Characterizing American Black Bear (*Ursus americanus*) Highway Crossing Locations in Central Georgia

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Abstract: The Central Georgia Bear Population (CGBP) is of special conservation concern due to its relatively small population size and isolation from other bear populations in the southeastern United States. Plans to widen Georgia State Route (SR) 96, which bisects the CGBP, have potential to negatively impact the population. Highway underpasses are being planned to mitigate these impacts. During 2012–2015, we captured and fitted 63 American black bears (*Ursus americanus*) with global-positioning-system collars and used remote, infrared cameras to document bear crossings along SR 96. We evaluated landscape characteristics associated with 212 bear crossings (210 documented via global-positioning-system collars, two with cameras) using a resource selection function approach and generalized linear mixed-models. We noted that bears were more likely to cross SR 96 where the highway bisected upland habitats. Likewise, we observed that as distance between SR 96 and forest edge increased, the likelihood for a bear to cross the highway decreased. Specifically, the odds of bear crossings decreased 98% for every 10 m farther away SR 96 was from a forest edge. Bear crossings were spatially concentrated, with 167 (78.8%) crossings attributed to seven bears occurring within a 2.5-km segment of SR 96. We recommend placement of an underpass within this segment to facilitate bear movements under the highway surface.

Key words: American black bear, highway crossing, *Ursus americanus,* wildlife underpass

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Human encroachment in the form of roads, rights-of-way, railroads, and pipelines have potential to influence bear behavior (Mattson et al. 1987, Brody and Pelton 1989, Beringer et al. 1990, Kaczensky et al. 2003), and these anthropogenic features can fragment and degrade habitat for various species (Andrews 1990, Jackson 2000, Primack 2006, Laurance et al. 2009, Latham et al. 2011). Roads, in particular, impact wildlife populations through direct loss of habitat, increased mortality to individuals using habitats along roads, and potential limitation of access to resources (Trombulak and Frissell 2000, Jaeger et al. 2005). Likewise, roads can contribute to fragmentation of populations both demographically (Trombulak and Frissell 2000, Hostetler et al. 2009) and genetically (Thompson et al. 2005, Riley et al. 2006), resulting in smaller, more vulnerable subpopulations (Jaeger et al. 2005, Beckmann and Hilty 2010). Populations of species maintaining large home ranges and exhibiting wide-ranging movement patterns, such as many carnivores, can be especially affected by highways (Brody and Pelton 1989, Maehr et al. 1991, Foster and Humphrey 1995, Waller and Servheen 2005, Poessel et al. 2014, Litvaitis et al. 2015).

The United States contains an estimated 6.7 million km of roads (Federal Highway Administration 2014), and roads affect the ecology of approximately 20% of the total area of the nation (Forman 2000). In addition to wildlife conservation issues, the interaction of wildlife and highways has a human cost in the form of vehicle damage, personal injury, and in extreme cases human fatality (Conover et al. 1995, Groot Bruinderink et al. 1996, Romin and Bissonette 1996). Since the 1970s, wildlife managers and road engineers have increased efforts to develop methods to mitigate negative effects of roads on wildlife and reduce (or eliminate) the human cost of wildlife-vehicle collisions (Kroll 2015). Numerous methods have been used to reduce wildlife-vehicle collisions, including the use of underpasses to provide habitat connectivity (Clevenger and Waltho 2000). Likewise, contemporary research has focused on evaluating how habitat characteristics influence wildlife use of highway corridors, in hopes of identifying ways to prevent vehicles collisions with wildlife (Lewis et al. 2011).

The Central Georgia Bear Population (CGBP) consists of approximately 250 American black bears (*Ursus americanus*) inhabiting forested land along the Ocmulgee River, roughly 150 km southeast of Atlanta (Figure 1, Hooker et al. 2015). Relatively low abundance and isolation from other bear populations make conservation of the CGBP of special concern (Hooker et al. 2019). Bi-

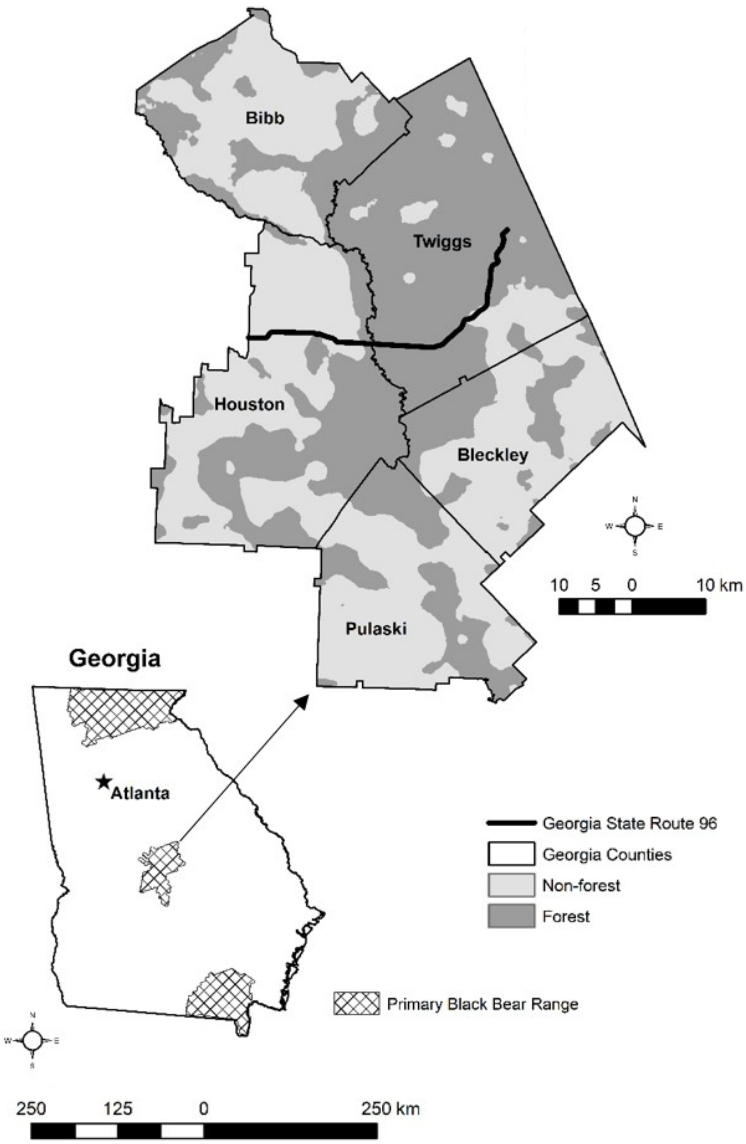

Figure 1. Primary range of three Georgia American black bear (*Ursus americanus*) populations (lower left) and five Georgia counties inhabited by the Central Georgia Bear Population depicting forested habitat bisected by Georgia State Route 96, Georgia, 2012–2015. Black bear range data from Scheick et al. 2011 and Scheick and McCown 2014.

secting the area inhabited by the CGBP is Georgia State Route (SR) 96, a two-lane highway with a mean daily traffic load of >8,000 vehicles, 12% of which are large commercial trucks (Georgia's State Traffic and Report Statistics 2012). To accommodate increasing traffic loads, the Georgia Department of Transportation (GDOT) is widening SR 96 into a four-lane divided highway and is mandated by the Federal Highway Administration to investigate potential ecological impacts. Due to the location of SR 96 relative to local bear habitat and the fact that two to three bear-vehicle collisions occur annually on SR 96 (B. Bond, Georgia Department of Natural Resources, unpublished data), the widening project plan includes installation of underpasses to reduce bear-vehicle collisions while allowing wildlife movement across the highway. At the request of the GDOT, we evaluated incidences and locations of bear crossings of SR 96 prior to the highway widening project. Our objectives were to quantify bear crossings of SR 96, characterize habitat and landscape features associated with crossing locations, and quantify incidences of bear roadkill on SR 96 and other roads within the geographic extent of the CGBP.

Study Area

We conducted research along a 27-km section of SR 96 and adjacent bear habitat within Houston and Twiggs counties, Georgia. Predominant forest types adjacent to this segment of SR 96 were bottomland hardwood forests within the Ocmulgee River flood plain and planted pine (*Pinus* spp.), naturally regenerated pine, and mixed pine-hardwood in the uplands. Common overstory tree species included loblolly pine (*Pinus taeda*), red and white oaks (*Quercus* spp.), sweetgum (*Liquidambar styraciflua*), red maple (*Acer rubrum*), American beech (*Fagus grandifolia*), yellow poplar (*Liriodendron tulipifera*), water tupelo (*Nyssa aquatica*), and bald cypress (*Taxodium distichum*). The Ocmulgee River flowed through the study site from north to south and was a defining geographical feature. Elevation above sea level ranged from ~60 m to ~190 m. Nearby human population centers included Macon, Warner Robins, Bonaire, Cochran, and Hawkinsville. Land west of the study area was dominated by human development, whereas land to the north, south, and east was primarily agricultural and managed forest lands.

East of Bonaire, SR 96 crossed the flood plain of the Ocmulgee River, and the span of highway within the flood plain was on a levee approximately 6 m high. SR 96 was bridged over the Ocmulgee River and four ephemeral drainages associated with the river. In contrast, SR 96 east of the Ocmulgee River flood plain was mostly at the same level as the surrounding ground and there were no underpasses within this section of highway. We noted numerous culverts of various design along SR 96, but surmised that only three were large enough to allow bears to pass beneath the highway. Between Bonaire and Tarversville, land adjacent to SR 96 was mostly forested. East of Tarversville, SR 96 was adjoined by a mix of woodlots and agricultural fields. Parallel and adjacent to SR 96 directly to the north, between Bonaire and Tarversville, was an electric-power transmission line devoid of trees, and vegetation under the line was maintained at a height of <1 m. The western half of the right-of-way was approximately 140 m wide, whereas the eastern half was 55 m.

The U.S. Department of Transportation's Federal Highway Administration (FHWA) and the GDOT developed a plan to widen a 24 km-long stretch of SR 96 between Bonaire and the intersection of SR 96 and U.S. Interstate 16 (I-16). The proposed widening was intended to facilitate traffic flow between I-16 and U.S. Interstate 75 (I-75). The section of SR 96 to be widened bisected an area of forest land associated with the Ocmulgee River drainage and in doing so, bisected the CGBP. The widening project called for inclusion of eight underpasses along with woven-wire outrigger fencing from east of Bonaire to the intersection of SR 96 and Georgia State Route 87 at Tarversville. The fencing was designed to funnel wildlife to underpasses and prevent wildlife from crossing the highway surface but would not be constructed along the entire length of highway as numerous driveways and other access points occurred along the highway.

Methods

Bear Capture and Monitoring

During summers 2012–2014, we captured bears with modified Aldrich foot snares (Johnson and Pelton 1980) using soured corn and artificial flavoring (Mother Murphy's, Greensboro, North Carolina) to attract bears. We focused trapping efforts within the SR 96 corridor (i.e., within ~2 km either side of the highway) along the 27 km of SR 96 that we defined as our study area. We anesthetized captured bears with Telazol (Fort Dodge Animal Health, Fort Dodge, Iowa) or large animal xylazine (100mg/ml) combined with Telazol (XZT). We reversed bears anesthetized with XZT using atipamazol hydrochloride (Antisedan, Orion Pharma, Orion Corporation, Espoo, Finland) and diazepam approximately 45 minutes after initial anesthesia. We monitored rectal temperature throughout the anesthesia event, and bears exhibiting elevated rectal temperatures were cooled by having cold water poured on their extremities. We monitored pulse and blood oxygen saturation levels using pulse-oximeters, and bears with blood oxygen levels below ~90% received supplemental oxygen via nasal cannula.

We ear-tagged all captured bears with paired, numbered button tags (All American, Y-Tex Corporation, Cody, Wyoming) and tattooed the inside of the right upper lip with a number corresponding to the ear-tag number. We implanted a passive integrated transponder (PIT) sub-cutaneously along the mid-line of the back between the scapulae. We recorded sex, weight, and a series of standard morphometric measurements, and extracted the first upper premolar (UPM1) using an apical 301 dental elevator. Collected teeth were used for cementum-annuli aging (Willey 1974). Our capture and handling methods were approved by the University of Georgia Institutional Animal Care and Use Committee (Protocol Number A2011 10-004-A1).

We collared bears with WildCell (Lotek Wireless Inc., Newmarket, Ontario, Canada) Global Positioning System (GPS)/General System for Mobile (GSM) collars (hereafter GPS-collar). For bears weighing ~45.4 kg or greater, we used WildCell MG series collars, whereas we used WildCell SG collars on bears in the ~22.7–45.4 kg range. In 2012, all collars were equipped with a timed, mechanized release programmed to release 52 weeks after activation, and a leather break-away (Garshelis and McLaughlin 1998). After 2012, collars had only a leather break-away.

We programmed each collar to collect a location every 20 minutes, and collars also had virtual fence technology. When a collared bear was within the area outlined by the virtual fence, the GPS location acquisition rate increased to one location every five minutes. Upon leaving the virtually fenced area, the collar reverted to the 20-minute location acquisition rate. The virtually fenced area was ~250 m either side of the SR 96 centerline between the intersection of SR 96 and Houston Lake Road west of Bonaire and the intersection of SR 96 and GA 358, south of Jefferson. All location data were transmitted to a desk-top base station via GSM and stored. Because we were interested in collecting fine temporal scale data when bears were near SR 96, and because bears become less active in winter, we opted to only collect fine temporal scale data during spring, summer, and fall months (May–November) to maintain battery life in collars.

Additional Monitoring

During summer and fall 2012 and 2014, we used infrared trail cameras (Bushnell, 5.0 Megapixel Trophy Cam, Overland Park, Missouri) to monitor wildlife activity under four of five underpasses on SR 96 and at one end of the three culverts potentially large enough to allow passage of a bear. Persistent flooding during summer and fall 2013 precluded camera surveys. We excluded the first bridge east of the Ocmulgee River (i.e., Bridge 4) and the west end of the Ocmulgee River Bridge (i.e., Bridge 3) from the survey due to high human activity in these areas. We placed cameras in series, facing one to the next, so that the full span of ground under a given bridge was within camera view (Figure 2). We placed cameras approximately 1 m above the ground and spaced them at the effective distance of the camera motion sensitive trigger (~7.5m). We painted the first bridge pile in front of each camera with a number corresponding to the camera identification number, positioning the numbers so they would be visible in photographs. If a pile was not visible, as was the case at culverts, we staked a numbered sign in front of the camera. We programmed each camera to take three photographs at one-second intervals each time the camera was triggered. Following the third photograph in a series, cameras paused for one minute before being capable of being triggered again. All photographs contained a date and time stamp.

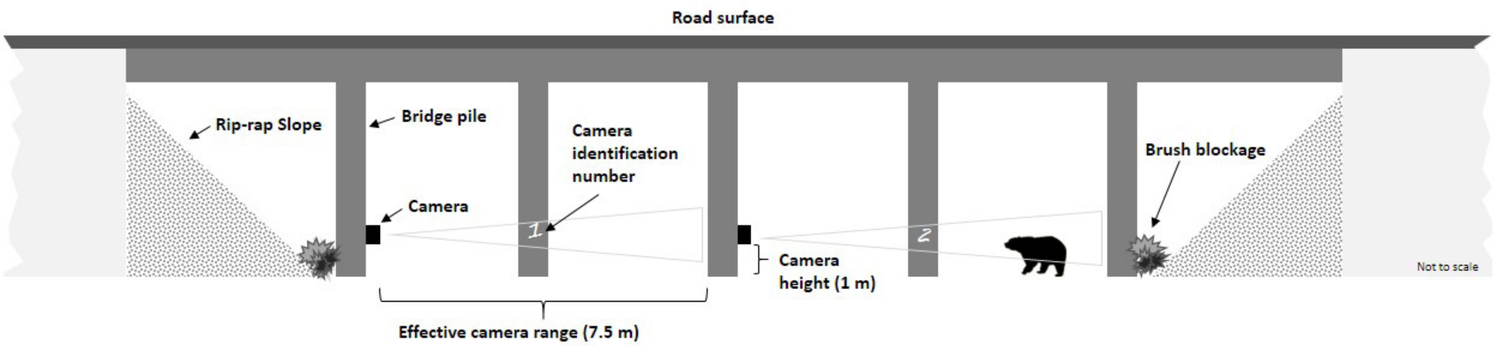

Figure 2. Schematic view of arrangement of trail cameras used to monitor activity of American black bears (*Ursus americanus*) crossing under bridges along Georgia State Route 96, Georgia.

Throughout the study, we documented incidences of bears killed along roads throughout the CGBP. We investigated reports of road-killed bears provided by the Georgia Department of Natural Resources, local law enforcement agencies, and the general public. In each case, we attempted to locate the site of the road kill and then record the location with a handheld GPS unit. If we found a bear carcass, we collected it, examined it for markings (i.e., ear tags, tattoos, and PIT-tags), documented biological information (e.g., sex and body condition), and collected a premolar for cementum annuli aging, and hair and tissue samples for genetic analysis.

Analysis

We screened GPS data using a multi-step approach to remove potentially erroneous locations. Initially, we plotted data from each bear and removed locations outside the study area or that were otherwise nonsensical. We then removed locations classified as two dimensional (2D) with dilution of precision values (PDOP) >5 (Lewis et al. 2007). Likewise, because GPS location data have inherent error from various sources (D'Eon et al. 2002, D'Eon and Delparte 2005, Frair et al. 2004), we evaluated location error by placing two GPS collars in the field and collecting a minimum of 24 hours of locations while collars remained stationary, using a fix schedule of one location every 20 minutes. We staked test collars in place approximately 0.5 m high with the GPS receiving unit oriented skyward. We placed collars at 20 locations throughout the study area in varied habitat types (e.g., planted pine forest, bottomland hardwood forest, open field, and standing corn crops) and along various topographical features (i.e., ridgelines and drainage bottoms). At each location, we used a handheld GPS unit to acquire ≥100 GPS locations and considered the mean of these locations as the known location. We then estimated average location error by comparing data collected by each collar to each known location.

We visually inspected location data for each bear to identify crossings of SR 96. For each crossing of SR 96, we selected a 24-hour segment of the movement path temporally centered on the crossing event (i.e., 12 hours prior to and 12 hours after crossing). Because some bears had a tendency to spend time directly adjacent to SR 96, collar error made it appear that the bear had crossed the road. Therefore, we considered a bear to have crossed SR 96 only if there were two or more locations and a demonstrated movement path immediately after a crossing event. We used a dynamic Brownian Bridge Movement Model (dBBMM) with function *brownian.bridge.dyn* in package *move* 2.0.0 in R version 3.3.1 to create a 95% utilization distribution (UD) for these 24-hour movement paths (Kranstauber et al. 2012, R Core Team 2016). We incorporated estimates of collar error (10 m) into the dBBMM and set margin and window sizes to 3 and 9, respectively. We intersected the resulting probability distributions with the centerline of SR 96 using ArcMap 10.3.1 (ESRI 2011) resulting in a segment of SR 96 where the crossing most likely occurred (e.g., Figure 3). We then used Geospatial Modeling Environment 0.7.4.0 (GME, Beyer 2015) to estimate crossing locations by generating a random location along the centerline of SR 96 within each of the segments. We pooled locations at which bears were photographed crossing under bridges with the crossing locations from within the UDs.

We used a resource selection function (RSF) approach to evaluate habitat characteristics associated with crossing locations (Manly et al. 2002). We used GME to generate random locations along the centerline of SR 96 within our study area so that each crossing location was paired with a random location. We analyzed habitat selection as a binomial response variable (1 = crossing, 0 = random location) yielding the proportional probability of use of locations (Boyce et al. 2002).

To describe landscape characteristics associated with crossing and random locations, we used ArcMap 10.3.1 to assign landscape variable values to both classes of locations. We selected variables based on their potential to influence bear crossings of SR 96 and

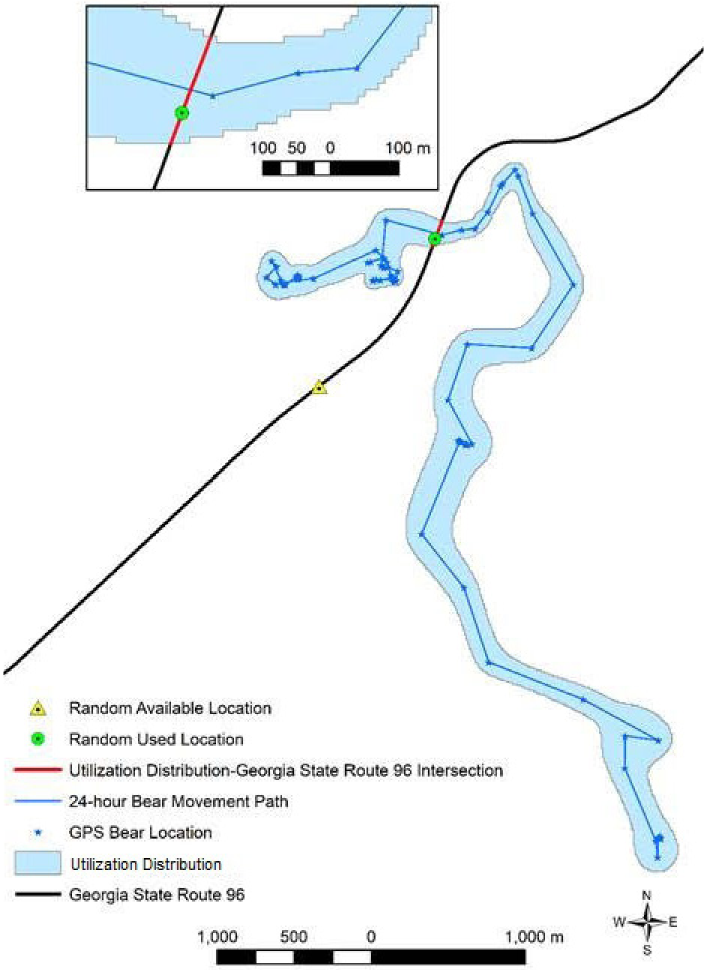

Figure 3. Depiction of method used to define American black bear (*Ursus americanus*) crossings of Georgia State Route 96 using dynamic Brownian Bridge Movement Model utilization distributions derived from 24-hour bear movement paths, Georgia, USA, 2012–2015. USA, 2012–2014.

their relevance to GDOT in placing the proposed underpasses. Previous research has noted that adjacency of forests, habitats used for foraging and travel (e.g., open areas), and riparian areas leading up to highway surfaces can be important predictors of crossing locations (Lewis et al. 1990, Waller and Servheen 2005). Hence, we used World Imagery in ArcMap 10.3.1 and digitized agricultural field edges and the forest edges adjacent to SR96 excluding single trees and narrow tree lines (e.g., rows of trees multiple trees in length but the width of single trees, ESRI Inc. 2011). We used National Hydrography Data to determine where drainages intersected SR 96 (U.S. Geological Survey 2013). We then measured the distance from each location along the SR 96 centerline to the closest forest edge (DIST-FE), the nearest agricultural field (DIST-AF), and the nearest intersection of SR 96 and a drainage (DIST-DI). We also categorized each location on whether it was within either bottomland or upland habitat (BU). To broadly categorize lands adjacent to SR 96 as either bottomland or upland we used 2011 National Land Cover Data (Homer et al. 2015).

We tested for correlation among continuous variables using Pearson's correlation coefficient. We developed a candidate set of RSF models and fit models to our data using a Generalized Linear Mixed Model (GLMM) in R version 3.3.1 with package *lme4* version 1.1-12 (Bates et al. 2015) We modeled individual bears as a random intercept to account for inherent differences in behavior among individual bears. We then ranked candidate models using second-order Akaike's Information Criterion (AIC_c, Burnham and Anderson 2002), and assessed model prediction using *k*-fold cross validation (Boyce et al. 2002). *K*-fold cross-validation partitions data into *k* equal-sized subsamples before performing *k* iterations of validation, ultimately resulting in *k*-1 bins being used for development of a training set. We conducted validation analysis in R 3.3.1 with package *boot* 1.3-20 and used a *k* of 10 (Canty and Ripley 2017). We used *k*-fold cross validation as it offers the advantage of using all observations for training and testing.

Results

We tracked 63 bears (33M:30F) fitted with GPS collars across 8,965 bear-tracking days during 2012–2015. Collectively, we observed that bears used habitats adjacent to the entire 27-km section of SR 96 we studied. Qualitatively, we noted that bear movements and space use were truncated by SR 96. We observed that 38 bears (60.3%, 17M:21F) entered the virtual fence (i.e., within 250 m of SR 96) long enough to generate at least one GPS location. However, only 11 GPS-collared bears (7M:4F) crossed SR 96 ($n = 210$ crossings, range = 1–114) and eight bears crossed four or fewer times. Two males accounted for 182 (86.7%) crossings. Of bears that crossed SR 96 and were monitored for multiple years ($n = 3$, 1M:2F), all crossed the highway in some years but not others. For instance, one female maintained a home range directly adjacent to SR 96 and crossed the highway four times during fall 2012 but did not cross again despite being monitored until the end of summer 2014.

Only two bears were photographed crossing beneath bridges along SR 96. A male bear was photographed beneath Bridge 5 in October 2012, and a female bear was photographed beneath Bridge 1 in October 2014. Only one bear, of undetermined sex, was photographed one time at a culvert: in 2012 approaching the mouth of the culvert. The bear did not appear to enter the culvert, however, and subsequent inspection of the substrate within the culvert revealed no bear tracks.

We noted that the greatest concentration of crossings, both numbers and individual bears that crossed, occurred near Tarv-

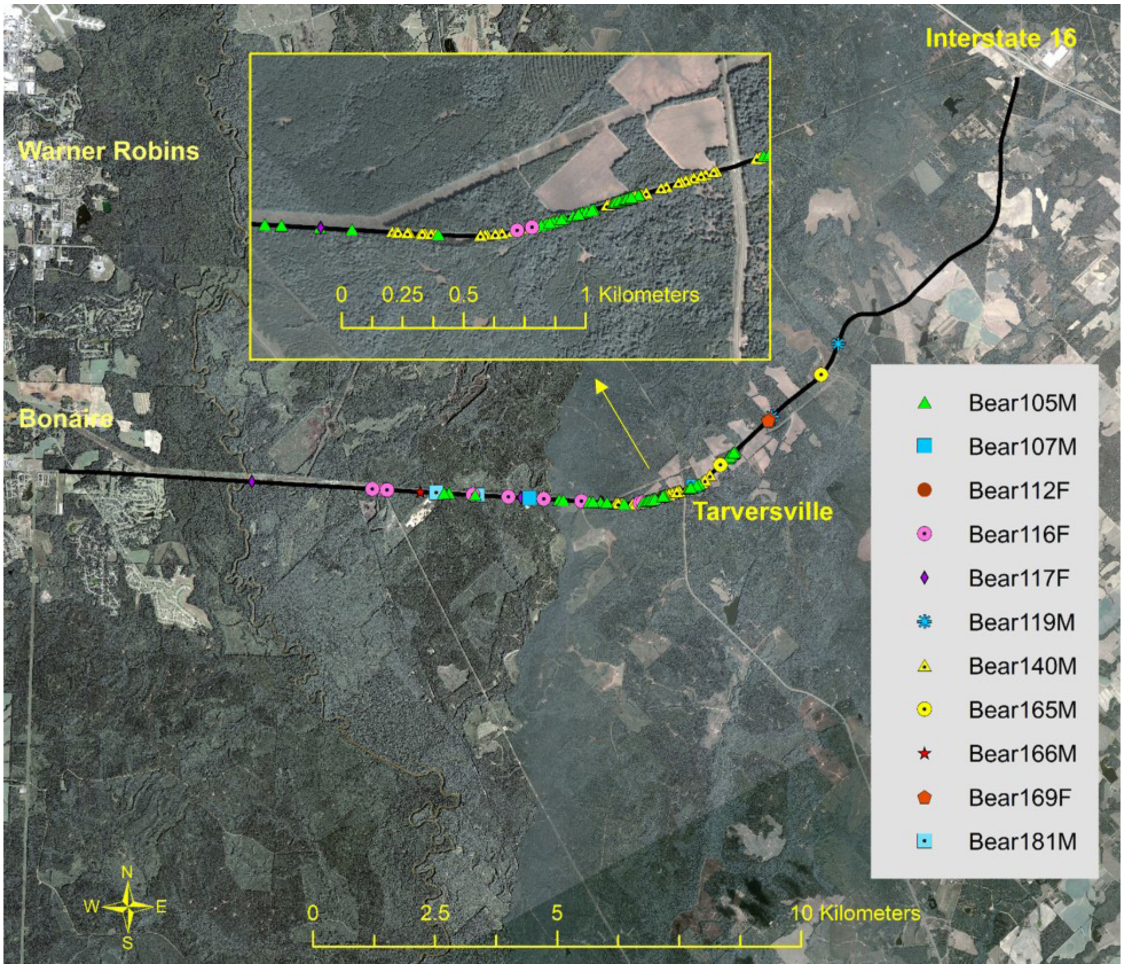

Figure 4. Segment of Georgia State Route 96 (black line) with locations where 11 GPS-collared American black bears (*Ursus americanus*) crossed near Tarversville, Georgia, USA, 2012–2015. Inset shows concentrations of locations along one segment west of Tarversville.

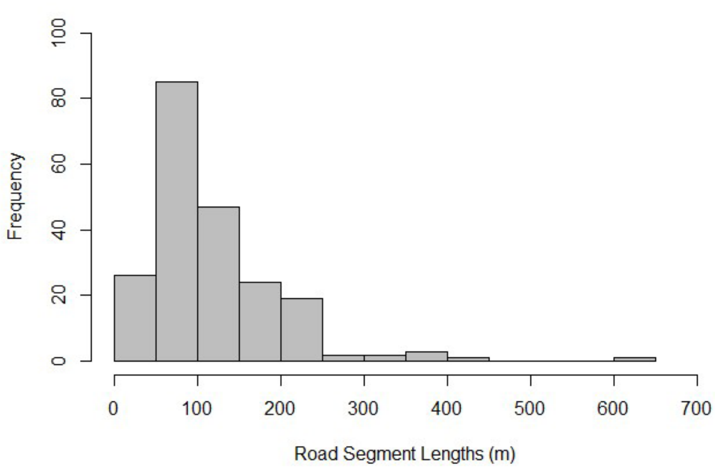

Figure 5. Histogram of lengths of 210 highway Georgia State Route 96 segments derived from utilization distributions estimated from dynamic Brownian bridge movement model analysis of American black bear (*Ursus americanus*) movement paths used to characterize bear highway crossings, Georgia, 2012–2015.

ersville and the intersection of SR 96 and SR 87 (Figure 4). The highway segments identified by intersecting the dBBMM 95% UDs with SR 96, (i.e., segments within which crossings by GPS-marked bears most likely occurred) ranged from 10 to 604 m, with a median of 93 m (Figure 5).

We observed only moderate correlation (r = -0.43) between two of three continuous variables so we retained all three variables. The global model was the most parsimonious and carried the most model weight (w_i > 0.99, Table 1). Cross validation yielded a classification rate of 0.80, suggesting that the global model had suitable power to distinguish between crossing and random locations. All fixed-effect parameter estimates were significant, with 95% confidence intervals not bounding zero. We found that bears were 4.35 (95% C.L. = 1.14–16.66) times as likely to cross SR 96 in upland habitats compared to lowland habitats (Table 2). Likewise, for every 10 m decrease in distance from SR96 to drainage intersections, agriculture fields, and forest edges, bears were 1.127 (95% C.L. = 1.063 – 1.195), 1.209 (95% C.L. = 1.140 – 1.282), and 48.911 (95% C.L. = 18.000 – 132.900) times as likely to cross SR 96.

Table 1. Akaike's Information Criterion with small sample size adjustment (AIC_c), number of parameters (K), ΔAIC_c, adjusted Akaike weight of evidence (w_i), and log-likelihood (LL) for candidate models generated using general linear mixed-effect models relating habitat variables to proportional probability of individual American black bears (*Ursus americanus*) crossing Georgia State Route 96, Georgia, 2012–2015.

Model	LL	K	AIC_c	ΔAIC_c	w_i
BU[a] + DIST-AG[b] + DIST-DI[c] + DIST-FE[d]	−179.49	6	371.19	0.00	0.999229
BU + DIST-AG + DIST-FE	−188.37	5	386.88	15.69	0.000391
DIST-AG + DIST-FE	−189.42	4	386.94	15.75	0.000380
BU + DIST-FE	−204.58	4	417.26	46.07	0.000000
DIST-FE	−207.48	3	421.02	49.83	0.000000
Null[e]	−293.89	2	591.82	220.63	0.000000

a. Categorical habitat variable; bottomland or upland forest (reference category)
b. Continuous variable; distance to agriculture field
c. Continuous variable; distance to drainage intersection with Georgia State Route 96
d. Continuous variable; distance to forest edge
e. Random effect (i.e., bears) only

Table 2. Parameter estimates of landscape-level variables from top-performing model (i.e., the global model with lowest AICc) used to predict crossings of Georgia State Route 96 by American black bears (*Ursus americanus*), Georgia, 2012–2015.

Parameter	Estimate	Std. Error	Z	P
BU[a]	−1.470	0.685	−2.146	0.032
DIST-DI[b]	−0.012	0.003	−4.025	<0.001
DIST-AF[c]	−0.019	0.003	−6.035	<0.001
DIST-FE[d]	−0.389	0.051	−7.550	<0.001

a. Categorical habitat variable; bottomland or upland forest (reference category)
b. Continuous variable; distance to drainage intersection with Georgia State Route 96
c. Continuous variable; distance to agriculture field
d. Continuous variable; distance to forest edge

During 2012–2014, we investigated 23 reports of bears struck by vehicles throughout the geographic extent of the CGBP. We confirmed mortality in 20 cases (87.0%, 15M:5F) and documented three instances (13.0%) where a bear was struck but no carcass was located. In two of tge three cases in which no carcass was located, we were able to use GPS location data or microsatellite genotyping of hair collected from a vehicle to identify the bears involved (1M:1F). Twenty-two of the cases involved bears of known identity; of those, five (22.7%) involved bears we had previously live-captured. Only five (21.7%, 3M:1F:1unk.) vehicle-bear collisions occurred on SR 96; the remainder occurred on several other highways in central Georgia: eight (34.8%, 5M:3F) on SR 87, four (17.4%, 4M) on SR 247/247 spur, four (17.4%, 3M:1F) on I-16, one (0.04%, 1M) at the Interstate 75/475 interchange south of Macon, and one (0.04%, 1F) on Moody Road within Bonaire.

Discussion

Roads can have substantive effects on wildlife populations through mortality (Ramp et al. 2005), habitat fragmentation and loss (Nielsen et al. 2006), connectivity and barrier effects (Bhattacharya et al. 2003), and changes to individual movements (Jaeger et al. 2005). Likewise, the ability for individuals within a wildlife population to move freely can influence aspects of population structure (Bowne and Bowers 2004). We noted that bear movements and ranges adjacent to SR 96 were typically bounded by the forest edge at highway verge or the forest edge adjacent to the right-of-way that paralleled SR 96. Notably, most bears we monitored did not cross the highway, and those that did only crossed sporadically. Of the bears we documented crossing SR 96, most crossed few times and of those we tracked for multiple years, all crossed in some years but not others. Likewise, we observed that bear crossings of SR 96 were concentrated within a 2.5-km segment (i.e., 9.3% of the 27 km we monitored); this segment contained 167 of 212 (78.8%) of crossings we documented, but these crossings were made by only seven bears (4M:3F). The three females that crossed within this segment did so after traveling distances of 3–5 km away from their apparent home ranges. This 2.5-km segment of SR 96 also contained the locations of three of the five (60.0%) bear-vehicle collisions we investigated on SR 96 and has historically been the location of previous vehicle-bear collisions (B. Bond, Georgia Department of Natural Resources, unpublished data).

Spatial clustering of locations where wildlife cross highways is generally related to topographic and habitat characteristics along highway corridors and rights-of-way (Bissonette and Adair 2008). Previous studies have noted that crossing locations used by bears are clustered at relatively small spatial scales (Waller and Servheen 2005), which is an important consideration given the vagility and allometric scaling exhibited by bears (McNab 1963, Bissonette and Adair 2008). We noted that 4 km of the 27-km study area along SR 96 was in bottomland forest, but only three crossings occurred in this road segment, and each crossing was by a different bear (1M:2F). Each bear crossed SR 96 via a different underpass and we documented no bears crossing the SR 96 road surface where the highway bisected bottomland forest habitats. Most of the 4-km segment of SR 96 that crossed bottomlands (i.e., the Ocmulgee River flood plain) was upon a steep-sided levee, overgrown with thick stands of species such as greenbrier (*Smilax* spp.) and cane (*Arundinaria tecta*), creating a barrier between the road-side forest and SR 96 (Forman and Alexander 1998). Along the base of the levee, especially near SR 96 bridges, we observed game trails that likely directed animal movement toward the underpasses as opposed to across the surface of the highway. Our camera surveys under SR 96 bridges revealed extensive use of these trails and underpasses by white-tailed deer (*Odocoileus virginianus*) and feral pigs (*Sus scrofa*), but we only detected three bear crossings. This small number of bear crossings, relative to the number of bear crossings observed in upland habitats, was likely reflective of broader patterns of habitat selection by bears on our study area, as Hooker (2017) noted little use of bottomlands throughout the CGBP by GPS-collared bears. Bottomland habitats in our study area often flooded extensively during winter and spring, and foods used by bears in summer and fall (e.g., blackberry and dewberry [*Rubus* spp.], agricultural crops} during our monitoring of bear crossings of SR 96 were primarily found in upland habitats.

The juxtaposition and adjacency of cover to highways may influence locations where wildlife crossings occur (McLellan and Shackleton 1988, Cain et al. 2003). Indeed, previous authors have noted that adjacency to forest cover positively influenced highway crossings by grizzly bear (*Ursus arctos*; Waller and Servheen 2005), and elk (*Cervus elaphus*; Clevenger and Waltho 2005). Lewis et al. (2011) suggested that shorter distance to forest cover facilitated road crossings by black bears in Idaho but postulated that such relationships may not be apparent on landscapes where little variability existed in distances between the highway surface and the edges of forest cover. We noted that distances between forest cover and the surface of SR 96 were highly variable (mean = 37.7 m, SD = 48.1 m), yet clearly distance between the highway and the nearest forest edge influenced where bears crossed SR 96. Although highly adaptable, black bears are ultimately a forest species (Pelton 2003), as cubs are adapted to climbing in response to threats and all ages of bears use forest structure to feed and loaf (Herrero 1972).

Bears are periodically struck and killed on SR 96, but we documented highway crossings by 29% of bears that maintained home ranges adjacent to, or overlapping, the highway corridor. Our findings suggest that the vehicle collisions with bears on SR 96 do not represent an excessive source of mortality for the CGBP, at least when compared to other highways in Central Georgia and to other sources of mortality such as harvest (which totaled 19 bears [8M:11F] during the time period of this study [B. Bond, Georgia Department of Natural Resources, unpublished data]). We documented 20 bears being killed by vehicles in central Georgia with four (20%) being killed on SR 96.

Although roads can fragment wildlife populations and contribute to reduced gene flow (Epps et al. 2005), the creation and maintenance of highway crossing structures can facilitate gene flow and improve admixture (Sawaya et al. 2014). Hooker et al. (2019) has already documented low genetic diversity and evidence of long-term genetic isolation and drift in the CGBP, hence it is important to consider future genetic viability in the CGBP once construction of SR96 is complete. The principle of >10 migrants to a population per generation to maintain a healthy genetic pool (Vucetich and Waite 2000)—or even more conservative estimates of one migrant per generation (Mills and Allendorf 1996)—suggest it is unlikely that SR 96 (prior to the planned widening) was a substantial barrier to gene flow. Indeed, van Manen et al. (2012) suggested that crossing rates similar to those we observed were sufficient to maintain genetic connectivity across a newly-widened highway in North Carolina though they cautioned that their research was conducted immediately after highway widening occurred and was not a long-term analysis. Because bears are long-lived with slow reproductive rates, effects of roads on genetic integrity and gene flow could take longer to detect (Sheperd et al. 2008). Although we documented a few male and female bears successfully crossing SR 96, future work should quantify whether these periodic crossings equate to sufficient gene flow to ensure a sustainable bear population in the CGBP.

Management Implications

We recommended that GDOT eliminate proposed underpasses 3 and 5 from the SR 96 widening plan because these underpasses were to be located in areas that either received little use by GPS-collared bears or had less suitable habitat features for bears. Furthermore, we recommended that GDOT add a new underpass to the proposed project in a 2.5-km segment where we noted a high incidence of bear-crossing activity (blue arrow, Figure 6). We also recommended that GDOT ensure the highway verge was mowed and free of forest between underpasses, thus encouraging bears to travel the forest edge toward underpasses as opposed to crossing on the highway surface. GDOT adopted all three of these recommendations. We recommend future research focus on monitoring potential changes to bear crossing rates of SR 96 after completion of the widening project. If bears fail to use highway underpasses, widening of the highway could frustrate movements of bears maintaining home ranges along SR 96. Conversely, increased movements across the highway corridor associated with highway underpasses could help prevent division of the CGBP.

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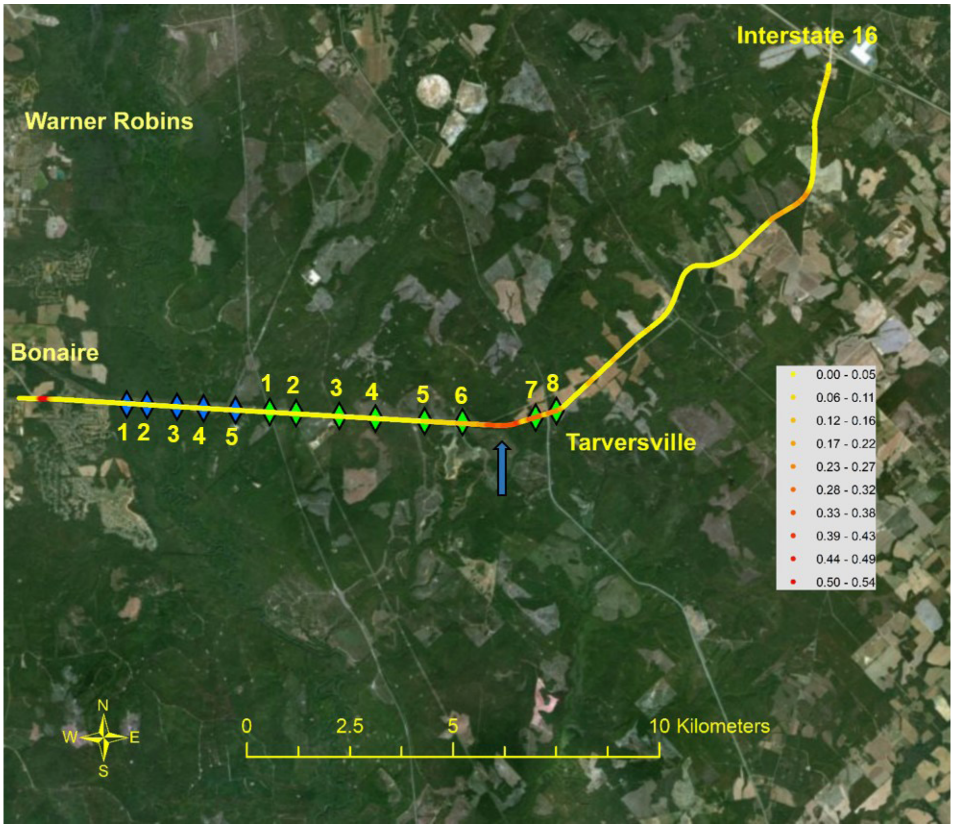

Figure 6. Segment of State Route 96 (yellow-red shaded line) used to evaluate American black bear (*Ursus americanus*) highway crossings with existing underpasses (blue diamonds) and proposed underpasses (green diamonds), Georgia, 2012–2015. Line shading indicates relative probability of a highway location having characteristics consistent with being a bear crossing.

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