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Bears in Big South Fork: A Spatially Explicit Density Estimate of a Reintroduced Population

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Bears in Big South Fork: A Spatially Explicit Density Estimate of a Reintroduced Population

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ABSTRACT

American black bears (*Ursus americanus*) were extirpated from the Cumberland Plateau in Tennessee and Kentucky in the late 19th to early 20th centuries due to habitat loss and overexploitation. Eastridge and Clark (2001) experimentally translocated 14 female black bears from Great Smoky Mountains National Park to Big South Fork National River and Recreation Area (BSF) from 1996 to 1997. In 2010–2012, a population estimate based on DNA extracted from hair samples collected at barbed wire hair traps revealed that the population had expanded to 190 individuals in Tennessee and 38 in Kentucky. The population was thought to have expanded its range in the Cumberland Plateau, so an updated estimate of bear density and abundance was needed across a wider spatial extent to direct future management.

I used spatially explicit capture-recapture (SECR) to estimate bear density and abundance within and surrounding BSF in northern Tennessee and southern Kentucky. Barbed-wire sampling stations (i.e., hair traps) were constructed in a 3- × 3-trap layout per cluster with 2 km between hair traps within a cluster and 16 km between cluster centers. I used DNA from hair samples obtained from hair traps to identify individual bears and establish genetic capture histories. I utilized spatial covariates to model inhomogeneous densities within the study area. Population abundance estimates across the 36,035-km^2 study area were 436.2 males (95% CI = 234.1–812.5) and 450.9 females (95% CI = 295.0–689.1) for a total of 887.1 (95% CI 607.5–1,295.3) bears, excluding cubs. Average density

estimates were 0.012 (95% CI = 0.007–0.023) male bears/km^2 and 0.013 (95% CI = 0.008–0.020) female bears/km^2, totaling 0.025 (95% CI = 0.017–0.037) bears/km^2. The mean annual growth rate was 20.4% since 1998. Based on my population estimates, growth rates, and harvest reports, harvest rates in Kentucky averaged 4.2% from 2013 to 2019 ranging from 1.8% to 6.1% annually. In Tennessee, harvest rates from 2014 to 2019 averaged 12.2% ranging from 4.8% to 23.5%. Kentucky has seen greater population growth than Tennessee (31.1% and 15.0%, respectively), possibly due to more restrictive harvest regulations and availability of contiguous forested federal lands.

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INTRODUCTION

American black bears (*Ursus americanus*) were extirpated from the Cumberland Plateau in the late 19th to early 20th century primarily due to habitat loss and overexploitation. While bears began to return to some portions of the Cumberland Plateau in Kentucky near the Virginia border in the late 1980's as a result of forest recovery and increased human tolerance (Unger et al. 2013), bears in Big South Fork National River and Recreation Area (BSF) were thought to be extirpated. The Tennessee Wildlife Resources Agency (TWRA), Kentucky Department of Fish and Wildlife Resources (KDFWR), National Park Service (NPS), U.S. Fish and Wildlife Service, and the University of Tennessee formed a working group interested in restoring bears to BSF in early 1987 (Eastridge 2000). To assess the feasibility of reintroducing bears to BSF, researchers performed habitat suitability studies and concluded that habitat conditions were adequate for sustaining a black bear population (van Manen 1990, van Manen and Pelton 1997). In 1996 and 1997, Eastridge and Clark (2001) experimentally reintroduced black bears into BSF from Great Smoky Mountains National Park. Homing by bears is a significant issue when releasing bears into a new area because they can travel hundreds of kilometers back to their original home ranges (Beeman and Pelton 1976, McArthur 1981, Rogers 1988, Landriault et al. 2006). To mitigate against this homing instinct, Eastridge and Clark (2001) evaluated 2 methods used to reintroduce these bears: summer release using acclimation pens and winter release of pre-parturient and post-parturient females into dens. Winter-released post-parturient bears displayed the most restricted movements and highest survival rates following release. Of the 14 adult bears and cubs reintroduced to BSF, 3 adult founders left BSF and an additional 4 died, but reproduction was documented in 1999 (Eastridge 2000). Adult female survival was estimated at 0.66 (SE = 0.12; Eastridge and Clark 2001), which according to Gusset's (2009) definition constitutes a short-term success. About 18 bears (4 subadult females, 6 subadult males, and 8 adult females resided in and adjacent to BSF in 1998 (J. Clark, U.S. Geological Survey, unpublished data), and Eastridge and Clark (2001) estimated that the BSF bear population had a 24% chance of extinction without additional augmentation.

Many carnivore reintroduction failures are attributed to poor planning, small founder size, and absence of post-release monitoring (Hayward and Somers 2009, Weise et al. 2014, Seddon 2015). In Kentucky in 2010, Murphy (2011) performed a follow-up study of the reintroduced bears at BSF by collecting DNA from hair samples obtained via 126 barbed wire enclosures (i.e., hair traps). He then used those data to estimate the population size of bears in and immediately adjacent to BSF (i.e., McCreary County, Kentucky). In 2012, TWRA conducted a similar study in and adjacent to the Tennessee portion of BSF in Scott, Fentress, Morgan, and Pickett counties. Bear population estimates in Kentucky and Tennessee were 38 (95% CI = 31–66) and 190 (95% CI = 170–219), respectively, and growth rates were high, averaging 18.3% annually (Murphy et al. 2015) based on the Tennessee estimates alone. Murphy et al.

(2015) found that genetic diversity in the BSF bear population was not significantly reduced and suggested that the rapidly growing population and overlapping generations improved retention of genetic diversity and helped mitigate potentially deleterious genetic effects following the reintroduction. Moreover, genetic data revealed that the bear population at BSF showed little ingress from neighboring bear populations, suggesting that bears at BSF were overwhelmingly the product of the reintroduction effort (Hast 2010).

While these studies provided valuable insight into the status of black bears in BSF, there were some shortcomings. First, the Kentucky and Tennessee studies were executed during different years using slightly different methods. Trap densities and coverage differed, and the studies did not take place concurrently, so bear populations in Kentucky and Tennessee had to be separately estimated. Also, these studies were focused on BSF with limited trap coverage in areas further from the park (Figure 1, all tables and figures are located in the appendices). Finally, the estimates were not spatially explicit, so the extent of the population and heterogeneous densities could not be estimated.

Early performance of a reintroduced population may not be indicative of overall population viability over time, as these populations typically go through 3 stages: establishment, growth, and regulation (Sarrazin 2007). Now past the establishment phase and into the growth and regulation phases, officials need an updated estimate of the BSF bear population to continue to monitor population trajectory. Wildlife managers are not only interested in biological carrying capacity but also the wildlife acceptance capacity of the people that live in the home ranges of these bears (Decker and Purdy 1988).

Black bear management in around BSF falls under 3 different jurisdictions: KDFWR, TWRA, and NPS. The NPS manages bears within the borders of BSF in both Kentucky and Tennessee but KDFWR and TWRA manage bears outside the park in their respective states. Bear hunting seasons were opened in the counties surrounding BSF (there is no bear hunting within the National Park, Figure 2) in Kentucky in 2013 and Tennessee in 2014. Since the establishment of regulated hunting, 64 and 195 bears have been harvested in Kentucky and Tennessee, respectively, in the hunting zones adjacent to BSF (Table 1). However, no updated population estimate was available for estimating harvest rates. Consequently, managers needed better information on the extent of bear range and how densities spatially varied to better manage black bears for human acceptance, recreational harvest, and wildlife viewing opportunities.

Objectives and Hypotheses

My study objectives were to utilize spatially explicit capture-recapture to test the hypotheses that:

1. The bear population continues to grow,
2. The bear population is centered at BSF and continues to expand its range,
3. Spatial covariates help refine heterogeneous bear densities at BSF, and

4. Bear hunting in Kentucky and Tennessee is sustainable at the most recent levels.

STUDY AREA

Bear managers in Kentucky and Tennessee were asked to submit maps of where they were interested in estimating bear abundance and what was considered as primary and secondary range in each respective state. The intention of having primary and secondary study areas was to have high sampling intensity in areas of greater density (i.e., primary) while still providing some information on population expansion in areas where densities were lower (i.e., secondary). I refer to these collective areas plus a 24-km buffer around all trap locations as the BSF Study Area.

Our primary study area encompassed 14,911 km^2 along the southern Kentucky and northern Tennessee borders including and surrounding the 507-km^2 BSF (Figure 3). This area was characterized by a mosaic of forested areas, developed land, and agriculture made up of predominantly upland hardwood communities. With variable elevation ranging from 150 to 1070 m, steep slopes and nearly horizontal ridge tops are common within BSF but fade into rolling foothills of the Cumberland Plateau farther from the park boundaries. Mild, cool winters and hot, humid summers were common for this region. Average annual precipitation was 133 cm and average annual temperature was 13°C (Shaw and Wofford 2003). Public lands made up 55.5% (8,266 km^2) of the study area, of which 2,322 km^2 was state-managed in the form of wildlife management areas and state parks, and 5,944 km^2 was federally managed as national parks and national forests. My research was conducted in Bell, Clinton, Jackson, Knox, Laurel, Lincoln, McCreary, Pulaski, Rockcastle, Russel, Wayne, and Whitley counties in Kentucky and Anderson, Blount, Campbell, Claiborne, Clay, Cumberland, Grainger, Fentress, Morgan, Jefferson, Knox, Overton, Pickett, Putnam, Roane, Scott, Union, Van Buren, and White counties in Tennessee.

Officials at TWRA were interested in estimating bear abundance and density in both primary and secondary areas, whereas Kentucky was interested in just the primary study area. The secondary area in Tennessee spanned roughly 8,750 km^2 immediately adjacent to the southern, eastern, and western boundaries of the primary study area in Tennessee. Officials with the agency collected DNA samples from hair traps constructed and analyzed identically with my study except that the sampling took place in 2018 and trap clusters were 24 km apart on center to reduce the number of hair traps in the secondary area. I added those captures to the primary data set and analyzed the pooled data. Including the 24-km buffer around primary and secondary hair trap locations, the BSF Study Area was 36,035 km^2 in size.

MATERIALS AND METHODS

Hair Snare Design and Construction

DNA extraction from passive collection of hair samples has been an effective tool for estimation of bear population size (Woods et al. 1999, Mowat and Strobeck 2000, Boersen et al. 2003). Initial studies using DNA extraction from hair samples utilized traditional capture-recapture methods (Murphy et al. 2015). However, estimating density or even the spatial extent of the population is problematic because the area effectively sampled by the traps is difficult to estimate (Royle et al 2014). Spatially explicit capture-recapture (SECR) methods for estimating density have since been developed which combine the individual capture histories with spatial distribution of captures to directly infer density without the need for defining an effective trapping area (Borchers and Efford 2008).

In the past, the expense of creating a trapping array for studies over large (landscape-level) extents has been prohibitive (Settlage et al. 2008). However, spatially explicit models are robust to gaps in detector spacing allowing for cluster sampling of large study areas (Sollmann et al. 2012, Efford and Fewster 2013, Sun et al. 2014, Clark 2019). Animal densities can vary with land use, land cover, management jurisdiction, and topographic variations. The use of SECR allows for utilization of covariates to model inhomogeneous density across the interstitial space between trap clusters, thus providing a more refined density estimate. SECR has successfully been used with cluster sampling to estimate black bear populations and densities in recent years (Wilton et al. 2014, Humm et al. 2017, Humm and Clark 2020).

Clark (2019) conducted simulations to assess the configuration of traps and clusters on precision and bias of density estimates. The sampling design consisting of a 3- x 3-cluster of traps with 2,000 m between traps, 16,000 m between cluster centers, and checked for 6 consecutive weeks (occasions) performed well and has been used in recent studies of other black bear populations (Humm et al. 2017, Humm and Clark 2020). I utilized this hair snare cluster configuration in the primary sampling area and, I projected proposed trap sites onto a GIS map layer provided by wildlife managers as possible black bear range (Figure 4). I obtained permission to construct hair snare sites and collect data throughout the field season on public land from the National Park Service, U.S. Forest Service, and numerous state parks. For private lands, I first identified landowners using county tax data associated with each site and sent a postcard to the address on file. The postcard briefly explained the nature of the study, what I proposed to do, the time frame, and requested return of the postage paid postcard indicating if permission was granted. If postcards were unsuccessful, I followed up with phone calls, and if that was also unsuccessful, we went door-to-door to request permission. I directed field personnel to locate a suitable site with properly spaced trees as close to the proposed location as possible. If a suitable hair trap site could not be located because of property access, geographic obstacles, or human development, we selected another site within 500 m. I adjusted the location of traps within clusters if necessary, so that at least 5 traps per cluster could be constructed, as per Humm et al. (2020). The same hair-trap configuration was used in the secondary area by TWRA, except that trap clusters were 24 km apart on center to reduce the number of traps in areas where bear densities were expected to be lower.

Each hair snare consisted of 2 strands of 15.5-gage, high tensile barbed wire with (4 prongs per barb with spacing of 12.7 cm between barbs [Goucho®, Bekaert Corporation, Marietta, GA, USA]). We wrapped the wire tightly around 3–6 trees creating a roughly 25-m^2 enclosure (Woods et al. 1999). We placed the wire strands 35–40 and 65–70 cm above the ground. Where the terrain was inconsistent (e.g., small ditches, mounds) we excavated, backfilled, or blocked low or high areas with vegetation and woody debris (Laufenberg et al. 2016, Humm et al. 2017, Humm and Clark 2020). We suspended bakery sweets in the center of the enclosure from a line about 2 m in height except for the sites within the national park boundary, where we used sardines. From the same line, we also suspended strips of cloth soaked in a concentrated flavoring used in drinks and candies (Mother Murphy's Laboratories, Inc., Greensboro, NC, USA) as a scent attractant. We marked any hair snares constructed on public lands with flagging tape and a warning sign to prevent people from inadvertently stumbling into the barbed wire. Each site was labeled with its own numeric code to ensure proper labeling on sample forms (Supplement 1).

Sample Collection and Genetic Analysis

Technicians, TWRA, KDFWR, and NPS personnel, and I collected hair samples once per week for 6 consecutive weeks from June 2019 to August 2019 in the primary sampling area and from June 2018 to August 2018 in the secondary area. All hair on a single barb was considered a sample. We examined each barb along each strand of wire for hair samples and used forceps to collect the hair sample. We placed the sample into a coin envelope which was labeled with site identifier, top or bottom strand, barb number, week of sampling, and date. We sterilized forceps and all barbs with a flame after sample collection to avoid cross contamination of genetic material.

I sent all collected hair samples to Wildlife Genetics international (WGI; Nelson, British Columbia, Canada) for genotyping. Before genotyping, WGI personnel first conducted visual assessment of the samples discarding any that obviously did not come from a bear and those that did not contain guard hairs or >5 underfur hairs. We used a set of 8 microsatellites (*G10B, G10H, G10J, G10P, G10M, G10L*, *MU23*, and a *ZFX/ZFY* sex marker), many of which were used in previous projects from the region (Hast 2010, Murphy 2011, Murphy et al. 2015). A different set of microsatellites were used to genotype the secondary samples (*G1A, G1D, G10H, G10J, G10L, G10M, MU50, MU59* and a sex marker *ZFX/ZFY*) because this effort was part of a larger project (Humm et al. 2020). Four loci (*G10H, G10J, G10L,* and *G10M*) were common between the 2 analyses. Genotyping consisted of a first pass, cleanup, and error-check, as detailed by Paetkau and Strobeck (1994) and Paetkau (2003). WGI technicians first purified the DNA using QIAGEN DNeasy Blood and Tissue kits under the tissue protocol. WGI discarded samples that had low confidence scores at >3 markers on the first run of amplification. Samples that had incomplete genotypes after the first pass, but that had not been culled (i.e. those with high-confidence data for 4–7 markers), went through at least 1 round of reanalysis to resolve incomplete genotypes for some markers. The error-check consisted of an evaluation of pairs of genotypes that were similar and could have arisen through genotyping error (Paetkau 2003). Errors produce genotypes that match at all but 1 or, more rarely, all but 2 markers, so the error-check protocol essentially prevents the identification of false individuals (Kendall et al. 2009).

Population Analysis

Recently developed spatially explicit capture-recapture (SECR) methods for estimating density (*D*) hold an advantage over traditional mark-recapture (Efford 2004). The traditional method tends to overestimate density if the assumption of a closed population is violated due to individuals along the periphery of the study area moving in and out of the effective trapping area. This results in low-biased capture probabilities and high-biased estimated abundance (Boulanger and McLellan 2001). However, SECR incorporates the spatial distribution of captures and capture histories of individuals into maximum likelihood-based models (Borchers and Efford 2008).

After the hair samples were genotyped to identify individuals, I created individual capture histories (Supplement 2) for use in spatially explicit estimation methods incorporated into the R-based (R Core Team 2020) software package 'secr'. Package 'secr' works by estimating home range parameters and activity centers based on captures of individual animals at different traps and recapture rates across the 6-week sampling period. Based on where and the number of occasions in which an animal was detected, the activity center of detected animals can be estimated along with a scaling parameter (σ) that relates to home range. Based on the frequency by which individual animals were detected, detection probabilities can be estimated based on a half-normal detection function ($g(d) = g_0 \exp(-d^2/2\sigma^2)$), where g is probability of detection, g_0 is the probability of detection if the trap was placed at the activity center, d represents the distance from a hair snare to an animal's activity center, and σ is a spatial scaling parameter determining the rate of decrease in detection rate with d.

One of the advantages of SECR methods is that animals can have varying detection rates based on the location of their activity centers. Animals with activity centers near hair traps have a higher probability of being captured than those with activity centers distant to traps, based on the detection function. That also means that some animals may have low or even zero probabilities of detection; this enables sampling based on clusters of hair traps, with large areas with no hair traps. Inference in the non-sampled areas is based on the assumption that the clusters are deployed in bear habitats and non-habitats in proportion to their availability. Environmental covariates can then be used to model inhomogeneous density.

I separately estimated male and female densities because home range size, detection rates, and trap heterogeneity often differ by sex in bears. As a polygamous species, bear harvest and growth models are often exclusively based on female demographics (Humm et al. 2020). However, as this is a reintroduced population that may be rapidly growing, male density and abundance estimates are useful for estimating expansion because male bears typically disperse farther and at higher rates than females. Although the secondary study area was sampled in 2018, 1 year prior to the primary study area, I pooled all primary and secondary study area data across years assuming that population densities would not substantially change from 2018 to 2019 and that there would be no captures of individual bears in >1 trap cluster in different years or zones. This enabled me to maximize statistical power by jointly estimating g_0 and σ across both sampling periods.

To estimate density, I created a discretized mask based on a 1,000-m resolution or mesh size (i.e., 30-m pixel values within a 1,000- x 1,000-m window were reduced to 1 central point with attributes of the surrounding cells) and a 24,000-m buffer around the traps. I assigned landscape covariates based on the National Landcover Dataset (NLCD, Yang et al. 2018). I grouped some of the land cover types into categories to reduce the number of covariates and to expedite the modeling process. First, I grouped crops into attractive (Attract_cr) versus non-attractive crops (Noattractc) to bears. I defined attractive crops as those that are eaten by bears during the sampling period (i.e. corn, sorghum, and peanuts); all others were considered non-attractive (i.e. soybeans, tobacco, and cotton). My expectation was that bear densities would be higher in areas associated with attractive crops. I grouped open water, woody wetlands, and emergent herbaceous wetlands into a water layer. My hypothesis was that bear densities would be higher near water. I grouped developed, open space; developed, low intensity; developed, medium intensity; and developed, high intensity into a development layer (developed_). My prediction was that bear densities would be lower in developed areas. Bear densities are usually higher in forests, so I combined deciduous forest, evergreen forest, and mixed forest into a forest layer (forest_cov). Evergreen forest areas were few and immediately adjacent to mixed forest areas; therefore, I combined evergreen forests with mixed forest to create a mixed forest layer (mixed_for_). For the development, forest, deciduous forest, mixed forest, water, and attractive crop data layers, I performed a focal mean calculation in ArcMap 10.6 (ESRI, Redlands, CA, USA) using a 1,000- x 1,000-m moving window on the map layer to produce average percent coverage layers (i.e. Avg_Dev, Avg_For, Avg_Dec_Fo, Avg_Mix_Fo, Avg_water, and AvgAtrCrop). I performed a Euclidean distance calculation on the attractive crop, water, development, and the BSF layers to produce ‘distance to’ covariates. I scaled those covariates using the scale function in R which subtracted the mean of the vector from the covariate value then divided by the standard deviation (e.g., (Dist_Dev-mean)/SD). This scaling was done to facilitate convergence of the maximum likelihood estimator in 'secr'.

I followed model building procedures based on Zhang (2016). I first performed a correlation analysis to eliminate 1 of any pair of environmental covariates on *D* with correlation coefficients >0.7. I then evaluated the remaining covariates singly holding the base detection rate (g_0) and the home-range scaling parameter (σ) constant (g_0~1, σ~1). I used Akaike's Information Criterion adjusted for small sample size (AIC_c, Burnham and Anderson 1998) to assess whether effects were supported and used 95% confidence intervals of the covariate effects (i.e., β values) to determine if the slopes included 0 (i.e., no effect). I considered models to be supported if the AIC_c value was within 2.0 AIC_c of the top model (Burnham and Anderson 1998). After I identified the individual covariates on *D* that were supported, I combined biologically reasonable covariates into additive models and assessed these models with effects on detection parameters. I considered covariates to be biologically reasonable if the combination of the covariates would feasibly influence black bear density and were not redundant (despite correlation coefficients <0.7). For example, Avg_For + Avg_Mix_For in an additive model would be redundant whereas Avg_For + Scale_Dist_Dev would be biologically reasonable. I evaluated whether g_0 or σ were affected by a site-specific behavioral response (bk) and by a 2-factor finite mixture model of individual capture heterogeneity (h2, Pledger 2000). Once density estimates were obtained, I estimated abundance (*N*) by summing the estimated densities for all mask points within a respective jurisdiction. My estimates do not include cubs of the year, as supported by Laufenberg et al. (2016) who utilized long-term live capture coupled with hair sample data to conclude cubs were not captured using the same barbed-wire configuration.

To estimate population growth rate, I used the growth rate equation $N_t = N_o\lambda^t$ to estimate λ (the finite annual growth rate) based on 18 bears residing in BSF in 1998 (N_0), N_t being my abundance estimate, and t being the elapsed time (years) between N_t and N_0 (t = 21). I used the delta method to estimate SEs for combined estimates by sex with the R package ‘emdbook’ (Bolker 2020). I used model averaging to estimate real and beta parameters if >1 model was supported (Symonds and Moussalli 2011), and constructed asymmetric 95% CIs for *N* based on Williams et al. (2002).

I used Program CERVUS (version 3.0.3; Kalinowski et al. 2007) to estimate mean expected heterozygosity. I used the chi-square test with Bonferroni correction in CERVUS to test for deviance from Hardy Weinberg equilibrium for each locus for bears in the BSF Study Area. I estimated genetic diversity as expected heterozygosity, which I compared to the estimate in Murphy et al. (2015).

RESULTS

Technicians, agency personnel, and I constructed 440 (217 in Tennessee and 223 in Kentucky) of the proposed 492 hair snares in May-June 2019 arranged in 59 clusters of 4–9 traps/cluster. We collected 2,018 hair samples during the 6-week sampling period from mid-June to the end of July in 2019. Hair samples were collected from 213 (48.4%) hair snares but only 100 (22.7%) sites provided samples that met our minimum standards for analysis (i.e., guard hairs or >5 underfur hairs and passed visual inspection to be bear hair). The 138 hair traps sampled by TWRA in 2018 produced only 2 detections of bears.

Of the 2,018 samples sent to WGI, 516 (26%) lacked suitable material for analysis and 392 (19%) did not pass visual inspection for species identification. Of the remaining samples (1,110), 4 contained hair from >1 bear, 294 (15%) failed genotyping. The remaining 812 (40%) hair samples were analyzed at WGI using the microsatellites *G10B, G10H, G10J, G10P, G10M, G10L*, *MU23*, and a *ZFX/ZFY* sex marker for individual identification. All individuals were successfully genotyped at 8 microsatellites with no missing loci. The 812 samples were assigned to 169 individual bears (74F:95M; Table 2), 2 of which were previously genotyped from the 2012 TWRA data set used in Murphy et al. (2015). The TWRA hair snares produced only 2 individual male captures. Although only 4 loci were common to both data sets, the genotypes differed at 3 of the 4 loci so I considered those to be unique individuals. I incorporated those 2 capture events in the secondary area into my analysis.

For males, 2 models were supported based on AIC_c scores (Table 3). In both models, individual heterogeneity modeled as a 2-class finite mixture (h2) and site-specific behavioral response (bk) were supported as additive terms for g_0. For σ however, the top model supported individual heterogeneity (h2) whereas the second-ranked model supported both individual heterogeneity (h2) and a site-specific behavioral response (bk). I averaged those 2 models and the result supported a negative association between density and distance to BSF (Scale_dist_BISO; β = -0.894, 95% CI = -1.263–-0.525) and a positive association between density and percent forest (Avg_For; β =9.124, 95% CI = 0.595–17.653). Effects of distance to development were marginal as the 95% CI included zero after model averaging (Scale_Dist_Dev; β = 0.092, 95%CI = -0.161–0.345).

Females were similar in that 2 models were supported based on AIC_c scores (Table 4). Again, in both models, individual heterogeneity modeled as a 2-class finite mixture (h2) and site-specific behavioral response (bk) were supported as additive terms for g_0. For σ however, the top model supported individual heterogeneity (h2) and site-specific behavioral response (bk), whereas the second supported only individual heterogeneity (h2). The same covariate associations were supported for females (Scale_dist_BISO, β = -1.534, 95% CI = -2.048–-1.019; Avg_For, β = 11.117, 95% CI = 1.986–20.249), but with a stronger relationship with Scale_Dist_Dev, β = 0.236, 95% CI = 0.053–0.420), than for males.

Excluding cubs of the year, model averaged mean abundance (expected *N*) was 436.2 (95% CI = 234.1–812.5) males (0.012 males/km^2 [95% CI = 0.007–0.023]) and 450.9 (95% CI = 295.0–689.1) females (0.013 females/km^2 [95% CI = 0.008–0.020]) in the 36,035-km^2 BSF Study Area (including the 24,000-m buffer around the traps). The total number of bears estimated on my study area was 887.1 (95% CI = 607.5–1,295.3) bears of both sexes (0.025 bears/km^2 [95% CI = 0.017–0.037]). I estimated 58.4 males (95% CI = 32.1–106.5) and 106.6 females (95% CI = 67.2–169.1) within the BSF boundary. Kentucky's estimated population in the study area was 336.0 bears (170.2M, 95% CI = 89.1–325.3; 165.7F, 95% CI = 106.8–257.2) when BSF was included and 297.8 (156.4M, 95% CI = 80.9–302.4; 141.3F, 95% CI = 89.7–222.8) excluding bears within BSF. The number of bears in the Cumberland Plateau in Tennessee was 541.8 (256.6M, 95% CI = 144.7–487.8; 285.2F, 95% CI = 187.5–433.8) including bears in BSF and 423.9 (221.0M, 95% CI = 118.0–413.9; 202.9F, 95% CI = 129.9–317.1) excluding bears found within BSF (Table 5). Based on an estimated 18 bears in the population in 1998, the average annual growth rate of the reintroduced population was 20.4%. Bear densities tended to be higher within and adjacent to BSF and in forested areas farther from development. Male density ranged up to 0.28 males/km^2 (Figure 6), whereas the maximum female density was 1.35 females/km^2 (Figure 7). Male densities were higher in areas distant to BSF than female densities. Genetic diversity as indicated by expected heterozygosity was 0.745.

DISCUSSION

My mean density estimates were lower than those for many other bear density estimates in the Southeast (Table 6). However, many of the other studies were performed in relatively small study areas where well-established bear populations were present. Humm et al. (2017) and Humm and Clark (2020) utilized similar methods to those that I used and similarly sampled much larger study areas intentionally including areas where density and occupancy were expected to be low, and their estimates are more similar to my estimates than those using non-spatial methods, which tend to overestimate density (Gerber et al. 2012). The highest densities I estimated were closely associated with the original release sites from Eastridge and Clark (2001), particularly for females. The highest estimated bear densities for males were lower than for females but densities of males were higher in more areas more distant from BSF, resulting from the assumed dispersal of males across the landscape. This finding is supported by black bear ecology whereby males have a higher propensity to disperse than do females, whereas females typically do not disperse as widely and frequently share a portion of their mother's home range (Rogers 1987).

Murphy et al. (2015) estimated an average annual mean population growth rate for the Tennessee population of 18.3% (95% CI = 17.4–19.5) in BSF from 1998 to 2012. My average annual growth rate estimate from 1998 to 2019 was 20.4%, which suggests that the high rate of growth for this reintroduced population has continued. This rate of population growth is high but within what is biologically feasible for black bears (Bunnell and Tait 1981). Griffith et al (1989) suggested that ample habitat quantity and quality were crucial to reintroduction success, even more so than founder size or supplementation. Availability of large contiguous tracts of forested lands with high hard mast productivity could be one of the most crucial factors for the sustained growth of this reintroduced population. A habitat suitability study by van Manen and Pelton (1997) predicted nearly half of all hard mast producing trees would obtain peak production age within 10 years. This is likely why percent forest (Avg_For) was highly informative in the top models for males and females. My estimate of genetic diversity (H_E = 0.745) was higher than that which Murphy et al. (2015) estimated (H_E = 0.729) for the BSF population.

Regulated bear hunting seasons within my study area were initiated in Kentucky and Tennessee in 2013 and 2014, respectively, with no bear hunting in BSF. From 2013 to 2019, hunters in Kentucky killed 61 (46M:15F, 75.4% males) bears (8.7 bears/yr) in Bell, Knox, McCreary, Pulaski, Wayne, and Whitley counties. From 2014 to 2019, hunters in Tennessee harvested 195 (121M:74F, 62.1% males) bears (32.5 bears/yr) in Cumberland (North of I-40), Fentress, Morgan, Pickett (East of Hwy 111), and Scott (West of Hwy 27) counties (Table 1). Numerous studies have found male-biased vulnerability to harvest for American black bears (McIlroy 1972, Fraser et al. 1982, Kohlmann et al. 1999, Malcolm and Van Deelen 2010). Based on my population estimates, growth rates, and harvest reports, harvest rates in Kentucky from 2013 to 2019 averaged 4.8%, ranging from 2.1% to 6.9% annually. In Tennessee, harvest rates from 2014 to 2019 averaged 12.5% ranging from 4.9% to 24.4% (Table1). Overall, the percentage of females in the harvest in Tennessee has been higher (39.7%) than in Kentucky (24.6%).

Officials in Kentucky utilized a quota system to limit female bear harvest. Once the set quota of females was harvested, the bear hunting season in Kentucky was halted. Tennessee officials, in contrast, had pre-established hunting seasons, with no quotas on number of females taken by hunters. The bear population growth rate of bears in Tennessee and Kentucky since the Murphy et al. (2015) estimates were 15.0% and 31.1%, respectively. The difference in growth rates is likely attributable to the differing management strategies implemented shortly after that study. The more liberal hunting regulations in Tennessee may have slowed population growth, whereas Kentucky has seen extremely high growth, possibly because of more conservative harvest regulations and the availability of contiguous forest lands of Daniel Boone National Forest. These high growth rates in Kentucky may be above what is thought to be biologically achievable for the species, so it is possible that the Murphy et al. (2015) population estimate was biased low, likely because of the restricted sampling extent and because the widely spaced trap layout used during that study resulted in areas between traps that were not sufficiently sampled.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

My results indicate positive population growth at rates similar to those reported by Murphy et al. (2015), which suggests that vital rates have not yet begun to decline due to density effects. Population estimates alone are not necessarily augury of population health; therefore, I suggest a continued assessment of abundance over time should be conducted. This population of black bears has been studied several times since its reintroduction and continued monitoring will be invaluable for future management in Tennessee and Kentucky and illustrates the growth potential for this species in high quality habitat with few competitors. Further, more detailed landscape covariates would further refine the density estimates and better inform wildlife agencies as to what management strategies are most advantageous. Utilization of spatially explicit capture-recapture methods using DNA samples offers opportunities to be integrated with other data types to be used to estimate other informative parameters such as survival and fecundity (Royle et al. 2014, Chandler and Clark 2014). Previous genetic studies have showed retention of genetic diversity and my estimates of expected heterozygosity remain high; however, continued monitoring of genetic diversity and assessment of immigration for the BSF population should continue to be evaluated at BSF (Hast 2010, Murphy 2011, Murphy et al. 2015, Murphy 2016). Comparison of harvest rates and growth rates between Tennessee and Kentucky indicate that this population can withstand harvest and still have positive growth. If an agency's goal is to maintain a high population growth rate and range expansion of black bears, conservative regulations like those in Kentucky are beneficial. The population is still primarily centered around the original release sites within BSF from the 1996–1997 reintroduction by Eastridge and Clark (2001). This suggests that BSF will continue to act as a source population for harvest outside of the park; therefore, current harvest rates are not likely to reduce the population to the point of no recovery.

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APPENDICES

Appendix A: Tables

Table 1. Black bear harvest and harvest rates in Kentucky and Tennessee within the Big South Fork Study Area, 2018–2019.

State	Year	Total harvest	Male	Female	% female	Harvest rates	Estimated N[1]
TN	2014	14	9	5	35.7%	8.2%	170
TN	2015	48	25	23	47.9%	23.5%	204
TN	2016	34	27	7	20.6%	13.9%	245
TN	2017	14	12	2	14.3%	4.8%	294
TN	2018	61	32	29	47.5%	17.3%	353
TN	2019	24	16	8	33.3%	5.7%	424
TN	2014-19	195	121	74	38.0%	12.2%*	--
KY	2013	2	2	0	0.0%	1.8%	113
KY	2014	7	6	1	14.3%	5.2%	135
KY	2015	9	7	2	22.2%	5.6%	162
KY	2016	9	6	3	33.3%	4.6%	194
KY	2017	6	6	0	0.0%	2.6%	233
KY	2018	17	12	5	29.4%	6.1%	280
KY	2019	11	7	4	36.4%	3.3%	336
KY	2013-19	61	46	15	24.6%	4.2%*	--

[*] Values with asterisks indicate average harvest rate across all years since respective hunting seasons began.
[1] Estimated *N* was derived from applying the estimated annual growth rate backward from the 2019 population estimate.

Table 2. Capture summaries for female and male bears in the Big South Fork Study Area, 2018–2019.

Female Capture Summary							
Occasion (sample collection period)	1	2	3	4	5	6	Total
n (no. individuals detected)	15	23	24	22	26	24	134
u (no. individuals unmarked)	15	19	14	9	9	8	74
f (no. time captured)	42	18	5	5	3	1	74
M(*t*+1) (no. marked and released)	15	34	48	57	66	74	74
Losses	0	0	0	0	0	0	0
Detections	16	24	27	25	35	28	155
Detectors visited	14	22	21	18	29	25	129
Detectors used	578	579	579	579	579	579	3473

Male Capture Summary							
Occasion (sample collection period)	1	2	3	4	5	6	Total
n (no. individuals detected)	19	23	27	27	31	30	157
u (no. individuals unmarked)	19	18	18	13	14	14	96
f (no. time captured)	63	17	9	4	1	2	96
M(*t*+1) (no. marked and released)	19	37	55	668	82	96	96
Losses	0	0	0	0	0	0	0
Detections	20	28	29	28	38	34	177
Detectors visited	20	22	23	24	32	32	153
Detectors used	578	579	579	579	579	579	3473

Table 3. Top models used to fit spatially explicit capture-recapture models to capture histories of male black bears at hair trap sites in the Big South Fork Study Area, 2018–2019.

Model	No. parameters	Log likelihood	AICc	ΔAICc	AICc weight
D[1]~Avg_For[2] + Scale_Dist_Dev[3] + Scale_dist_BISO[4]; g_0[5]~bk[6] + h2[7]; σ~h2[8]; pmix[9]~h2	10	-709.29	1441.16	0.00	0.5036
D~Avg_For + Scale_Dist_Dev + Scale_dist_BISO; g_0~bk + h2; σ~bk + h2; pmix~h2	11	-708.02	1441.19	0.03	0.4964
D~Avg_For + Scale_Dist_Dev + Scale_dist_BISO; g_0~bk + h2; σ~1; pmix~h2	9	-725.65	1471.40	30.24	0
D~Avg_For + Scale_Dist_Dev + Scale_dist_BISO; g_0~bk; σ~1	7	-733.56	1482.40	41.23	0

[1] Density
[2] Percent forest
[3] Scaled distance to developed land cover
[4] Scaled distance to the BSF
[5] Detection probability at activity center
[6] Site-specific behavioral response
[7] Home range scaling parameter
[8] Two-class finite mixture model of individual heterogeneity
[9] Proportions if classes in h2

Table 4. Top models used to fit spatially explicit capture-recapture models to capture histories of female black bears at hair trap sites in the Big South Fork Study Area, 2018–2019.

Model	No. parameters	Log likelihood	AICc	ΔAICc	AICc weight
D[1]~Avg_For[2] + Scale_Dist_Dev[3] + Scale_dist_BISO[4]; g_0[5]~bk[6] + h2[7]; σ[8]~bk + h2; pmix[9]~h2	11	-524.40	1075.07	0.00	0.74
D~Avg_For + Scale_Dist_Dev + Scale_dist_BISO; g_0~bk + h2; σ~h2; pmix~h2	10	-526.81	1077.11	2.04	0.26
D~Avg_For + Scale_Dist_Dev + Scale_dist_BISO; g_0~bk + h2; σ~1; pmix~h2	9	-546.79	1114.39	39.32	0.00
D~Avg_For + Scale_Dist_Dev + Scale_dist_BISO; g_0~bk; σ~1	7	-553.59	1122.89	47.82	0.00

[1] Density
[2] Percent forest
[3] Scaled distance to developed land cover
[4] Scaled distance to the BSF
[5] Detection probability at activity center
[6] Site-specific behavioral response
[7] Two-class finite mixture model of individual heterogeneity
[8] Two-class finite mixture model of individual heterogeneity
[9] Proportions if classes in h2

Table 5. Estimates of black bear abundances excluding cubs, Big South Fork Study Area, 2019.

	Males	Females	Total
BSF[1]	58.4 (32.1–106.5)	106.6 (67.2–169.1)	165.1 (30.5–892.0)
KY including BSF	170.2 (89.1–325.3)	165.7 (106.8–257.2)	336.0 (129.9–896.0)
KY not including BSF	156.4 (80.9–302.4)	141.4 (89.7–222.8)	297.8 (103.5–856.7)
TN including BSF	265.6 (144.7–487.8)	285.2 (187.5–433.8)	550.8 (302.0–1004.7)
TN not including BSF	221.0 (118.0–413.9)	202.9 (129.9–317.1)	423.9 (196.4–914.7)

[1] Big South Fork National River and Recreation Area
95% confidence interval are in parenthesis

Table 6. Estimated densities of black bears in the southeastern US.

Location	Bears/km^2	Reference
Eglin, FL	0.025	Humm (2017)
Big South Fork KY & TN	0.03	Murphy (2011)
Carvers Bay, SC	0.04	Drewry (2010)
Eglin, FL	0.041	Simek et al. (2005)
Apalachicola, FL	0.082	Humm (2017)
Southern Appalachian Bear Study SC	0.118, 0.002*	Humm & Clark (2020)
Southern Appalachian Bear Study TN	0.119, 0.017*	Humm & Clark (2020)
Southern Appalachian Bear Study GA	0.121, 0.011*	Humm & Clark (2020)
Osceola, FL	0.127	Humm (2017)
Ocala/St. Johns, FL	0.127	Humm (2017)
Southern Appalachian Bear Study (GA, NC, SC, TN)	0.13	Humm & Clark (2020)
Big Cypress, FL	0.132	Humm (2017)
Big Cypress, FL	0.131	Simek et al. (2005)
Osceola, FL	0.14	Simek et al. (2005)
Southern Appalachian Bear Study NC	0.141, 0.026*	Humm & Clark (2020)
Upper Atchafalaya River Basin, LA	0.15–0.18	Lowe (2011)
White River National Wildlife Refuge, AR	0.22–0.25	Clark et al. (2010)

Table 6 Continued.

Ocala, FL	0.24	Simek et al. (2005)
Lewis Ocean Bay, SC	0.31	Drewry (2010)
Tensas River Basin, LA	0.66	Hooker (2010)

*Densities with asterisks represent secondary study areas (e.g. primary, secondary; i.e. areas sampled separately that were suspected to have lower densities).

Appendix B: Figures

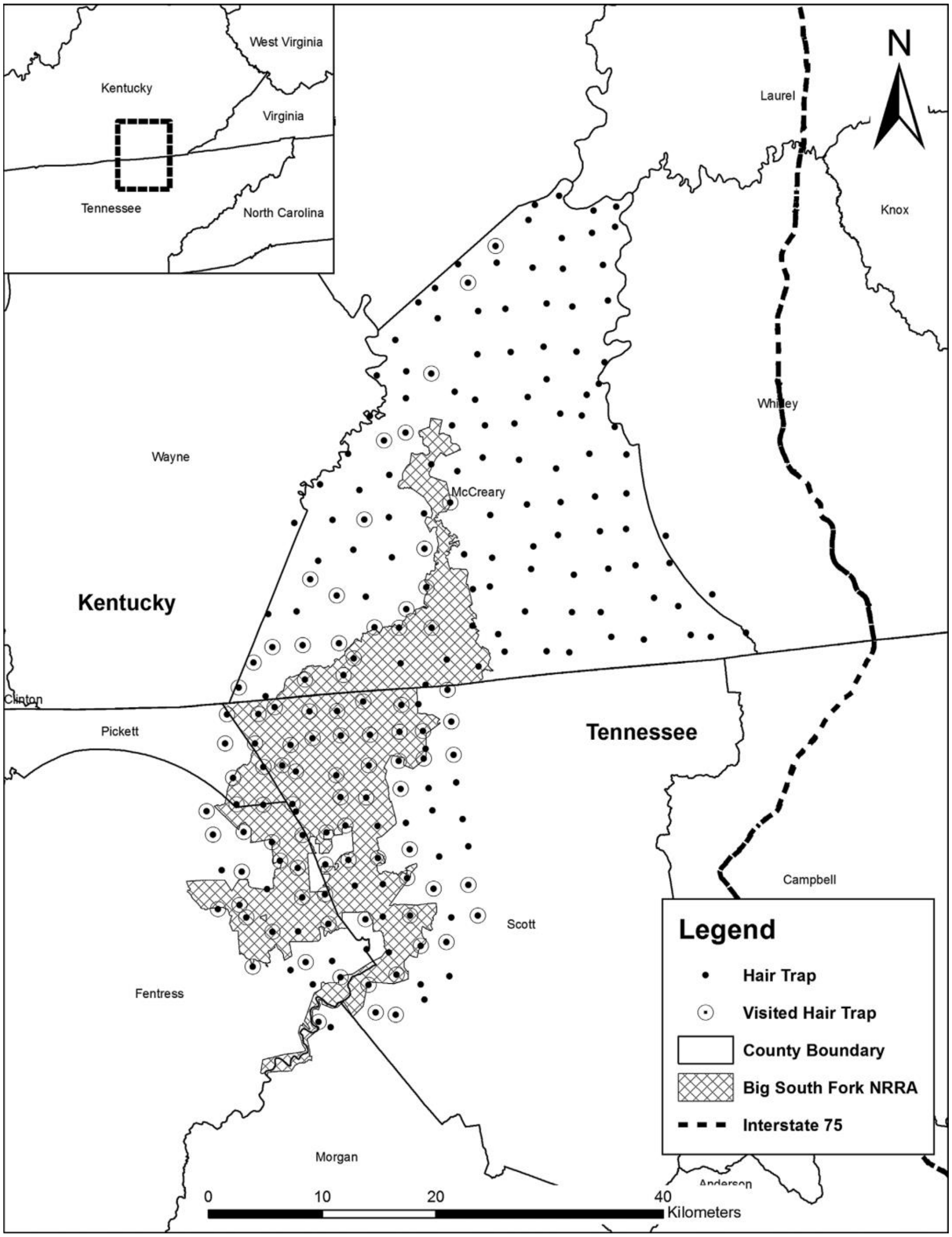

Figure 1. Locations of 233 black bear hair traps and 106 visited hair traps where Murphy et al. (2015) collected hair samples near the Big South Fork in Kentucky (2010), and Tennessee (2012), USA.

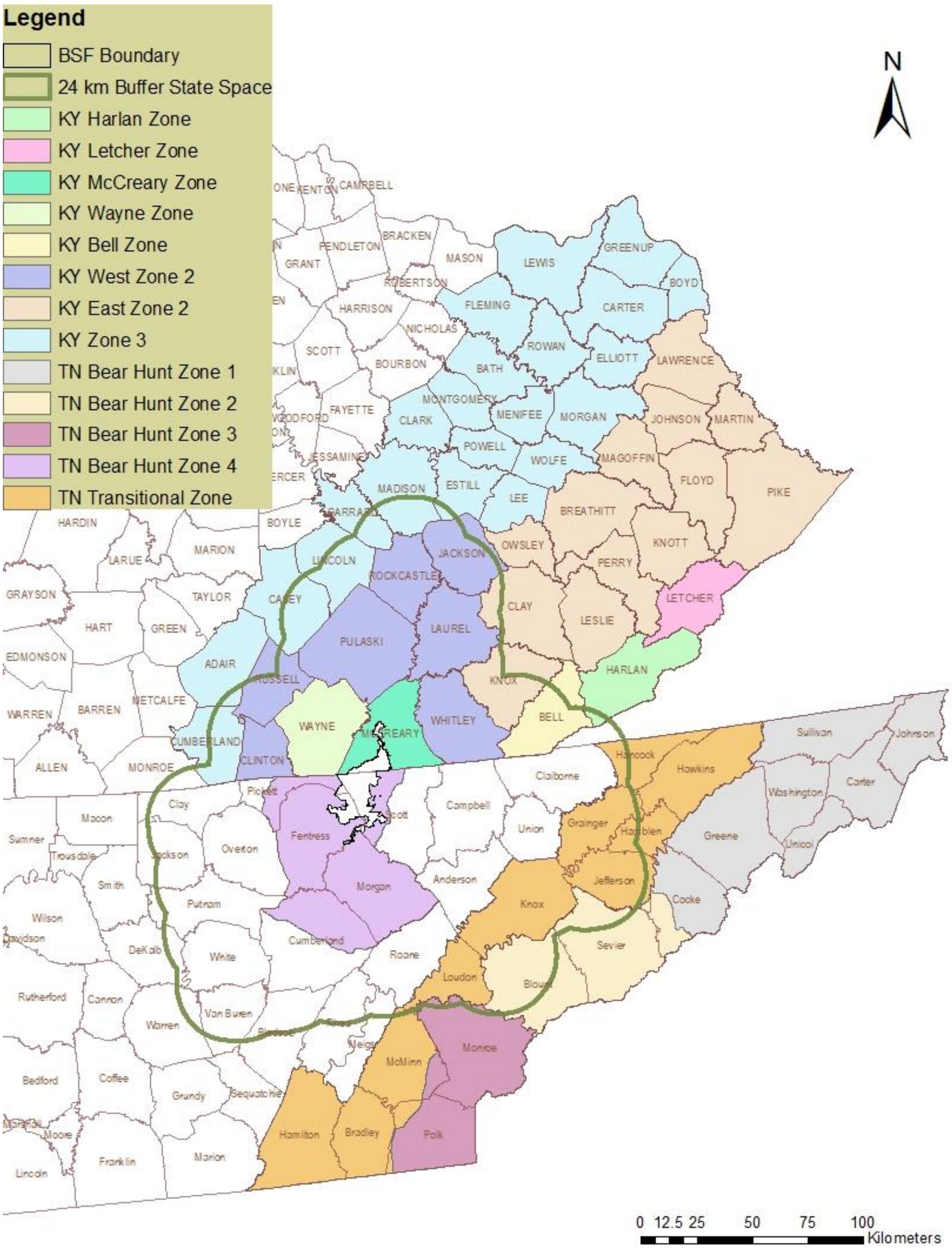

Figure 2. Bear Hunt Zones in Tennessee and Kentucky, Big South Fork Study Area, 2018–209 hunting season.

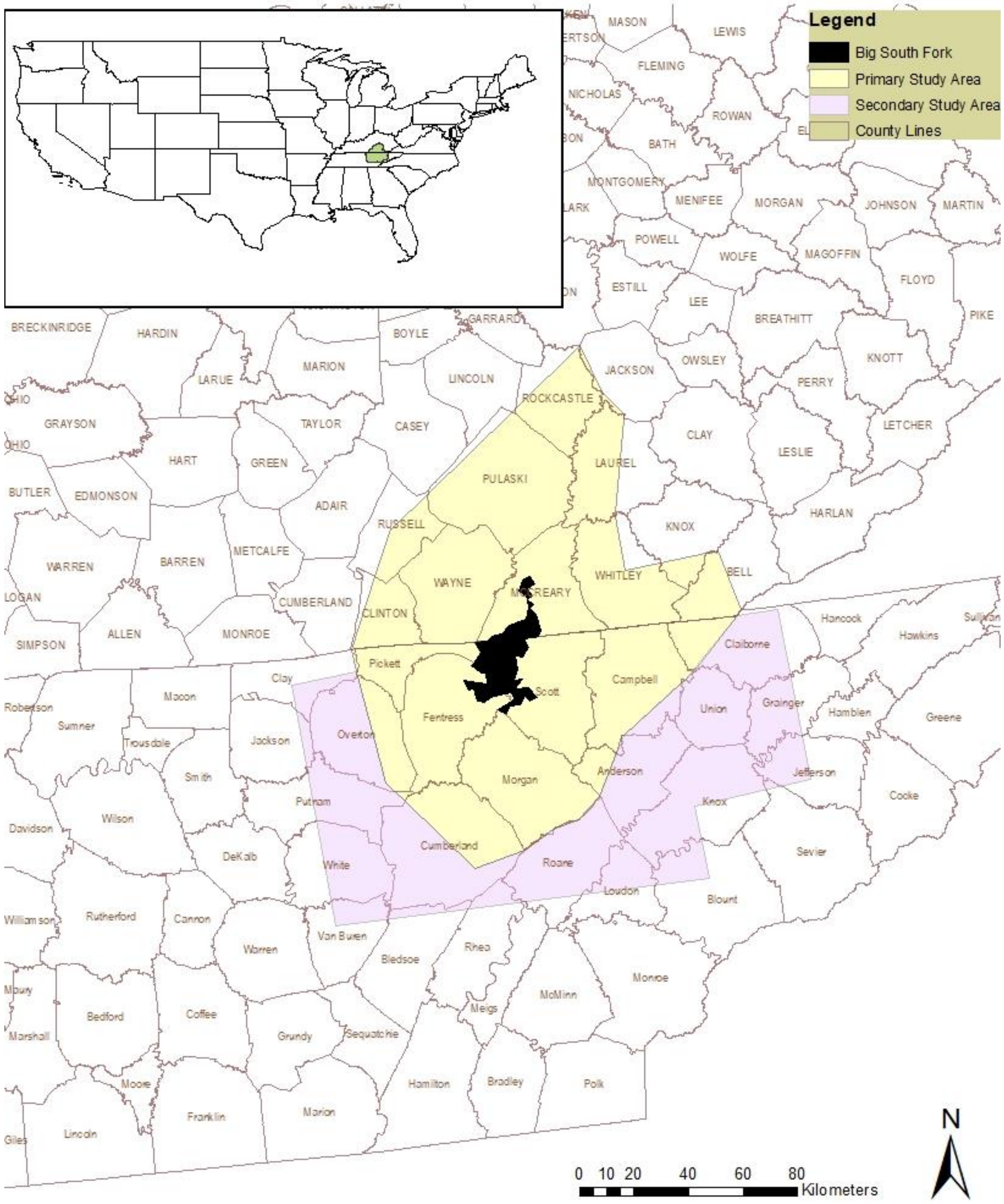

Figure 3. Map of primary and secondary black bear hair snare study areas on the Cumberland Plateau, Big South Fork Study Area in Tennessee and Kentucky, 2018–2019.

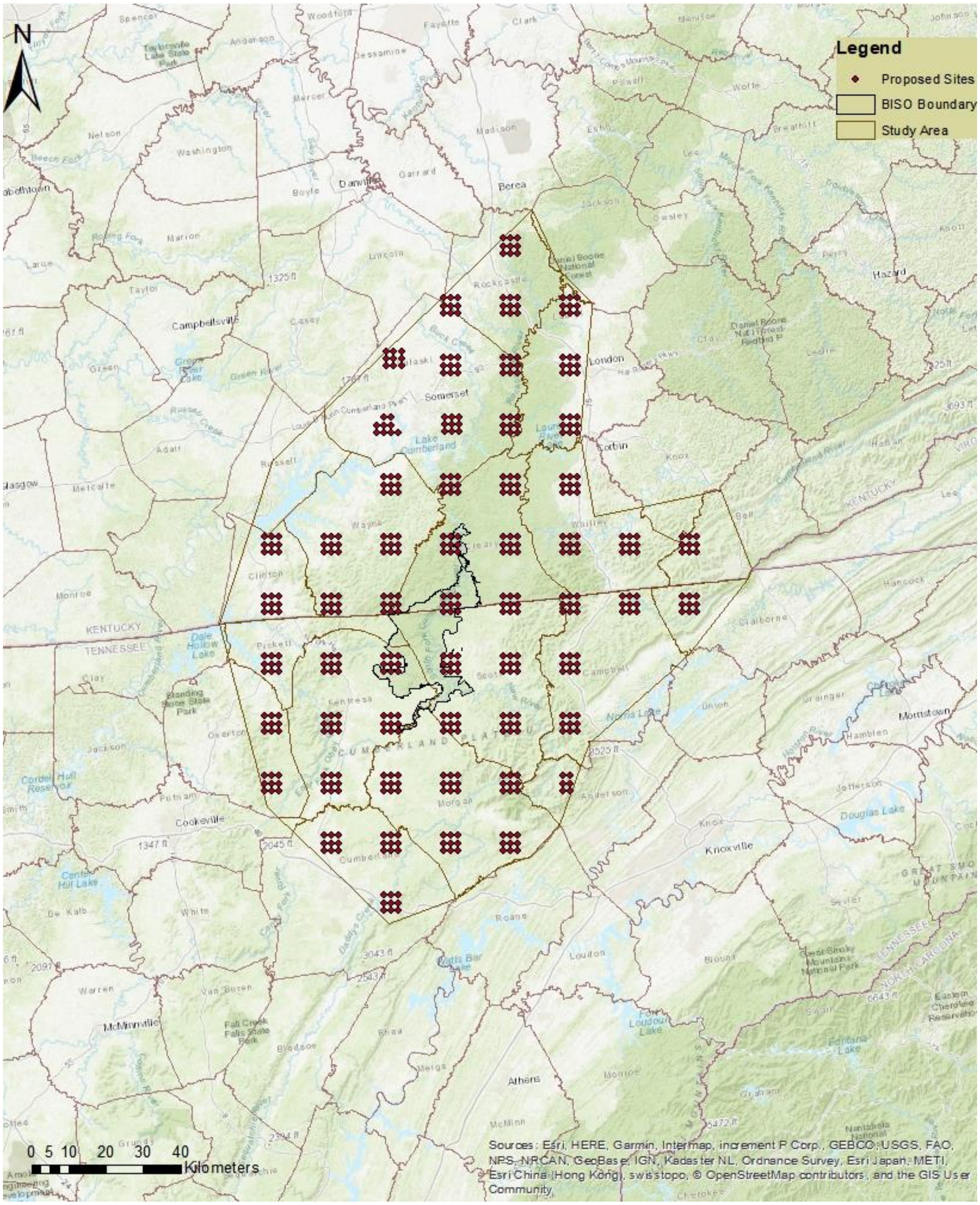

Figure 4. Proposed 492 black bear hair snare locations, Big South Fork Study Area, 2019

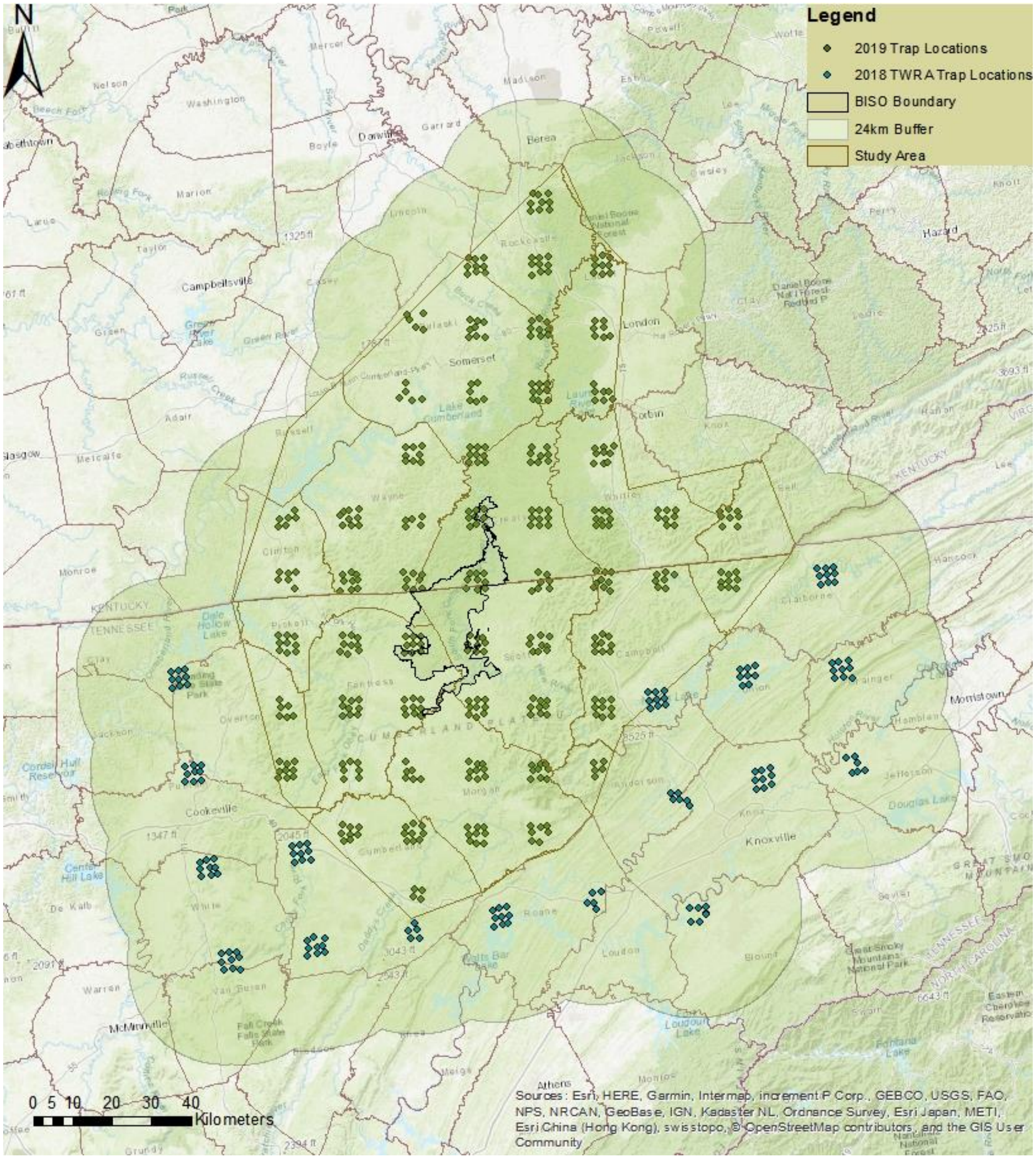

Figure 5. Locations of 578 black bear hair snares constructed, Big South Fork Study Area in Kentucky and Tennessee, USA in 2018 (blue dots) and 2019 (green dots). Hair snares are roughly spaces 2 km within clusters and 16 km from cluster center to center for 2019 and 24 km cluster center to center for 2018.

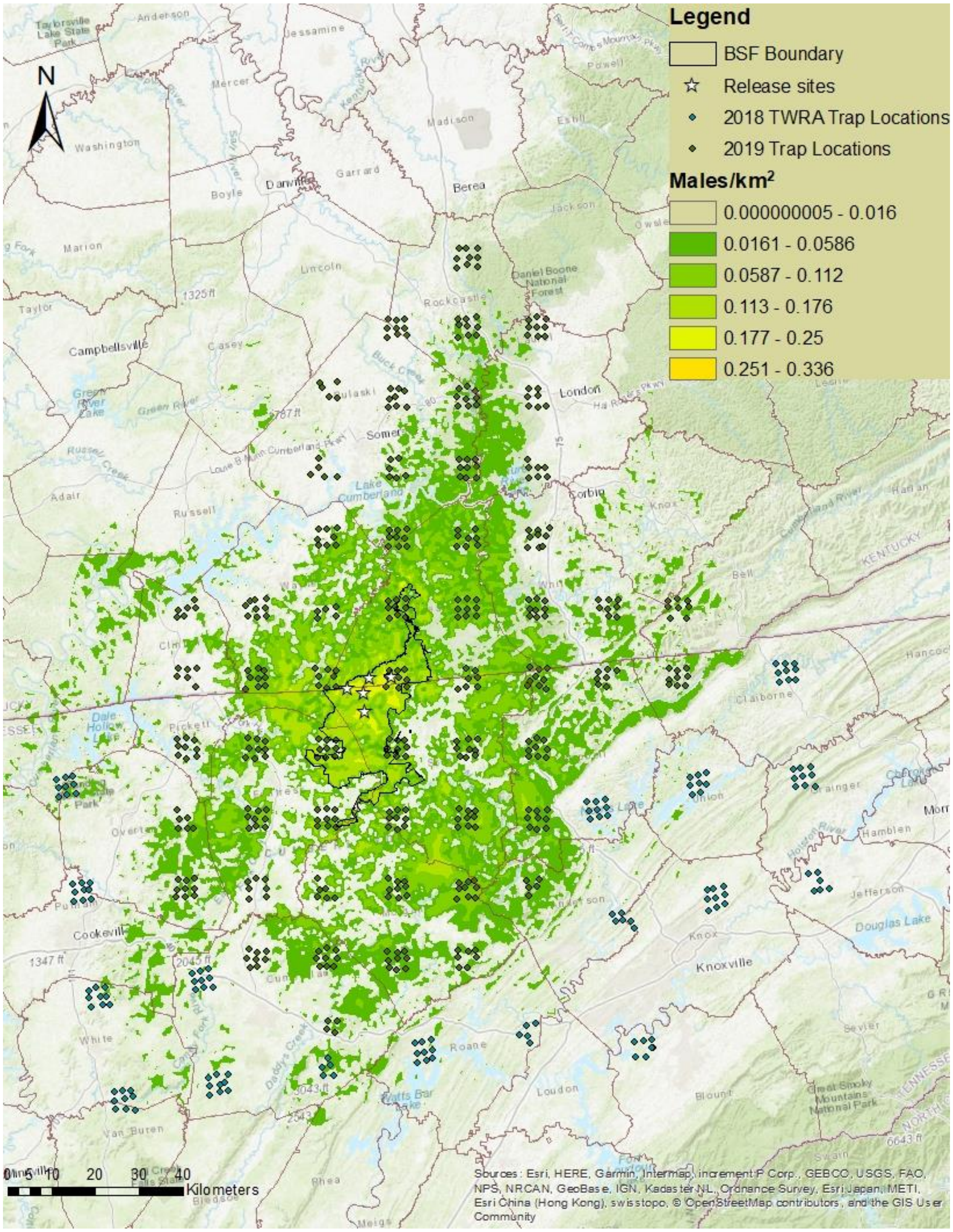

Figure 6. Density of males (bears/km^2) excluding cubs, Big South Fork Study Area, 2018–2019. Stars indicate approximate release sites of the 1996–1997 reintroduction.

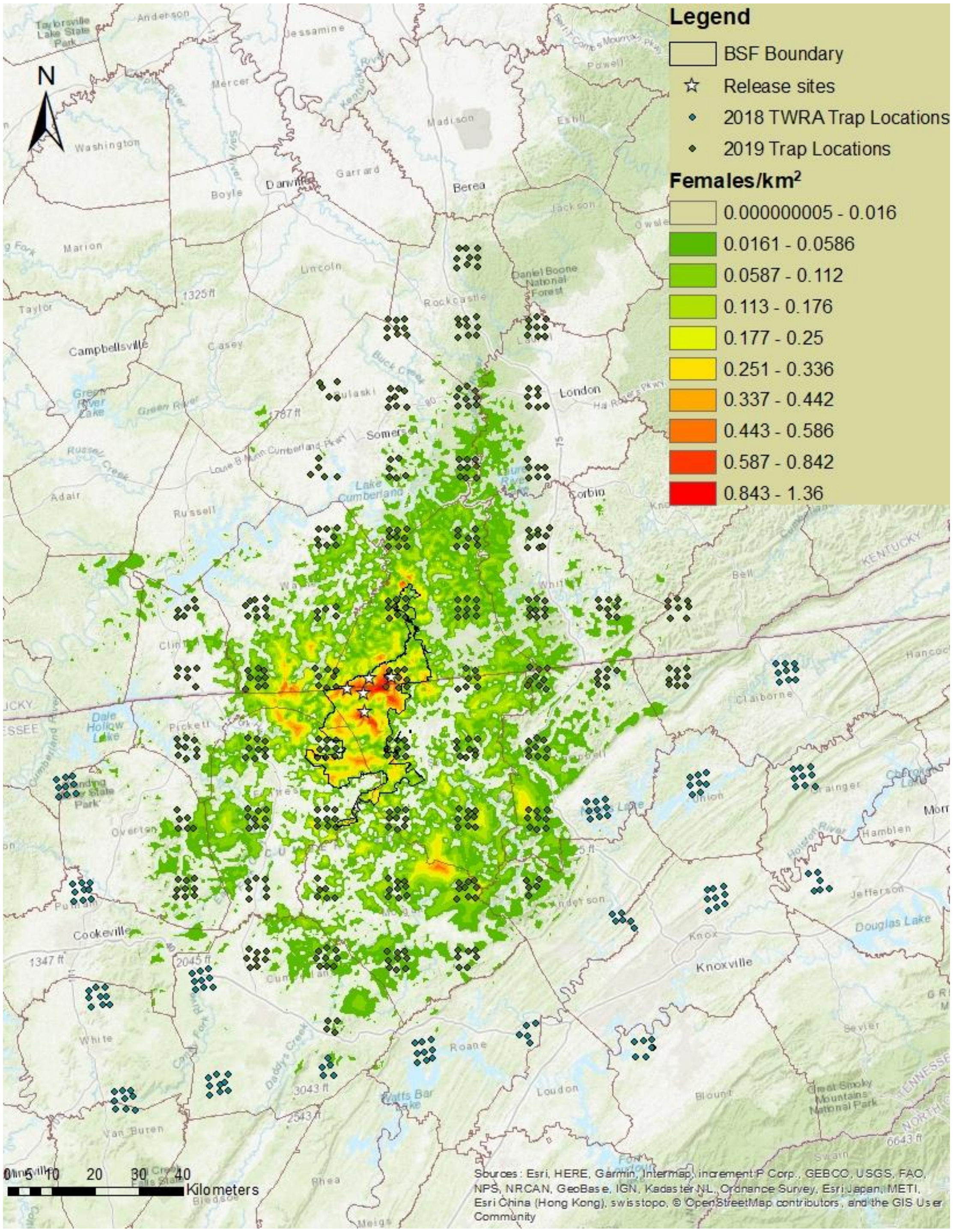

Figure 7. Density of females (bears/km^2) excluding cubs, Big South Fork Study Area, 2018–2019. Stars indicate approximate release sites of the 1996–1997 reintroduction.

Appendix C: Supplementary Data

Supplement 1. List of hair snare identifiers and coordinates of construction in latitude-longitude and UTM, Big South Fork Study Area 2018–2019.

Year	Site_ID	Latitude	Longitude	Easting	Northing
2019	1.2	35.93272	-84.870	692173.8	3978584
2019	1.3	35.93022	-84.848	694183.3	3978350
2019	1.5	35.91655	-84.875	691706.6	3976779
2019	1.6	35.90833	-84.855	693522.3	3975907
2019	2.1	36.09662	-85.050	675527.6	3996426
2019	2.2	36.08837	-85.029	677440.2	3995549
2019	2.3	36.08757	-85.006	679516.8	3995503
2019	2.4	36.07821	-85.058	674868.8	3994369
2019	2.5	36.07317	-85.033	677103.1	3993855
2019	2.6	36.07152	-85.012	679015.7	3993711
2019	2.7	36.05955	-85.053	675382.7	3992308
2019	2.8	36.06003	-85.033	677139.8	3992397
2019	3.1	36.07571	-84.874	691466.9	3994439
2019	3.2	36.08033	-84.852	693429.1	3994996
2019	3.3	36.07443	-84.828	695607.4	3994389
2019	3.4	36.06259	-84.880	690974.8	3992973
2019	3.5	36.05983	-84.857	692968.9	3992710
2019	3.6	36.05636	-84.828	695669.9	3992385
2019	3.7	36.04459	-84.874	691478.6	3990985
2019	3.8	36.04232	-84.856	693102.1	3990769
2019	3.9	36.04172	-84.839	694682.4	3990738
2019	4.1	36.05860	-84.700	707154.5	3992897
2019	4.2	36.05527	-84.672	709645.8	3992586
2019	4.3	36.05501	-84.654	711313.6	3992598
2019	4.4	36.04061	-84.699	707326.8	3990905
2019	4.5	36.04196	-84.676	709328.5	3991102
2019	4.6	36.03949	-84.652	711492.1	3990879
2019	4.7	36.02590	-84.698	707458.7	3989274
2019	4.8	36.02025	-84.680	709061.0	3988685
2019	4.9	36.01837	-84.657	711147.1	3988526
2019	5.1	36.04533	-84.519	723472.2	3991825
2019	5.2	36.03989	-84.492	725957.0	3991285
2019	5.3	36.04005	-84.475	727450.7	3991341
2019	5.4	36.03034	-84.521	723329.3	3990157
2019	5.6	36.02573	-84.474	727571.4	3989754

Supplement 1 Continued.

2019	5.7	36.00953	-84.521	723389.1	3987848
2019	5.8	36.00649	-84.502	725151.8	3987555
2019	6.1	36.25435	-85.210	660846.4	4013647
2019	6.2	36.24876	-85.189	662715.9	4013062
2019	6.3	36.25205	-85.165	664819.6	4013467
2019	6.4	36.23319	-85.214	660512.5	4011293
2019	6.5	36.23291	-85.195	662241.0	4011294
2019	6.6	36.23101	-85.171	664373.6	4011123
2019	6.7	36.21835	-85.219	660096.8	4009639
2019	6.8	36.21610	-85.195	662278.3	4009429
2019	6.9	36.21730	-85.173	664207.9	4009598
2019	7.1	36.23383	-85.031	676913.4	4011682
2019	7.2	36.23847	-85.010	678828.6	4012236
2019	7.4	36.21800	-85.031	676944.9	4009926
2019	7.6	36.21456	-84.988	680844.5	4009624
2019	7.7	36.19857	-85.034	676756.6	4007766
2019	7.9	36.23303	-84.986	680959.1	4011677
2019	7.9	36.19893	-84.988	680847.5	4007889
2019	8.1	36.22276	-84.854	692922.2	4010793
2019	8.4	36.19984	-84.853	693060.4	4008253
2019	8.5	36.20091	-84.836	694571.9	4008404
2019	8.7	36.18551	-84.859	692540.8	4006650
2019	8.8	36.18189	-84.836	694616.4	4006294
2019	8.9	36.17844	-84.815	696525.7	4005954
2019	9.1	36.20585	-84.673	709221.5	4009293
2019	9.2	36.19801	-84.651	711236.5	4008470
2019	9.3	36.19688	-84.635	712675.8	4008380
2019	9.4	36.18333	-84.673	709217.7	4006792
2019	9.5	36.18287	-84.654	710942.3	4006782
2019	9.6	36.18522	-84.634	712782.4	4007088
2019	9.7	36.16959	-84.680	708700.9	4005254
2019	9.8	36.16379	-84.653	711086.1	4004668
2019	9.9	36.16591	-84.631	713082.5	4004951
2019	10.1	36.18110	-84.497	725138.3	4006941
2019	10.2	36.18083	-84.473	727246.4	4006966
2019	10.3	36.18013	-84.457	728661.8	4006924
2019	10.4	36.16888	-84.496	725193.1	4005586
2019	10.5	36.16873	-84.482	726474.7	4005602

Supplement 1 Continued.

2019	10.6	36.16651	-84.454	729026.0	4005422
2019	10.7	36.14867	-84.505	724432.3	4003323
2019	10.8	36.14871	-84.478	726902.3	4003391
2019	10.9	36.14507	-84.460	728549.3	4003029
2019	11.1	36.16877	-84.323	740824.9	4005990
2019	11.2	36.16735	-84.292	743535.9	4005908
2019	11.4	36.15218	-84.319	741169.6	4004158
2019	11.5	36.15257	-84.299	742985.8	4004252
2019	11.7	36.13619	-84.324	740803.4	4002373
2019	12.1	36.39592	-85.190	662328.9	4029386
2019	12.4	36.37620	-85.187	662588.9	4027202
2019	12.5	36.37695	-85.166	664477.1	4027321
2019	12.7	36.35678	-85.193	662160.4	4025039
2019	12.8	36.35401	-85.171	664071.4	4024767
2019	12.9	36.35396	-85.155	665564.6	4024791
2019	13.1	36.38062	-85.010	678529.3	4028006
2019	13.2	36.37382	-84.985	680788.3	4027299
2019	13.3	36.37456	-84.965	682566.1	4027418
2019	13.4	36.36462	-85.012	678328.0	4026227
2019	13.5	36.35771	-84.996	679833.4	4025491
2019	13.6	36.35550	-84.968	682329.4	4025298
2019	13.7	36.34005	-85.014	678235.6	4023498
2019	13.8	36.34309	-84.994	679986.4	4023872
2019	13.9	36.33882	-84.973	681915.5	4023437
2019	14.1	36.36197	-84.834	694353.8	4026277
2019	14.2	36.36264	-84.810	696529.1	4026400
2019	14.3	36.35692	-84.790	698328.3	4025807
2019	14.4	36.34047	-84.836	694168.5	4023887
2019	14.5	36.34137	-84.812	696359.9	4024036
2019	14.6	36.33895	-84.791	698243.3	4023810
2019	14.7	36.32831	-84.837	694122.6	4022536
2019	14.8	36.32684	-84.812	696418.2	4022424
2019	14.9	36.32142	-84.793	698149.7	4021862
2019	15.1	36.34119	-84.652	710759.6	4024354
2019	15.2	36.34376	-84.628	712829.8	4024689
2019	15.3	36.33974	-84.608	714680.3	4024289
2019	15.4	36.32844	-84.653	710707.9	4022937
2019	15.5	36.32699	-84.635	712325.6	4022816

Supplement 1 Continued.

2019	15.6	36.32274	-84.610	714522.6	4022398
2019	15.7	36.30972	-84.659	710143.6	4020845
2019	15.8	36.30327	-84.637	712181.9	4020179
2019	15.9	36.30819	-84.616	714051.3	4020771
2019	16.1	36.33054	-84.472	726935.4	4023579
2019	16.2	36.32275	-84.449	728992.6	4022769
2019	16.3	36.32159	-84.432	730561.4	4022682
2019	16.4	36.31038	-84.480	726289.4	4021324
2019	16.5	36.30983	-84.456	728423.0	4021319
2019	16.6	36.30964	-84.438	730049.1	4021340
2019	16.7	36.29252	-84.482	726147.1	4019338
2019	16.8	36.29310	-84.456	728478.8	4019463
2019	16.9	36.28842	-84.438	730057.2	4018985
2019	17.1	36.30943	-84.295	742829.3	4021666
2019	17.2	36.30655	-84.275	744689.4	4021398
2019	17.3	36.30596	-84.248	747101.6	4021400
2019	17.4	36.29435	-84.300	742460.9	4019981
2019	17.5	36.29231	-84.276	744607.8	4019815
2019	17.6	36.28712	-84.253	746697.2	4019298
2019	17.7	36.27454	-84.299	742628.0	4017785
2019	17.8	36.26931	-84.282	744161.3	4017248
2019	17.9	36.26780	-84.257	746397.9	4017144
2019	18.1	36.53814	-85.171	663680.1	4045195
2019	18.2	36.53731	-85.147	665864.1	4045144
2019	18.3	36.53191	-85.127	667705.7	4044581
2019	18.4	36.52298	-85.171	663785.4	4043514
2019	18.5	36.52071	-85.151	665574.9	4043297
2019	18.6	36.51322	-85.124	667968.5	4042512
2019	18.7	36.50511	-85.172	663734.5	4041530
2019	18.8	36.49723	-85.153	665451.8	4040688
2019	18.9	36.49776	-85.125	667900.7	4040795
2019	19.1	36.52400	-84.990	679925.1	4043950
2019	19.2	36.51980	-84.965	682191.5	4043531
2019	19.3	36.51390	-84.947	683817.4	4042911
2019	19.4	36.50160	-84.989	680066.6	4041466
2019	19.5	36.49830	-84.966	682170.3	4041144
2019	19.6	36.49560	-84.949	683663.6	4040876
2019	19.7	36.48540	-85.000	679145.5	4039649

Supplement 1 Continued.

2019	19.8	36.48010	-84.979	681057.1	4039101
2019	19.9	36.48340	-84.949	683701.4	4039523
2019	20.1	36.50379	-84.810	696108.0	4042060
2019	20.2	36.50079	-84.790	697919.6	4041768
2019	20.3	36.49896	-84.766	700046.5	4041614
2019	20.4	36.48391	-84.810	696177.4	4039854
2019	20.5	36.48444	-84.792	697835.5	4039951
2019	20.6	36.48240	-84.768	699939.3	4039772
2019	20.7	36.46790	-84.818	695533.3	4038063
2019	20.8	36.46473	-84.796	697440.6	4037754
2019	20.9	36.46507	-84.773	699519.8	4037839
2019	21.1	36.48770	-84.629	712395.6	4040659
2019	21.2	36.48229	-84.607	714330.4	4040106
2019	21.3	36.48100	-84.591	715800.8	4040000
2019	21.4	36.47041	-84.638	711653.5	4038721
2019	21.5	36.46485	-84.610	714163.9	4038165
2019	21.6	36.46798	-84.588	716126.3	4038562
2019	21.7	36.45447	-84.638	711654.9	4036952
2019	21.8	36.45150	-84.616	713641.8	4036671
2019	21.9	36.44840	-84.593	715747.8	4036379
2019	22.1	36.46750	-84.457	727827.3	4038810
2019	22.2	36.46840	-84.428	730425.3	4038979
2019	22.3	36.46579	-84.403	732660.1	4038749
2019	22.4	36.45198	-84.461	727525.8	4037079
2019	22.5	36.44714	-84.428	730511.6	4036620
2019	22.6	36.44374	-84.413	731841.3	4036278
2019	22.7	36.43594	-84.454	728210.1	4035316
2019	22.8	36.43263	-84.439	729609.5	4034985
2019	22.9	36.43306	-84.414	731819.3	4035092
2019	23.1	36.44864	-84.276	744170.5	4037162
2019	23.2	36.45428	-84.252	746235.1	4037847
2019	23.3	36.44678	-84.234	747882.3	4037061
2019	23.4	36.43048	-84.276	744204.1	4035147
2019	23.5	36.43477	-84.258	745759.8	4035667
2019	23.6	36.42703	-84.229	748424.1	4034884
2019	23.7	36.41927	-84.279	743952.3	4033895
2019	23.8	36.41679	-84.257	745979.7	4033677
2019	23.9	36.41267	-84.235	747891.4	4033274

Supplement 1 Continued.

2019	25.1	36.68211	-85.146	665656.6	4061211
2019	25.2	36.67551	-85.123	667762.3	4060519
2019	25.3	36.67626	-85.101	669725.9	4060642
2019	25.4	36.66480	-85.152	665165.6	4059280
2019	25.5	36.66090	-85.126	667442.3	4058891
2019	25.9	36.64024	-85.109	669071.9	4056631
2019	26.1	36.65898	-84.969	681559.7	4058966
2019	26.2	36.66204	-84.942	683942.4	4059357
2019	26.3	36.65609	-84.929	685142.8	4058722
2019	26.4	36.64541	-84.967	681763.8	4057464
2019	26.5	36.64193	-84.944	683831.0	4057122
2019	26.6	36.64267	-84.928	685228.2	4057233
2019	26.7	36.62346	-84.980	680635.1	4055004
2019	26.8	36.62376	-84.949	683435.1	4055096
2019	26.9	36.62492	-84.931	685019.6	4055259
2019	27.1	36.64868	-84.795	697080.2	4058165
2019	27.2	36.64273	-84.766	699724.3	4057566
2019	27.3	36.63824	-84.745	701639.3	4057112
2019	27.4	36.63089	-84.789	697655.0	4056204
2019	27.6	36.62709	-84.750	701143.8	4055863
2019	27.7	36.61333	-84.793	697381.4	4054248
2019	27.8	36.60667	-84.772	699232.4	4053552
2019	27.9	36.60602	-84.749	701323.6	4053528
2019	28.1	36.62661	-84.606	714041.1	4056122
2019	28.2	36.62504	-84.587	715756.3	4055990
2019	28.3	36.62497	-84.567	717533.6	4056027
2019	28.4	36.61502	-84.615	713331.6	4054817
2019	28.5	36.61064	-84.586	715877.8	4054395
2019	28.6	36.60313	-84.565	717756.0	4053608
2019	28.7	36.59490	-84.620	712858.3	4052572
2019	28.8	36.58983	-84.589	715654.9	4052079
2019	28.9	36.59004	-84.569	717511.8	4052149
2019	29.2	36.61223	-84.411	731574.4	4054980
2019	29.3	36.60402	-84.387	733680.8	4054125
2019	29.5	36.59007	-84.409	731801.3	4052525
2019	29.6	36.58934	-84.384	734074.3	4052506
2019	29.7	36.57258	-84.438	729241.1	4050515
2019	29.8	36.57506	-84.417	731112.7	4050840

Supplement 1 Continued.

2019	29.9	36.57099	-84.387	733799.6	4050461
2019	30.1	36.59764	-84.249	746091.9	4053764
2019	30.2	36.59246	-84.224	748313.8	4053252
2019	30.3	36.59249	-84.203	750200.6	4053310
2019	30.4	36.56989	-84.253	745835.6	4050675
2019	30.5	36.57695	-84.235	747413.9	4051504
2019	30.6	36.57007	-84.215	749220.4	4050792
2019	30.7	36.56146	-84.260	745252.6	4049721
2019	30.8	36.55949	-84.231	747794.4	4049575
2019	30.9	36.54989	-84.214	749392.0	4048556
2019	31.1	36.57260	-84.075	761752.4	4051445
2019	31.2	36.57513	-84.050	763934.1	4051793
2019	31.3	36.56827	-84.026	766114.6	4051098
2019	31.4	36.55829	-84.081	761263.7	4049841
2019	31.5	36.55873	-84.056	763447.4	4049957
2019	31.7	36.54491	-84.078	761529.9	4048363
2019	31.8	36.54014	-84.057	763428.2	4047891
2019	32.1	36.56061	-83.894	777957.9	4050622
2019	32.2	36.55408	-83.873	779848.1	4049958
2019	32.3	36.55632	-83.849	782063.0	4050279
2019	32.4	36.53709	-83.897	777835.4	4048005
2019	32.5	36.53897	-83.876	779688.6	4048274
2019	32.6	36.53854	-83.850	782022.9	4048303
2019	32.7	36.52722	-83.897	777808.0	4046908
2019	32.8	36.52451	-83.878	779548.1	4046663
2019	32.9	36.52014	-83.857	781422.5	4046239
2019	33.3	36.81576	-85.084	670856.4	4076148
2019	33.4	36.79907	-85.129	666920.9	4074217
2019	33.5	36.80120	-85.105	669097.4	4074496
2019	33.6	36.79870	-85.084	670979.5	4074256
2019	33.7	36.78445	-85.135	666378.9	4072583
2019	33.8	36.78563	-85.115	668194.1	4072750
2019	34.1	36.80042	-84.943	683518.2	4074707
2019	34.2	36.80245	-84.929	684740.4	4074959
2019	34.3	36.80103	-84.901	687293.2	4074857
2019	34.4	36.79232	-84.956	682335.5	4073783
2019	34.5	36.78285	-84.931	684608.0	4072780
2019	34.6	36.78260	-84.907	686772.1	4072800

Supplement 1 Continued.

2019	34.7	36.77015	-84.952	682736.8	4071331
2019	34.8	36.76669	-84.929	684836.4	4070992
2019	34.9	36.76605	-84.906	686935.8	4070966
2019	35.4	36.76336	-84.773	698782.2	4070935
2019	35.5	36.76505	-84.751	700707.8	4071168
2019	35.6	36.76751	-84.724	703135.0	4071498
2019	35.7	36.74974	-84.774	698721.6	4069423
2019	35.9	36.74851	-84.728	702823.5	4069382
2019	36.1	36.76660	-84.589	715172.3	4071693
2019	36.2	36.76732	-84.567	717196.8	4071823
2019	36.3	36.76779	-84.544	719190.9	4071926
2019	36.4	36.75195	-84.590	715152.8	4070065
2019	36.5	36.75348	-84.573	716690.4	4070274
2019	36.6	36.74866	-84.547	719015.8	4069799
2019	36.7	36.73186	-84.591	715117.9	4067834
2019	36.8	36.73640	-84.570	716941.5	4068384
2019	36.9	36.72958	-84.548	718945.4	4067678
2019	37.1	36.75304	-84.410	731221.5	4070606
2019	37.2	36.75134	-84.386	733318.2	4070475
2019	37.3	36.74767	-84.363	735395.9	4070124
2019	37.4	36.73457	-84.413	731009.3	4068550
2019	37.5	36.73150	-84.391	732987.2	4068262
2019	37.6	36.73068	-84.365	735319.8	4068235
2019	37.7	36.71767	-84.416	730741.6	4066666
2019	37.8	36.71644	-84.394	732785.4	4066585
2019	37.9	36.71425	-84.369	734989.6	4066401
2019	38.1	36.73552	-84.230	747376.1	4069113
2019	38.2	36.73391	-84.208	749297.1	4068990
2019	38.3	36.72949	-84.189	750985.8	4068549
2019	38.4	36.71506	-84.229	747484.4	4066843
2019	38.5	36.71160	-84.215	748724.4	4066495
2019	38.6	36.71109	-84.190	751013.8	4066506
2019	38.7	36.70175	-84.231	747399.5	4065363
2019	38.8	36.69785	-84.214	748920.3	4064974
2019	38.9	36.69770	-84.194	750714.6	4065010
2019	39.1	36.71650	-84.051	763395.8	4067479
2019	39.2	36.71547	-84.026	765668.7	4067435
2019	39.3	36.71140	-84.000	767924.0	4067054

Supplement 1 Continued.

2019	39.4	36.69933	-84.052	763384.1	4065571
2019	39.5	36.69493	-84.031	765232.7	4065140
2019	39.6	36.69867	-84.005	767538.8	4065627
2019	39.8	36.68152	-84.029	765493.1	4063659
2019	39.9	36.67823	-84.009	767303.3	4063349
2019	40.1	36.69718	-83.875	779226.8	4065835
2019	40.2	36.69937	-83.848	781585.3	4066156
2019	40.3	36.69204	-83.825	783692.9	4065411
2019	40.4	36.68610	-83.875	779267.3	4064605
2019	40.5	36.67968	-83.850	781505.1	4063965
2019	40.6	36.67881	-83.823	783861.2	4063947
2019	40.7	36.66187	-83.873	779494.7	4061921
2019	40.9	36.65738	-83.831	783234.4	4061545
2019	42.4	36.86197	-84.206	749046.9	4083205
2019	43.1	36.92924	-84.745	700825.5	4089399
2019	43.2	36.92741	-84.723	702792.2	4089243
2019	43.3	36.92843	-84.699	704981.2	4089408
2019	43.4	36.90836	-84.751	700379.7	4087070
2019	43.6	36.90873	-84.708	704172.7	4087201
2019	43.7	36.89736	-84.751	700425.6	4085850
2019	43.8	36.89420	-84.730	702232.3	4085542
2019	43.9	36.89155	-84.707	704333.8	4085298
2019	44.1	36.91012	-84.563	717085.3	4087676
2019	44.2	36.90882	-84.542	718941.9	4087579
2019	44.3	36.90765	-84.520	720918.0	4087500
2019	44.4	36.89560	-84.567	716795.7	4086056
2019	44.5	36.89339	-84.547	718544.1	4085855
2019	44.6	36.88917	-84.527	720408.0	4085435
2019	44.7	36.87735	-84.572	716437.6	4084020
2019	44.8	36.87595	-84.546	718679.9	4083923
2019	44.9	36.87276	-84.526	720518.2	4083616
2019	45.1	36.89360	-84.388	732707.9	4086255
2019	45.3	36.88995	-84.342	736830.5	4085964
2019	45.4	36.88087	-84.391	732528.8	4084837
2019	45.5	36.87365	-84.366	734793.3	4084097
2019	45.6	36.87204	-84.344	736724.8	4083972
2019	45.7	36.85959	-84.396	732101.0	4082462
2019	45.8	36.85725	-84.373	734227.9	4082260

Supplement 1 Continued.

2019	45.9	36.85777	-84.343	736840.6	4082391
2019	46.1	36.87517	-84.207	748924.9	4084668
2019	46.2	36.87382	-84.183	751043.1	4084580
2019	46.3	36.87464	-84.154	753656.1	4084748
2019	46.5	36.86276	-84.184	751019.4	4083351
2019	46.6	36.85870	-84.165	752759.3	4082952
2019	46.7	36.84134	-84.216	748293.0	4080892
2019	46.8	36.83857	-84.186	750904.9	4080660
2019	46.9	36.83996	-84.175	751882.4	4080844
2019	48.1	37.07191	-84.725	702277.4	4105272
2019	48.4	37.05354	-84.727	702089.6	4103229
2019	48.6	37.04048	-84.748	700241.4	4101735
2019	48.8	37.03239	-84.714	703352.8	4100911
2019	48.9	37.03127	-84.682	706173.8	4100854
2019	49.1	37.05320	-84.538	718905.9	4103610
2019	49.2	37.05412	-84.518	720659.1	4103757
2019	49.4	37.03508	-84.545	718380.3	4101584
2019	49.7	37.01655	-84.547	718256.4	4099524
2019	49.8	37.01284	-84.530	719712.1	4099149
2019	49.9	37.01594	-84.506	721881.7	4099550
2019	50.1	37.03565	-84.363	734526.4	4102079
2019	50.2	37.03443	-84.342	736394.1	4101996
2019	50.3	37.03200	-84.322	738240.6	4101778
2019	50.4	37.02004	-84.363	734599.7	4100349
2019	50.5	37.01822	-84.345	736227.2	4100192
2019	50.6	37.01824	-84.322	738263.4	4100251
2019	50.7	37.00058	-84.367	734312.6	4098180
2019	50.8	36.99648	-84.351	735714.1	4097763
2019	50.9	36.99440	-84.324	738157.3	4097601
2019	51.1	37.01787	-84.188	750205.6	4100555
2019	51.4	37.00238	-84.188	750214.4	4098835
2019	51.5	37.00028	-84.163	752410.0	4098666
2019	51.6	36.99719	-84.147	753926.1	4098368
2019	51.7	36.98109	-84.192	749939.2	4096461
2019	51.8	36.98002	-84.167	752193.6	4096409
2019	51.9	36.97839	-84.141	754447.9	4096296
2019	52.1	37.22544	-84.697	704356.6	4122368
2019	52.3	37.22345	-84.651	708391.8	4122247

Supplement 1 Continued.

2019	52.4	37.21356	-84.693	704746.0	4121059
2019	52.8	37.19490	-84.677	706146.8	4119021
2019	52.9	37.18878	-84.657	707975.8	4118386
2019	53.1	37.19631	-84.518	720279.3	4119536
2019	53.2	37.19291	-84.497	722120.8	4119208
2019	53.3	37.18815	-84.482	723547.3	4118716
2019	53.4	37.17508	-84.523	719886.7	4117168
2019	53.5	37.17906	-84.507	721342.1	4117649
2019	53.7	37.15889	-84.528	719487.6	4115361
2019	53.8	37.15952	-84.508	721283.3	4115478
2019	53.9	37.15482	-84.482	723603.0	4115017
2019	54.1	37.17899	-84.341	736055.1	4118041
2019	54.2	37.18057	-84.319	737976.7	4118271
2019	54.3	37.17055	-84.299	739820.3	4117210
2019	54.4	37.16222	-84.350	735332.5	4116158
2019	54.5	37.15502	-84.326	737492.8	4115420
2019	54.6	37.15475	-84.300	739798.8	4115454
2019	54.7	37.14386	-84.350	735385.9	4114121
2019	54.8	37.14157	-84.323	737811.9	4113934
2019	54.9	37.14261	-84.301	739724.6	4114104
2019	55.1	37.16101	-84.161	752112.4	4116510
2019	55.2	37.15909	-84.138	754173.9	4116358
2019	55.4	37.14478	-84.168	751512.2	4114689
2019	55.5	37.14407	-84.140	754058.9	4114687
2019	55.7	37.12549	-84.167	751721.9	4112553
2019	55.8	37.12214	-84.144	753774.1	4112242
2019	55.9	37.12077	-84.123	755615.9	4112145
2019	56.1	37.33779	-84.502	721302.1	4135273
2019	56.2	37.33316	-84.481	723142.0	4134808
2019	56.3	37.33205	-84.458	725203.6	4134740
2019	56.4	37.31731	-84.506	720993.3	4132992
2019	56.5	37.31525	-84.483	723073.8	4132818
2019	56.6	37.31384	-84.462	724920.0	4132710
2019	56.7	37.29953	-84.511	720590.4	4131006
2019	56.8	37.30383	-84.482	723127.9	4131551
2019	56.9	37.29902	-84.460	725129.1	4131071
2019	57.1	37.31929	-84.320	737437.8	4133662
2019	57.2	37.31624	-84.300	739245.6	4133374

Supplement 1 Continued.

2019	57.3	37.31905	-84.273	741646.3	4133755
2019	57.4	37.30664	-84.322	737353.3	4132254
2019	57.5	37.30302	-84.300	739288.1	4131908
2019	57.6	37.29749	-84.274	741597.9	4131359
2019	57.7	37.42405	-84.309	738153.9	4145317
2019	57.7	37.28087	-84.328	736929.1	4129380
2019	57.8	37.28501	-84.300	739342.6	4129909
2019	57.9	37.28282	-84.278	741323.3	4129722
2019	58.1	37.29900	-84.140	753486.0	4131878
2019	58.2	37.30426	-84.117	755482.5	4132523
2019	58.3	37.29677	-84.095	757525.0	4131754
2019	58.4	37.28610	-84.142	753375.9	4130443
2019	58.5	37.28226	-84.122	755191.0	4130070
2019	58.6	37.28065	-84.101	757034.9	4129949
2019	58.7	37.26855	-84.148	752866.9	4128477
2019	58.8	37.26369	-84.122	755170.5	4128007
2019	58.9	37.26345	-84.102	756980.0	4128036
2019	59.1	37.46313	-84.295	739259.3	4149689
2019	59.2	37.46046	-84.278	740750.6	4149435
2019	59.3	37.45849	-84.249	743363.3	4149293
2019	59.4	37.44189	-84.306	738371.6	4147304
2019	59.5	37.44176	-84.273	741263.3	4147374
2019	59.6	37.43974	-84.250	743278.8	4147207
2019	59.8	37.42615	-84.280	740655.4	4145622
2019	59.9	37.42107	-84.254	742982.3	4145125
2018	AC1	36.48407	-85.489	635349.0	4038701
2018	AC2	36.48552	-85.466	637411.0	4038894
2018	AC3	36.48657	-85.448	639023.0	4039037
2018	AC4	36.46674	-85.487	635561.0	4036782
2018	AC5	36.46662	-85.469	637186.0	4036794
2018	AC6	36.46932	-85.448	639041.0	4037124
2018	AC7	36.44768	-85.489	635380.0	4034664
2018	AC8	36.45040	-85.468	637291.0	4034996
2018	AC9	36.45127	-85.444	639410.0	4035126
2018	AE1	36.26896	-85.478	636710.0	4014855
2018	AE2	36.26941	-85.454	638837.0	4014939
2018	AE3	36.26667	-85.433	640778.0	4014664
2018	AE4	36.25139	-85.475	637037.0	4012909

Supplement 1 Continued.

2018	AE5	36.25306	-85.450	639255.0	4013129
2018	AE6	36.25361	-85.438	640377.0	4013209
2018	AE7	36.23250	-85.482	636446.0	4010804
2018	AE8	36.23222	-85.457	638668.0	4010808
2018	AE9	36.23278	-85.436	640589.0	4010901
2018	AF1	36.04940	-85.467	638120.0	3990514
2018	AF2	36.05362	-85.448	639813.0	3991009
2018	AF3	36.05250	-85.425	641907.0	3990919
2018	AF4	36.03466	-85.469	637971.0	3988876
2018	AF5	36.03362	-85.439	640610.0	3988803
2018	AF6	36.03433	-85.424	641951.0	3988904
2018	AF7	36.01574	-85.467	638134.0	3986780
2018	AF8	36.01681	-85.436	640914.0	3986943
2018	AF9	36.01713	-85.419	642448.0	3987003
2018	AG1	36.06082	-85.201	662043.0	3992191
2018	AG2	36.06397	-85.179	664009.0	3992578
2018	AG3	36.06502	-85.157	665948.0	3992731
2018	AG4	36.04405	-85.198	662325.0	3990336
2018	AG5	36.04361	-85.178	664153.0	3990321
2018	AG6	36.04609	-85.156	666094.0	3990632
2018	AG7	36.02586	-85.197	662437.0	3988318
2018	AG8	36.02883	-85.175	664424.0	3988685
2018	AG9	36.02719	-85.153	666456.0	3988542
2018	AH1	35.83889	-85.432	641616.0	3967213
2018	AH2	35.83959	-85.411	643517.0	3967321
2018	AH3	35.83702	-85.389	645461.0	3967068
2018	AH4	35.81930	-85.435	641366.0	3965035
2018	AH5	35.82149	-85.408	643814.0	3965318
2018	AH6	35.82514	-85.384	645942.0	3965758
2018	AH7	35.80249	-85.432	641654.0	3963175
2018	AH8	35.80195	-85.407	643940.0	3963152
2018	AH9	35.79750	-85.384	645998.0	3962692
2018	AI1	35.84564	-85.190	663460.0	3968339
2018	AI2	35.85100	-85.169	665344.0	3968969
2018	AI3	35.84748	-85.139	668031.0	3968629
2018	AI4	35.82909	-85.188	663703.0	3966507
2018	AI5	35.82903	-85.161	666080.0	3966545
2018	AI6	35.83136	-85.148	667245.0	3966825

Supplement 1 Continued.

2018	AI7	35.81055	-85.192	663380.0	3964444
2018	AI8	35.81458	-85.164	665874.0	3964937
2018	AI9	35.81491	-85.142	667870.0	3965012
2018	AJ3	35.85819	-84.881	691330.0	3970292
2018	AJ5	35.84119	-84.900	689671.0	3968369
2018	AJ6	35.84215	-84.877	691766.0	3968521
2018	AJ8	35.82396	-84.898	689918.0	3966462
2018	AJ9	35.82078	-84.872	692214.0	3966159
2018	F1	36.54218	-83.619	265565.0	4047277
2018	F2	36.53970	-83.596	267597.0	4046947
2018	F3	36.53835	-83.573	269680.0	4046741
2018	F4	36.52340	-83.616	265809.0	4045185
2018	F5	36.52501	-83.594	267714.0	4045312
2018	F6	36.52428	-83.571	269814.0	4045175
2018	F7	36.50321	-83.617	265632.0	4042948
2018	F8	36.50707	-83.593	267751.0	4043319
2018	F9	36.50437	-83.575	269429.0	4042975
2018	K1	36.32439	-83.611	265657.0	4023093
2018	K2	36.32565	-83.593	267265.0	4023188
2018	K3	36.32536	-83.566	269657.0	4023093
2018	K4	36.30638	-83.610	265657.0	4021093
2018	K5	36.30686	-83.588	267097.0	4021093
2018	K6	36.30734	-83.565	269657.0	4021093
2018	K7	36.28837	-83.609	265657.0	4019093
2018	K8	36.28885	-83.587	267657.0	4019093
2018	K9	36.28455	-83.561	269990.0	4018552
2018	L1	36.33614	-83.875	241923.0	4025069
2018	L2	36.33659	-83.853	243895.0	4025061
2018	L3	36.34069	-83.831	245897.0	4025458
2018	L4	36.31961	-83.878	241661.0	4023242
2018	L5	36.32209	-83.855	243711.0	4023456
2018	L6	36.31740	-83.836	245383.0	4022886
2018	L7	36.29917	-83.874	241951.0	4020963
2018	L8	36.30141	-83.854	243737.0	4021159
2018	M1	36.31154	-84.145	756363.0	4022287
2018	M2	36.30987	-84.121	758518.0	4022166
2018	M3	36.31106	-84.097	760685.0	4022363
2018	M4	36.29353	-84.144	756487.0	4020291

Supplement 1 Continued.

2018	M5	36.29412	-84.122	758482.0	4020415
2018	M6	36.29464	-84.098	760584.0	4020535
2018	M7	36.27617	-84.143	756635.0	4018367
2018	M8	36.27748	-84.118	758835.0	4018578
2018	M9	36.27822	-84.098	760667.0	4018714
2018	Q1	36.10910	-83.607	265308.0	3999197
2018	Q2	36.10876	-83.583	267461.0	3999102
2018	Q5	36.09219	-83.580	267747.0	3997255
2018	Q7	36.07190	-83.597	266122.0	3995045
2018	Q8	36.07416	-83.582	267442.0	3995261
2018	Q9	36.07285	-83.558	269609.0	3995058
2018	R1	36.10325	-83.867	241867.0	3999207
2018	R2	36.10458	-83.852	243292.0	3999313
2018	R3	36.10630	-83.826	245633.0	3999436
2018	R4	36.08341	-83.871	241446.0	3997016
2018	R5	36.08505	-83.851	243281.0	3997144
2018	R6	36.08918	-83.825	245604.0	3997535
2018	R7	36.06171	-83.870	241459.0	3994606
2018	R8	36.06452	-83.849	243380.0	3994862
2018	R9	36.06980	-83.828	245303.0	3995392
2018	S1	36.07922	-84.116	759724.0	3996586
2018	S2	36.07781	-84.092	761845.0	3996492
2018	S3	36.05905	-84.073	763650.0	3994463
2018	S4	36.06281	-84.109	760384.0	3994783
2018	S5	36.06311	-84.094	761767.0	3994857
2018	S6	36.05909	-84.073	763647.0	3994467
2018	S9	36.04467	-84.065	764367.0	3992887
2018	V1	35.81464	-84.103	761738.0	3967262
2018	V2	35.81464	-84.079	763937.0	3967328
2018	V3	35.81524	-84.057	765934.0	3967455
2018	V4	35.79891	-84.057	765988.0	3965642
2018	V5	35.81524	-84.057	765934.0	3967455
2018	V6	35.79800	-84.058	765836.0	3965537
2018	V7	35.78378	-84.103	761860.0	3963839
2018	V8	35.78147	-84.078	764129.0	3963650
2018	W2	35.87597	-84.369	737550.0	3973389
2018	W3	35.87694	-84.345	739728.0	3973555
2018	W4	35.85723	-84.389	735753.0	3971260

Supplement 1 Continued.

2018	W5	35.85450	-84.369	737630.0	3971006
2018	W8	35.83937	-84.366	737885.0	3969334
2018	X1	35.86606	-84.657	711515.0	3971626
2018	X2	35.86887	-84.639	713159.0	3971977
2018	X3	35.86952	-84.615	715290.0	3972101
2018	X4	35.84586	-84.653	711966.0	3969395
2018	X5	35.84710	-84.635	713555.0	3969570
2018	X6	35.84848	-84.614	715496.0	3969770
2018	X7	35.82727	-84.657	711631.0	3967323
2018	X8	35.82954	-84.634	713763.0	3967626
2018	X9	35.83205	-84.617	715293.0	3967942

Supplement 2. Capture histories for each individual black bear identified utilizing genetic data collected from hair snares in the Big South Fork Study Area in 2019.

Individual	# of Samples	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
550	8	1	1		1		
4593	3	1					
4776	5		1		1		
4550	5	1					1
4595	1	1					
348	1	1					
3302	3	1	1				
4616	1		1				
284	2			1		1	
2268	5			1			
2266	7			1	1		
56	1					1	
4848	17			1	1	1	1
4950	2					1	
321	4	1	1			1	
4867	1					1	
4054	1						1
3698	1						1
527	4		1				
1504	6	1			1	1	1
1503	1	1					
1506	10	1	1	1	1	1	
572	10	1		1		1	
243	5	1			1		
249	30	1	1	1	1	1	1
4607	9	1		1			
4664	4	1					
26	4	1	1				
3251	1	1					
3273	24	1			1	1	1
3223	3	1		1			
3260	11	1			1	1	
3213	1	1					
4557	1	1					
4555	1	1					

Supplement 2 Continued.

4549	8	1			1		1
4551	4	1					
4687	1	1					
4685	7	1				1	1
4721	25	1	1	1	1	1	
4713	4	1		1		1	
4689	22	1	1	1	1	1	1
2256	21	1			1	1	1
3209	1	1					
3197	7	1					
2764	26	1	1	1	1	1	1
1512	1		1				
183	2		1				
186	1		1				
162	6		1				
163	3		1	1			
152	3		1				
543	14		1			1	1
614	34		1	1		1	1
286	1		1				
261	2		1				
4723	2		1				1
486	7		1			1	1
30	3		1				
3014	9		1		1	1	1
3016	1		1				
3293	3		1				
3295	9		1	1			
3274	9		1		1		1
3309	27		1	1	1	1	1
3303	8		1	1			
3281	1		1				
3045	9		1				
3018	26		1	1	1	1	1
3039	1		1				
3040	1		1				
4568	4		1				
4761	1		1				

Supplement 2 Continued.

4567	3	1	1			
4765	3	1				
4769	2	1				
4757	2	1				
431	3	1	1			
3525	8	1	1			
4785	3	1	1			
1522	10		1	1	1	1
1519	10		1	1	1	1
189	3		1			
1524	2		1			
270	3		1		1	
4692	1		1			
4799	3		1		1	
4800	5		1			
4803	1		1			
475	6		1	1		
33	1		1			
3073	10		1		1	1
3067	1		1			
3096	1		1			
3082	2		1			
3088	7		1	1		
4513	1		1			
340	3		1			
330	1		1			
344	2		1			
432	3		1	1		1
4570	21		1	1	1	
4537	1		1			
3108	10		1	1	1	1
2627	6		1		1	
1540	5			1		1
1535	3			1		
1537	2			1		1
192	3			1		
258	2			1		
251	9			1	1	

491	5	1		1
353	1	1		
34	4	1		
3144	1	1		
3146	1	1		
3124	7	1	1	
3147	3	1		1
4915	2	1		
4826	5	1	1	
4816	1	1		
3815	4	1		
2787	1	1		
2795	8	1	1	1
1559	2		1	1
1560	2		1	
255	1		1	
256	3		1	
4933	3		1	1
4931	1		1	
4993	1		1	
4992	1		1	
448	5		1	
3864	1		1	
3211	4		1	
3344	4	1	1	
3882	1		1	
4857	3		1	
4845	2		1	
4846	3		1	1
4853	2		1	
4946	4		1	1
334	1		1	
3571	1		1	
173	2			1
1592	3			1
102	1			1
4832	2			1
4838	3			1

Supplement 2 Continued.

4830	2				1
397	3				1
403	1				1
3485	2				1
3409	1				1
4960	5				1
2891	2				1
331	2				1
3556	1				1
4997	3				1
3699	2				1
2887	1				1
2912	5				1
2916	5				1
2909	1				1
3323	1			1	
3313	3		1	1	
3314	1			1	
3355	1	1			
3328	2		1		

VITA

Josh Alston was born and raised in the foothills of east Tennessee. After High school, he attended Walter's State Community College while working full time in construction. He transferred to the University of Tennessee where he received a Bachelor of Science degree in Wildlife and Fisheries Science. Josh then went on to work for USDA APHIS Wildlife Services in North Carolina. After being contacted about an open graduate position at the University of Tennessee, he returned to pursue a Master of Science in Wildlife and Fisheries Science. His professional interests include black bear management and research and wildlife damage mitigation.