
266	Pisgah	5.5	F	1994	143	17.7	0	0	OU.anis	14.2	21.7	16.1	-	-
274	Pisgah	4.5	F	1994	226	8.1	0	0	OU.anis	6.8	9.5	6.7	-	-
278	Pisgah	3.5	F	1994	153	15.9	0	0	OU.anis	12.8	19.4	20.4	-	-
301	Pisgah	9.5	F	1994	136	48.5	0	0	OU.anis	37.6	60.6	1.4 days	-	-
312	Pisgah	7.5	M	1994	122	69.3	0	0	OU.anis	53.1	87.7	1.4 days	-	-
314	Pisgah	2.5	F	1994	147	34.5	0	0	OU.anis	28	41.6	13.4	-	-
317	Pisgah	3.5	F	1994	198	8.4	0	0	OU.anis	7.1	9.9	4.1	-	-
323	Pisgah	2.5	M	1994	139	46.6	0	0	OU.iso	36.3	58.1	1.1 days	-	-
187	Pisgah	9.5	M	1995	130	66.2	0	0	OU.anis	47.7	87.7	1.7 days	-	-
226	Pisgah	7.5	M	1995	145	59.1	0	0	OU.anis	47.3	72.1	15.3	-	-
229	Pisgah	8.5	M	1995	154	80.5	0	0	OU.anis	61.2	102.3	1.7 days	-	-
245	Pisgah	7.5	M	1995	42	178.6	0	0	OU.anis	107.4	267.7	3.9 days	-	-

260	Pisgah	7.5	F	1995	168	10.1	0	0	OU.anis	7.9	12.7	1.2 days	-	-
264	Pisgah	4.5	F	1995	155	18.3	0	0	OUF.anis	15.2	21.6	2.7	2.7	13.4
266	Pisgah	6.5	F	1995	108	24.9	0	0	OU.anis	19.3	31.2	17.7	-	-
274	Pisgah	5.5	F	1995	98	28.9	0	0	OU.anis	22	36.6	13.6	-	-
278	Pisgah	4.5	F	1995	205	15.4	0	0	OU.anis	11.5	19.7	2.5 days	-	-
280	Pisgah	6.5	M	1995	120	58.5	0	0	OU.anis	45.3	73.4	22.5	-	-
282	Pisgah	4.5	F	1995	119	11.9	0	0	OU.anis	9.5	14.5	6.6	-	-
314	Pisgah	3.5	F	1995	138	56.4	0	0	OU.anis	44.2	70.2	21.3	-	-
317	Pisgah	4.5	F	1995	205	9.1	0	0	OU.anis	7.7	10.5	2.9	-	-
323	Pisgah	3.5	M	1995	176	47.9	0	0	OU.anis	38.8	57.9	13.9	-	-
325	Pisgah	1.5	F	1995	177	15.4	0	0	OU.anis	12	19.2	1.1 days	-	-
338	Pisgah	4.5	M	1995	31	105.4	0	0	OU.iso	63.1	158.3	4.4 days	-	-
352	Pisgah	2.5	M	1995	117	133.9	0	0	OU.anis	95.4	178.7	1.3 days	-	-
354	Pisgah	1.5	M	1995	102	20.5	0	0	OU.anis	15.5	26.1	20.5	-	-
362	Pisgah	2.5	F	1995	171	11.6	0	0	OU.anis	9.4	13.9	9.5	-	-
375	Pisgah	1.5	F	1995	98	43.1	0	0	OU.anis	33.9	53.5	8.9	-	-
379	Pisgah	1.5	M	1995	99	29.3	0	0	OU.iso	21.9	37.8	21.4	-	-
272	Pisgah	8.5	F	1999	51	7	0	0	OU.anis	4.7	9.6	7.2	-	-

400	Pisgah	2.5	F	1999	43	10.7	0	0	OU.iso	7.5	14.4	5.5	-	-
192	Pisgah	14.5	F	2000	36	19.9	0	0	OU.anis	13.1	28.2	3.9	-	-
310	Pisgah	6.5	F	2000	46	18.6	0	0	IID	13.5	24.4	-	-	-
396	Pisgah	5.5	F	2000	54	30.7	0	0	OU.anis	21.2	42	13.1	-	-
400	Pisgah	3.5	F	2000	49	27.6	0	0	OU.anis	19.2	37.6	5.8	-	-
430	Pisgah	3.5	F	2000	56	8.3	0	0	OU.anis	5.8	11.2	4.6	-	-
460	Pisgah	4	F	2000	48	8.6	0	0	OU.anis	6.1	11.6	2.3	-	-
465	Pisgah	3.5	F	2000	31	1.7	0	0	IID	1.2	2.4	-	-	-
396	Pisgah	6.5	F	2001	115	11.3	0	0	OU.anis	8.8	14.1	11.3	-	-
400	Pisgah	4.5	F	2001	121	5.7	0	0	OU.anis	4.7	6.9	4.8	-	-
437	Pisgah	5.5	F	2001	57	8.3	0	0	OUF.anis	5.9	11.2	2.4	2.4 hours	13.6
460	Pisgah	5.5	F	2001	111	9.2	0	0	OU.iso	7.3	11.4	7.1	-	-
491	Pisgah	5.5	F	2001	82	12.1	0	0	IID	9.6	14.8	-	-	-
516	Pisgah	3.5	M	2001	49	38.9	0	0	OU.anis	27.7	52	11.2	-	-
520	Pisgah	2.5	F	2001	68	21	0	0	OU.anis	15.5	27.3	4.3	-	-
524	Pisgah	4.5	F	2001	68	26	0	0	OU.iso	19.4	33.6	6.1	-	-