GEORGIA DOT RESEARCH PROJECT 11-29

FINAL REPORT

Efficacy of Road Underpasses for Minimizing Bear-Vehicle Collisions on the 4-Lane Section of Georgia Highway 96 – Phase I

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16. Abstract:
The Central Georgia Bear Population, the smallest of Georgia's three populations of American black bear (*Ursus americanus*), is of special concern due to its size and potential isolation from other bear populations. Plans to widen Georgia State Route 96 (SR 96), which bisects the Central Georgia Bear population, has potential to negatively impact the population. Highway underpasses are being planned to mitigate these impacts. During 2012-2014, we used global-positioning-system (GPS)-tracking and remote, infrared trail cameras to document bear crossings along SR 96. We evaluated landscape characteristics associated with 212 (210 by GPS-collared bears plus two photographs) crossings using a resource selection function approach and generalized linear mixed-models. Distance between SR 96 and forest edge was positively associated with bear crossings. Bear crossings were generally concentrated with 169 (79.7%) crossings generated by seven bears occurring within a 3-km segment of SR 96. Based on our research results and evaluation of habitat features, we recommended placing underpasses in these locations and eliminating two underpasses that had been planned at locations along SR 96 that either received very little use by our GPS-collared bears or had less suitable habitat for bears. We also recommended eliminating the proposed fencing design alongside the roadway because it was not likely to decrease the potential of bears accessing the roadway. Furthermore, the fencing had the potential for allowing bears to become "entrapped" within the highway right-of-way, which might increase the chance of a bear-vehicle collision if a bear was unable to easily escape the roadway because of the fencing. Rather than fencing, we recommended that vegetation management be used to connect underpass openings to forest edges along the highway rights-of-way. Georgia Department of Transportation adopted our recommendations and saved $1.18 million on the future construction costs for this project.

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FINAL PROJECT REPORT

GEORGIA DOT RESEARCH PROJECT 11-29

EFFICACY OF ROAD UNDERPASSES FOR MINIMIZING BEAR-VEHICLE COLLISIONS ON THE 4-LANE SECTION OF GEORGIA HIGHWAY 96 – PHASE 1

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EXECUTIVE SUMMARY

Phase I research was directed at learning more about how bears interact with State Route 96 (SR 96) and determining locations where underpasses might be used by bears to safely cross the highway corridor. This research is particularly timely because GDOT plans to widen SR 96 into a four-lane divided highway and is mandated to investigate potential ecological impacts. Because bear-vehicle collisions occur annually on SR 96, the widening project plan includes installation of underpasses to reduce wildlife-vehicle collisions while allowing wildlife movement across the highway corridor. At the request of the GDOT, Phase I 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, evaluate habitat and landscape features associated with crossing locations, and quantify incidence of bear roadkill on SR 96 as well as other nearby roads in central Georgia.

During summers 2012-2014, we monitored 63 bears affixed with Global Positioning System (GPS) radio collars along a 27-km section of SR 96 within Houston and Twiggs Counties, Georgia. Most of the GPS-collared bears (52 of 63; 83%) did not cross the highway. The home ranges and movements of several bears were clearly defined by SR 96; the home ranges of several instrumented bears were actually truncated by the highway right-of-way. Of the 11 GPS-collared bears that did cross SR 96, frequency of crossings was sporadic and concentrated within a 2.5-km segment of SR 96 that bordered upland forest habitat. These 11 GPS-collared bears crossed SR 96 210 times during our three years of monitoring, but two of these 11 bears accounted for 182 of the 210 crossings (87%); both of these bears were killed in bear-vehicle collisions.

Roadway crossings by bears were influenced significantly by habitat features along the road edges. Fewer bear crossings occurred where bottomland hardwood forests bordered SR 96. We observed an overall increase in bear crossings on sections of SR 96 located closer to forest edge, agriculture fields, and intersections of drainages. Distance to forest edge was the most important factor determining the likelihood of bear crossings.

During summer and fall 2012 and 2014, we used infrared trail cameras to monitor wildlife activity under four of five existing bridges along SR 96 and at one end of culverts large enough to allow passage of a bear. Only 2 bears were photographed crossing beneath SR 96 bridges and only one bear was photographed as it crossed at a culvert.

During the study, we documented 23 incidences of bears being struck by vehicles in central Georgia, of which five occurred on SR 96. SR 96 does not appear to be a major source of mortality for bears, at least when compared to other highways in central Georgia and to other sources of mortality such as hunter harvest.

We met with GDOT officials on 13 November 2014 to discuss fencing and vegetation management along SR 96 and how to minimize the likelihood of bears accessing the roadway. Based on the evaluation of our road-crossing data and bear behavior, we reported to GDOT on 17 December 2014 with recommendations of eliminating the proposed fencing design alongside the roadway because it was not likely to decrease the potential of bears accessing the roadway. Furthermore, the proposed fence design had the potential for allowing bears to become "entrapped" within the highway right-of-way, which might increase the chance of a bear-vehicle collision if a bear was unable to easily escape the roadway because of the fencing. Rather than fencing, we recommended that GDOT use vegetation management to ensure connectivity between the forest edge and the openings of all current and future SR 96 underpasses. We also recommended routine mowing of vegetation on the right-of-way between the highway underpasses to help "funnel" bears along the forest edge toward underpasses.

We subsequently met with GDOT officials on 13 February 2015 to review the proposed locations of wildlife underpasses along SR 96. Based on our initial results of bear movement data, we reported to GDOT on 5 March 2015 and recommended the elimination of two of the proposed bridges because these locations were in areas that either received very little use by our GPS-collared bears or had less suitable habitat features for bears. Furthermore, we recommended that GDOT add a new bridge to the proposed project in an area along a 1-km segment of SR 96 where we noted suitable bear habitat and a high incidence of bear-crossing activity. GDOT adopted all three of these recommendations and saved $1.18 million on the future construction costs for this project by removal of the fencing, gates, and one of the bridges (personal communication, GDOT Design Group Manager).

DISSERTATIONS RESULTING FROM PHASE I:

Hooker, M. J. 2016. Movement, genetic structure, and space use of central Georgia black bears as influenced by a highway corridor. Ph.D. Dissertation. University of Georgia, Athens, Georgia, USA.

ORAL PUBLICATIONS RESULTING FROM PHASE I:

Hooker, M. J., M. J. Chamberlain, K. V. Miller, and R. J. Warren, 2012. Efficacy of road underpasses for minimizing bear-vehicle collisions on the 4-lane section of Georgia 96 – Phase I. Georgia Department of Natural Resources Wildlife Management Division and Warnell School of Forestry and Natural Resources Joint Research Meeting. Macon, Georgia, USA. 28 June 2012.

Hooker, M. J., C. A. Gray, and J. T. Sylvest. 2013. UGA bear project. Kiwanis International Speaker Series. Athens, Georgia, USA. 19 March 2013.

Hooker, M. J., M. J. Chamberlain, K. V. Miller, and R. J. Warren. 2013. Efficacy of road underpasses for minimizing bear-vehicle collisions on the 4-lane section of Georgia 96 – Phase I. Georgia Chapter of The Wildlife Society. Athens, Georgia, USA. 06 September 2013.

Hooker, M. J., M. J. Chamberlain, K. V. Miller, and R. J. Warren. 2014. Highway-related movement of American black bear (*Ursus americanus*) in central Georgia. 23th International Conference on Bear Research and Management. Thessaloniki, Greece. 5 – 11 October 2014.

Hooker, M. J., M. J. Chamberlain, K. V. Miller, R. J. Warren, A. K. Ashley, C. A. Gray, and J. T. Sylvest. 2016. Central Georgia bear project. Georgia Department of Natural Resources Wildlife Management Division and Warnell School of Forestry and Natural Resources Joint Research Meeting. Mansfield, Georgia, USA. 10 August 2016.

POSTER PRESENTATIONS RESULTING FROM PHASE I:

Hooker, M. J., M. J. Chamberlain, K. V. Miller, and R. J. Warren. 2013. Efficacy of road underpasses for minimizing bear-vehicle collisions on the 4-lane section of Georgia 96 – Phase I. Georgia Department of Transportation / Georgia Transportation Institute Annual Poster Session. Atlanta, Georgia, USA. 24 September 2013.

Hooker, M. J., M. J. Chamberlain, K. V. Miller, and R. J. Warren. 2014. Identifying American black bear (*Ursus americanus*) highway crossings in central Georgia, USA. Georgia Department of Transportation / Georgia Transportation Institute Annual Poster Session. Atlanta, Georgia, USA. 23 September 2014.

Hooker, M. J, C.A. Gray, and M. J. Chamberlain. 2015. An observation of pyoderma (bacterial dermatitis) in a neonate black bear (*Ursus americanus*) from central Georgia, USA. 22nd Eastern Black Bear Workshop. Louisville, Mississippi, USA. 26 – 29 April 2015.

Hooker, M. J and M. J. Chamberlain. 2015. Highway related movement of American black bear (*Ursus americanus*) in central Georgia. 22nd Eastern Black Bear Workshop. Louisville, Mississippi, USA. 26 – 29 April 2015.

Hooker, M. J., M. J. Chamberlain, K. V. Miller, and R. J. Warren. 2016. Identifying American black bear (*Ursus americanus*) highway crossings in central Georgia, USA. 24th International Conference on Bear Research and Management. Anchorage, Alaska, USA. 13 – 16 June 2016.

IDENTIFYING AMERICAN BLACK BEAR (*URSUS AMERICANUS*) HIGHWAY CROSSING LOCATIONS IN CENTRAL GEORGIA, USA

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Overview

The Central Georgia Bear Population (CGBP), the smallest of Georgia's three populations of American black bear (*Ursus americanus*), is of special concern due to its size and potential isolation from other bear populations. Plans to widen Georgia State Route (SR) 96, which bisects the CGBP, has potential to negatively impact the population. Highway underpasses are being planned to mitigate these impacts. During 2012-2014, we used global-positioning-system (GPS)-tracking and remote, infrared trail cameras to document bear crossings along SR 96. We evaluated landscape characteristics associated with 212 (210 by GPS-collared bears plus two photographs) bear crossings using a resource selection function approach and generalized linear mixed-models. Distance between State Route 96 and forest edge was positively associated with bear crossings. Bear crossings were generally concentrated with 169 (79.7%) crossings generated by seven bears occurring within a 2.5-km segment of SR 96. We recommend placement of an underpass within this segment. Likewise, we recommend that vegetation management be used to connect underpass openings to forest edges along the highway rights-of-way.

Introduction

The CGBP black bear population has an estimated 240 animals inhabiting about 450 km^2 of forested land along the Ocmulgee River, roughly 150 km southeast of Atlanta (Hooker et al. 2015, Fig. 1). This area is almost completely surrounded by human development and fragmented agricultural land. Relatively low abundance and potential isolation from other bear populations make conservation of the CGBP of special concern. The CGBP is separated from the two other Georgia bear populations by distances of ~150 km (Hooker et al. 2015:107), resulting in frustrated dispersal and poor connectivity among the populations. Between the CGBP and the

North Georgia Bear Population is the city of Atlanta, characterized by considerable urban sprawl and several interstate highways. Extensive tracts of agricultural properties with sparse forest cover lie between the CGBP and the bear population in South Georgia. Although bears are occasionally reported in areas between the three populations, the level of demographic and genetic separation among these populations is uncertain.

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, McCown et al. 2004), 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, have been shown to impact wildlife populations negatively in a number of ways. There is 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 2003, 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 (e.g., Florida panther [*Puma concolor coryi*]; Maehr et al. 1991, Foster and Humphrey 1995, bobcats [*Lynx rufus*]; Litvaitis et al. 2015, Poessel et al. 2014,ocelot [*Leopardus pardalis*]; Haines et al. 2005, American black bear; Brody and Pelton 1989, Wooding and Maddrey 1994, grizzly bears [*Ursus arctos*]; Waller & Servheen, 2005 and wolves [*Canis lupus*]; Mech 1989).

The United States contains an estimated 6.7 million km of roads (Federal Highway Administration 2014). Furthermore, it is estimated that the ecology of approximately one fifth of the country's total area is affected by roads (Forman 2000, Cerulean 2002). 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 et al. 1996, Romin and Bissonette 1996.)

Since the 1970s, wildlife managers and road engineers in the United States have increased efforts to develop and test 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 allow wildlife to pass beneath the road.

Bisecting the area inhabited by the CGBP is SR 96, a two-lane highway with an average 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 to investigate potential ecological impacts. Because bear-vehicle collisions occur annually on SR 96, the widening project plan includes installation of underpasses to reduce wildlife-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, evaluate 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 (Fig. 2). 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.), natural pine, and mixed pine-hardwood in the uplands. Common overstory tree species included loblolly pine (*Pinus taeda*), red and white oaks (*Quercus* ssp.), sweetgum (*Liquidambar styraciflua*), red maple (*Acer rubrum*), American beech (*Fagus grandifolia*), yellow poplar (*Liriodendron tulipifera*), water tupelo (*Nyssa aquatica*), and bald cypress (*Taxodium distichum*). Clear-cutting, tree thinning, and prescribed burning of the understory were common forestry practices in the study area.

Most forest land in the area was managed for seasonal, recreational hunting. Common large and medium-sized mammals included white-tailed deer (*Odocoileus virginianus*), feral pigs (*Sus scrofa*), black bear (*Ursus americanus*), coyote (*Canis latrans*), grey fox (*Urocyon cinereoargenteus*), bobcat (*Lynx rufus*), raccoon (*Procyon lotor*) opossum (*Didelphis virginianus*) and armadillo (*Dasypus novemcinctus*).

The Ocmulgee River flowed through the study site from north to south and was a defining geographical feature. Nearby human population centers included Macon (pop. 91,234), Warner Robins (pop. 72,531), Bonaire (pop. 13,999), Cochran (pop. 5150), and Hawkinsville (pop. 4589, U.S. Census Bureau 2010). Much land west of the study area was dominated by human development, whereas land to the south and east was primarily agricultural land. Major crops included cotton (*Gossypium hirsutum*), corn (*Zea* ssp.), peanut (*Arachis hypogaea*), sorghum (*Sorghum* ssp.) and other grain crops.

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 (Fig. 3). 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 bridges within this section of highway. There were numerous culverts of various design along SR 96, but only three were large enough to allow bears to pass beneath the highway (Fig. 4).

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. Paralleling 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 <1m. The western half of the right-of-way was approximately 140 m wide whereas the eastern half was 55 m.

Methods

GPS Tracking

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, USA) to attract bears to the snares. We focused our trapping efforts within the SR 96 corridor (i.e., within ~2 km either side of the highway) and along the full 27 km of SR 96 we defined as our study area. We anesthetized captured bears with Telazol® or large animal xylazine (100mg/ml) combined with Telazol®. We reversed bears anesthetized with XZT using atipamazol hydrochloride (Antisedan®) 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®), 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-cutaneous 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, 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 the collar (i.e., a collared bear) was within the area outlined by the virtual fence, the GPS location acquisition rate increased to one location every 5 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, GA and the intersection of SR 96 and GA 358, south of Jefferson, GA (Fig. 5). All location data were transmitted to a desk-top base station via GSM and stored.

Collar battery life is a function of many variables, including location acquisition rate. A more intense acquisition rate depletes batteries faster and shortens functional longevity. 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).

Camera Surveys

During summer and fall 2012 and 2014, we used infrared trail cameras (Bushnell®, 5.0 Megapixel Trophy Cam) to monitor wildlife activity under four of five SR 96 bridges and at one end of culverts 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 (Fig. 6).

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, and located painted numbers so they were visible in photographs. If a pile was not visible, such was the case at culverts, then we staked a numbered sign in front of the camera. We programmed each camera to take three photographs at 1-second intervals each time the camera was triggered. Following the third photograph in a series, cameras paused for 1 min before being capable of being triggered again. All photographs contained a date and time stamp.

Road kill Monitoring

Throughout the course of our study, we documented incidences of bears being killed along roads throughout the CGBP. We investigated reports of road-killed bears given to us by the Georgia Department of Natural Resources, local law enforcement agencies, and members of the general public. In each case, we attempted to locate the site of the road kill and record it with a handheld GPS unit. If a bear carcass was located, 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. Initially, we plotted each bear's data and removed locations that were outside the study area or otherwise nonsensical. We then removed locations classified as two dimensional (2D) with dilution of precision values (PDOP) >5 (Lewis et al. 2007). Likewise, GPS location data have inherent error from a number of sources (D'Eon et al. 2002; D'Eon and Delparte 2005; Frair et al. 2004), so we evaluated location error by placing GPS collars in the field and collecting a minimum of 24 hours of locations while collars remained stationary. We staked test collars in place approximately 0.5 m high with the GPS receiving unit oriented skyward. We placed collars 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 test collar, we used a handheld GPS unit to acquire ≥100 GPS locations and considered the average of these locations the known location of the test collar. We then estimated collar error by comparing location data collected by each collar to each respective collar's 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 bear's movement path temporally centered on the crossing event (i.e., 12 hours prior to crossing 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. We therefore 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) to create a 95% utilization distribution (UD) for these 24-hour movement paths (Kranstauber et al. 2012). We intersected the resulting probability distributions with the centerline of SR 96 using a Geographic Information System (GIS, ArcGIS 2011) resulting in a segment of SR 96 where the crossing most likely occurred. We then used Geospatial Modeling Environment (GME, Beyer 2015) to generate a random point 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 points along SR 96 within our study area so that each crossing point was paired with a random point. 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 ArcGIS 10.0 to assign landscape variable values to both locations. We selected variables based on their potential to influence bear crossings of SR 96, and their potential to be of use to GDOT in placing and designing underpasses. First, we measured the distance from each location to the closest forest edge (DIST-FE), excluding single trees and narrow tree lines (i.e., rows of trees multiple trees in length but only the width of single trees). We also measured distance from each location to agricultural fields (DIST-AF), and to the intersection of SR 96 and major drainages (DIST-DI). We also categorized each location on whether it was within either bottomland or upland habitat (BU). We tested for correlation among continuous variables using Pearson's Chi square.

We developed a candidate set of RSF models and fit models to our data using a General Linear Mixed Model (GLMM). We modeled individual bears as a random effect to account for inherent differences among individual bears (e.g., age and experience crossing roads). 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).

Results

We captured and GPS-tracked 63 bears (33 male [M]:30 female [F]) for a total of 8,965 bear-tracking days. Combined, these bears exhibited use patterns all along the 27-km section of SR 96 we studied. Qualitatively, bear locations demonstrated that home ranges and movement patterns were clearly influenced by SR 96 (Fig. 7). From spring 2012 through winter 2014–2015, 38 bears (60.3 %, 17M:21F) were within the virtual fence (i.e., within 250 m of SR 96) long enough to derive at least one GPS location. However, only 11 GPS-collared bears (7M:4F) crossed SR 96 210 times (Table 1) and eight bears crossed four or fewer times each. Two males (Bears 105 and 140) accounted for 182 (86.7%) of the 210 total crossings. Of bears that crossed

SR 96 and were tracked for multiple years (n = 3, 27.3 %, [1M:2F]), all crossed the highway in some years but not others. For instance, Bear 117 maintained a home range directly adjacent to SR 96 and crossed the highway four times during fall 2012, but didn't cross again despite being monitored until the end of summer 2014 (Fig. 8).

Only two bears were photographed crossing beneath SR 96 bridges. A male bear was photographed beneath Bridge 5 in October 2012, and a female bear was photographed beneath Bridge 1 in October 2014. There was only one case of a bear being photographed at a culvert. A bear of undetermined sex was photographed approaching the mouth of Culvert 1 in 2012. It did not appear that the bear entered the culvert and subsequent inspection of the substrate within the culvert revealed no bear tracks.

We noted that bear crossings of SR 96 were concentrated in the central portion of SR 96. The highest concentration, both in number of crossings and number of different bears that crossed, occurred near Tarversville and the intersection of SR 96 and SR 87 (Fig. 9). 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 10.0 m to 604.4 m, with a median of 92.7 m (Fig. 10).

We observed only moderate correlation between 2 of 3 continuous, fixed variables so we retained all three variables (Table 2). The global model was the most parsimonious and carried most model weight ($w_i > 0.99$, Table 3). Cross validation yielded a delta of 0.80, suggesting that the global model had suitable power to distinguish between crossing and random locations. All of the fixed-effect parameter estimates were significant, with 95% confidence intervals not bounding zero. We found that bears were more likely to cross SR 96 in upland habitat types (Table 4). Likewise, we noted an increase in bear crossings on sections of SR 96 closer to forest edge, agriculture fields, and intersections of drainages and SR 96. We found that distance to forest edge was the most influential parameter in the model. Scaled odds ratio for distance to forest edge (0.68) indicated that the occurrence of bear crossings increased 32.2% for every 25 m closer SR 96 was to a forest edge.

During 2012–2014, we investigated 23 reports of bears being struck by vehicles in central Georgia. Seven bears (5M:2F), five bears (3M:2F), and eight bears (7M:1F) were struck and killed in 2012, 2013, and 2014, respectively. In addition, in each year we documented one case where a bear was struck but no carcass was located. In two of these cases, we were able to use GPS location data or microsatellite genotyping of hair collected from a vehicle to identify the bears involved, and 5 (21.7%) cases involved bears we had live-captured. Only five (21.7%, 3M:1F:1unk.) vehicle collisions with bears occurred on SR 96. The remainder took place on several other highways in central Georgia: eight (34.8%, 5M:3F) on SR 87, four (17.4%, 4M) on SR 247/247spur, four (17.4%, 3M:1F) on I-16, one (0.04%, 1M) at the Interstate 75/475 interchange south of Macon, GA, and one (0.04%, 1F) on Moody Road within Bonaire, GA.

Discussion

Our findings suggest that bears within the SR 96 corridor are affected behaviorally by the highway. Bear home ranges directly adjacent to SR 96 were clearly bounded by the forest edge at highway verge or the forest edge adjacent to the power line that parallels SR 96. Notably, most bears we tracked near SR 96 did not cross the highway, and those that did cross were typically sporadic in doing so. Of the bears we documented crossing SR 96, most crossed few times and of those that we tracked for multiple years, all crossed in some years but not others. Both bears we documented crossing SR 96 the most (i.e., male Bear 105 and male Bear 140) were struck and killed by vehicles after we were no longer tracking them. Bear 105 was struck and killed on SR 96, whereas Bear 140 was struck on a highway intersecting SR 96.

Bear crossings of SR 96 were concentrated within a 2.5-km segment (i.e., 9.3% of the 27 km we monitored) that contained 167 of 212 (78.8%) crossings made by 7 of 11 bears that crossed (63.6%, 4M:3F). The three females that crossed within this segment did so after traveling distances of roughly 3-5 km away from their apparent home ranges. This 2.5-km segment of SR 96 also contained the locations of three of five (60.0%) vehicle-bear collisions we investigated, and has historically been the location of vehicle-bear collisions (B. Bond, Georgia Department of Natural Resources, unpublished data).

Four of the 27-km study area along SR 96 was in bottomland forest, yet this 4-km segment only contained three bear crossings, each single crossings by an individual bear (1M:2F). Each bear crossed SR 96 under a different bridge and we documented no bears crossing the SR 96 road surface within bottomland forest habitats. Most of the 4-km segment of SR 96 that crosses the bottomlands (i.e., the Ocmulgee River flood plain) is upon a steep-sided levee, overgrown with thick stands of species such as greenbrier (*Smilax* spp.), and cane (*Arundinaria tecta*), which forms a barrier between the road-side forest and SR 96. Along the base of the levee, especially near SR 96 bridges, we observed game trails that likely direct animal movement toward the underpasses as opposed to across the surface of the highway. Our camera surveys under the SR 96 bridges revealed extensive use of these trails and the underpasses by deer and feral pigs, but we only detected the three bear crossings. This diminished number of bear crossings, relative to number of bear crossings we observed in the uplands, is likely related to the fact that we observed little use of bottomlands throughout central Georgia by our GPS-collared bears. Bottomland habitats in our study area often flood during winter and spring, which may in part explain the lack of use. Furthermore, many foods used by bears in summer and fall (coinciding with our monitoring of bear crossings of SR 96) are found primarily in upland habitats (e.g., blackberry and dewberry, agricultural crops).

Although several landscape variables influenced where bears crossed SR 96, the most influential variable was distance between the highway and forest edge (i.e., cover). Previous studies have noted similar relationships for a number of species including grizzly bear (*Ursus arctos*) and elk (*Cervus elaphus*; Clevenger and Waltho 2005, Waller and Servheen 2005). Lewis et al. (2011) suggested that distance to forest cover was positively associated with black bear road crossings. However, they noted that the relationship between road crossings and distance to forest was not as strong as it might be in landscapes where high variability in distance between forest edge and roads occurred, as such variability didn't exist in their study area (Lewis et al. 2011). Conversely, we observed considerable variability in distances between forest edge and road throughout our study area.

Black bears, although highly adaptable, are ultimately a forest species and prefer areas of forest and thick understory (Pelton 2003). While black bears use more open habitats (e.g., agriculture fields and clear-cuts), their use of these features is often restricted to edges near forest cover (Lindzey and Meslow 1977). Black bears are adapted to climbing and from a young age will climb trees in response to threats, as well as to feed and loaf (Herrero 1972). We suspect this adaptation to trees and forest cover may partially explain the correlation we found between bear crossing locations and distance to forest cover. When near or attempting to cross SR 96, bears likely experience stress as a result of the unpredictability of traffic volumes and speeds, human presence, road noise, and vehicle lighting. When encountering these stressors, bears likely prefer to be in or near forest cover.

Although SR 96 appears to influence bear movements within the CGBP, and bears are periodically struck and killed, SR 96 does not create an impermeable barrier to bear movement. We documented highway crossings by 29% of bears that maintained home ranges adjacent to, or overlapping, the highway corridor. Likewise, 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 (B. Bond, Georgia Department of Natural Resources, unpublished data). During 2012 –2014, we documented 20 bears being killed by vehicles in central Georgia with only four (20 %) being killed on SR 96.

From the standpoint of gene flow, the principle of > 10 migrants per generation (Vucetich and Waite 2000) or the even more conservative estimate of one migrant per generation (Mills and Allendorf 1996), suggests that it is unlikely that SR 96 (prior to widening) is a substantial barrier to gene flow within the CGBP. 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. However, they cautioned that their research was conducted immediately after highway widening occurred. Because bears are long-lived with slow reproductive rates, their work may have been conducted too soon following highway construction to detect genetic effects influenced by the highway corridor. Although we documented male and female bears crossing SR 96, future work should quantify whether these periodic crossings actually equate to gene flow within the CGBP.

Management Implications

Based on our results, we recommended the elimination of two of the proposed bridges on SR 96 because these locations were in areas that either received very little use by our GPS-collared bears or had less suitable habitat features for bears. Furthermore, we recommended that GDOT add a new bridge to the proposed project in a 2.5-km segment of SR 96 where we noted suitable bear habitat and a high incidence of bear-crossing activity (Fig. 11). We also recommended eliminating the proposed fencing design alongside SR 96 because it was not likely to decrease the potential of bears accessing the roadway. Furthermore, the proposed fence design had the potential for allowing bears to become "entrapped" within the highway right-of-way, which might increase the chance of a bear-vehicle collision if a bear was unable to easily escape the roadway because of the fencing. Rather than fencing, we recommended that GDOT use vegetation management to ensure connectivity between the forest edge and the openings of all current and future SR 96 underpasses. We also recommend that GDOT ensures that the highway verge be 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 and saved $1.18 million on the future construction costs for this project by removal of the one of the bridges, fencing, and gates (personal communication, GDOT Design Group Manager).

Future research should 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, then the widened highway could exacerbate demographic separation and frustrated movements of bears maintaining home ranges along SR 96. Conversely, increased movements across the highway corridor associated with highway underpasses could help prevent genetic and demographic separation of the CGBP, thereby improving connectivity throughout the population.

Acknowledgments

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Table 1. Black bear crossings of SR 96 documented via GPS-tracking and camera surveys, central Georgia, USA 2012-2014.

Bear	Sex	Dates Tracked/ Date Photographed	Days Tracked	No. of Crossings
105	M	11 June 2012 – 27 February2013, 7 June 2014 – 27 November 2014	434	68
107	M	17 June 2012 – 13 November 2012	149	2
112	F	3 July 2012 – 11 March 2013, 8 May 2013 – 24 November 2013	451	1
116	F	25 July 2012 – 12 November 2012	110	9
117	F	3 August 2012 – 3 March 2013, 8 May 2013 – 12 November 2013, 21 March 2014 – 10 August 2014	542	4
119	M	19 August 2012 – 10 November 2012	83	2
140	M	27 May 2013 – 30 September 2013	126	114
165	M	3 June 2014 – 2 November 2014	152	2
166	M	5 May 2014 – 26 September 2014	113	4
169	F	14 June 2014 – 18 November 2014	157	2
181	M	12 July 2014 – 10 November 2014	121	2
P12[1]	M	4 October 2012	-	1
P14[1]	F	4 October 2014	-	1

[1] Bears P12 and P14 photographed crossing beneath bridges all other bears tracked via GPS.

Table 2. Correlation among fixed, continuous variables in resource selection function models for black bears, central Georgia, USA 2012-2014.[1]

	DIST-AF	DIST-FE	DIST-DI
DIST-AF	1.0000000	-0.0507536	-0.4381734
DIST-FE	-0.0507536	1.0000000	0.0793556
DIST-DI	-0.4381734	0.0793556	1.0000000

[1] DIST-AF = distance to agriculture field; DIST-FE = distance to forest edge; DIST-DI = distance to intersection of SR 96 and drainages.

Table 3. Summary of candidate general linear mixed-models with individual bear as a random effect for black bears, central Georgia, USA 2012-2014.

Model	Log(L)	K	AIC$_c$	Δ_i	w_i
BU[1] + DIST-AG[2] + DIST-DI[3] + DIST-FE[4]	-179.4948	6	371.1910	0.00000	0.999229
BU + DIST-AG + DIST-FE	-188.3696	5	386.8828	15.69174	0.000391
DIST-AG + DIST-FE	-189.4220	4	386.9394	15.74838	0.000380
BU + DIST-FE	-204.5818	4	417.2590	46.06794	0.000000
DIST-FE	-207.4816	3	421.0204	49.82933	0.000000
Null[5]	-293.8944	2	591.8173	220.62627	0.000000

[1] Categorical habitat variable; bottomland or upland forest

[2] Continuous variable; distance to agriculture field

[3] Continuous variable; distance to drainage intersection with Georgia State Route 96

[4] Continuous variable; distance to forest edge

[5] Random effect only

Table 4. Parameter estimates of landscape-level parameters from top-preforming model used to predict bear crossings of SR 96, central Georgia, USA 2012-2014.

Parameter	Estimate	Std. Error	Z	p
BU[1]	1.470481	0.685321	-2.146	0.0319
DIST-DI[2]	-0.012055	0.002995	-4.025	<0.001
DIST-AF[3]	-0.019361	0.003208	-6.035	<0.001
DIST-FE[4]	-0.388514	0.051458	-7.550	<0.001

[1] Categorical habitat variable; bottomland or upland forest

[2] Continuous variable; distance to agriculture field

[3] Continuous variable; distance to drainage intersection with Georgia State Route 96

[4] Continuous variable; distance to forest edge

Figure 1. Central Georgia Black BearStudy Area with SR 96. Georgia, USA, 2012–2014.

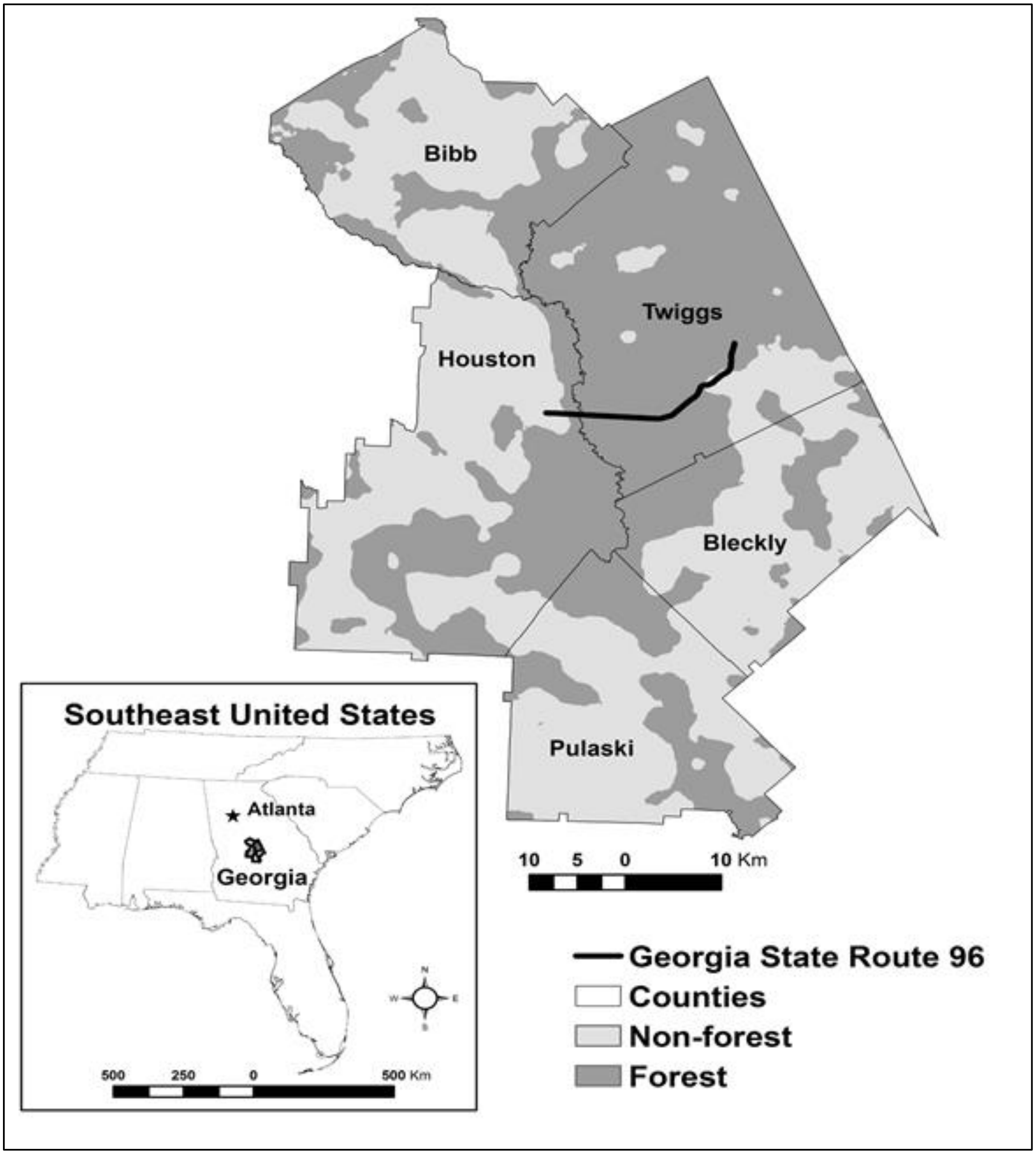


Figure 2. Segment of SR 96 (black line) used to evaluate black bear highway crossings, Central Georgia Black Bear Study, Georgia, USA, 2012–2014.

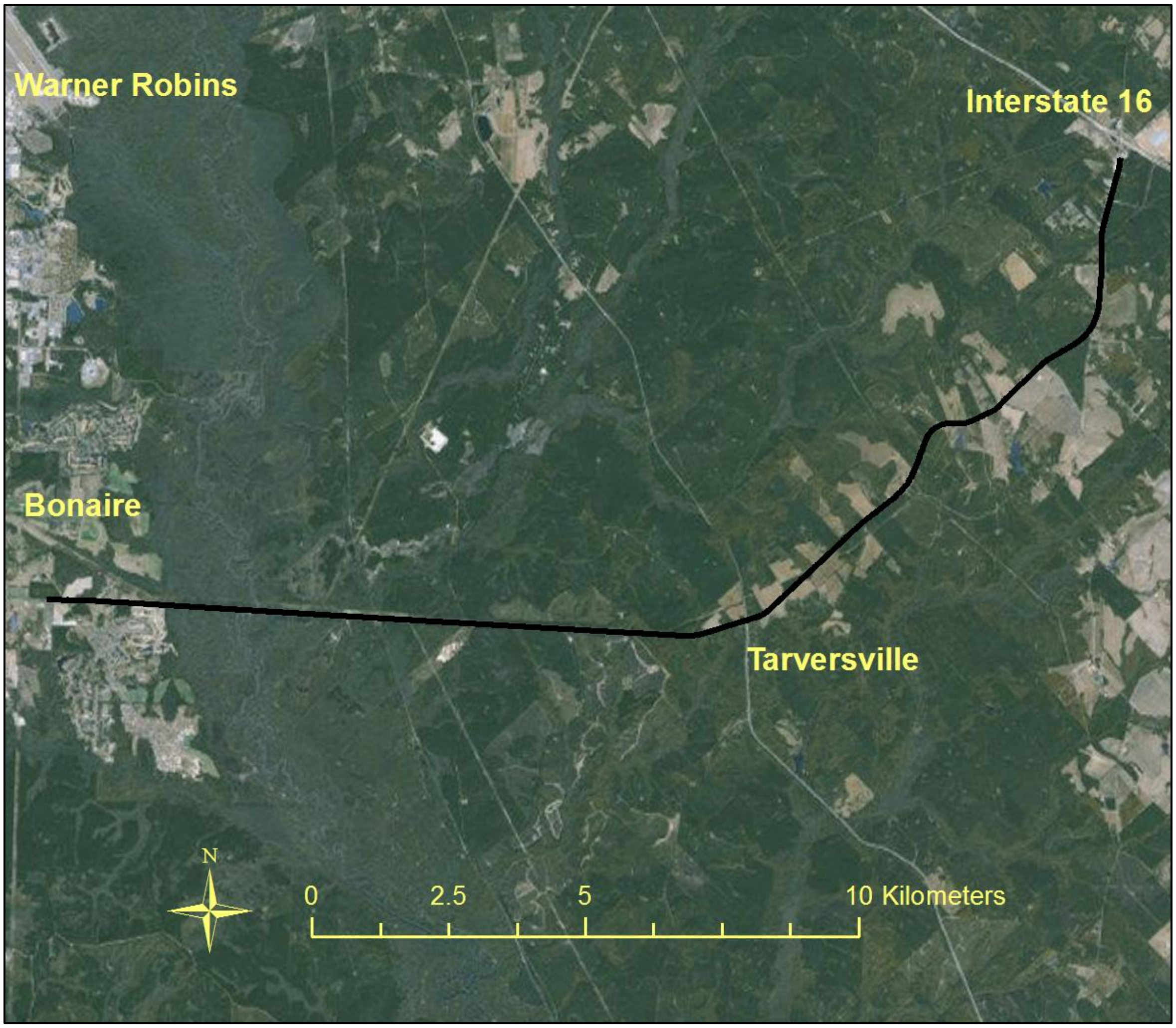


Figure 3. Segment of SR 96 (black line) used to evaluate black bear highway crossings with existing bridges (red diamonds) and proposed underpasses (tourmaline diamonds), Central Georgia Black Bear Study, Georgia, USA, 2012–2014.

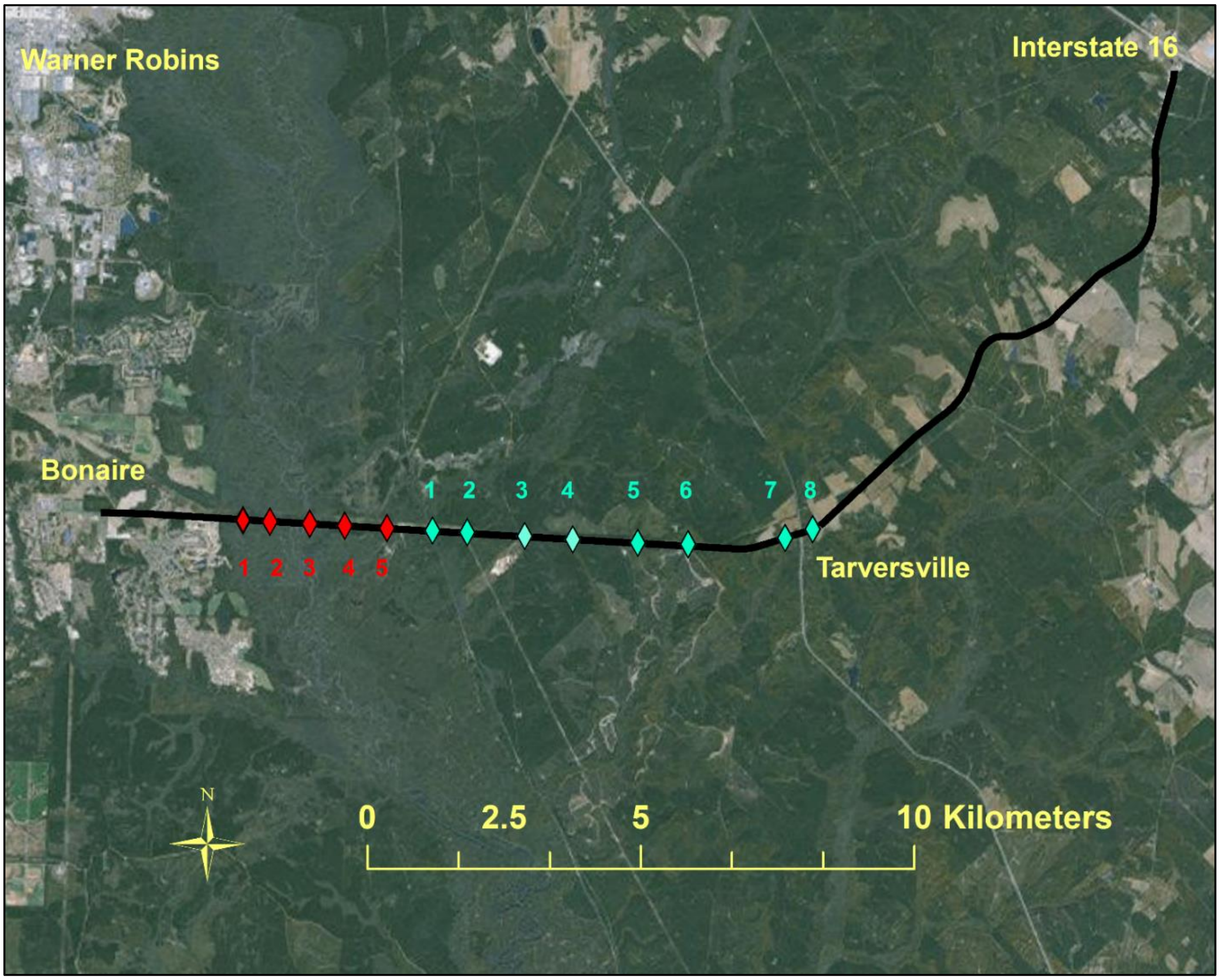


Figure 4. Segment of SR 96 (black line) with box culverts (red squares) monitored for bear activity via infrared trail camera, Central Georgia Black Bear Study, Georgia, USA, 2012–2014.

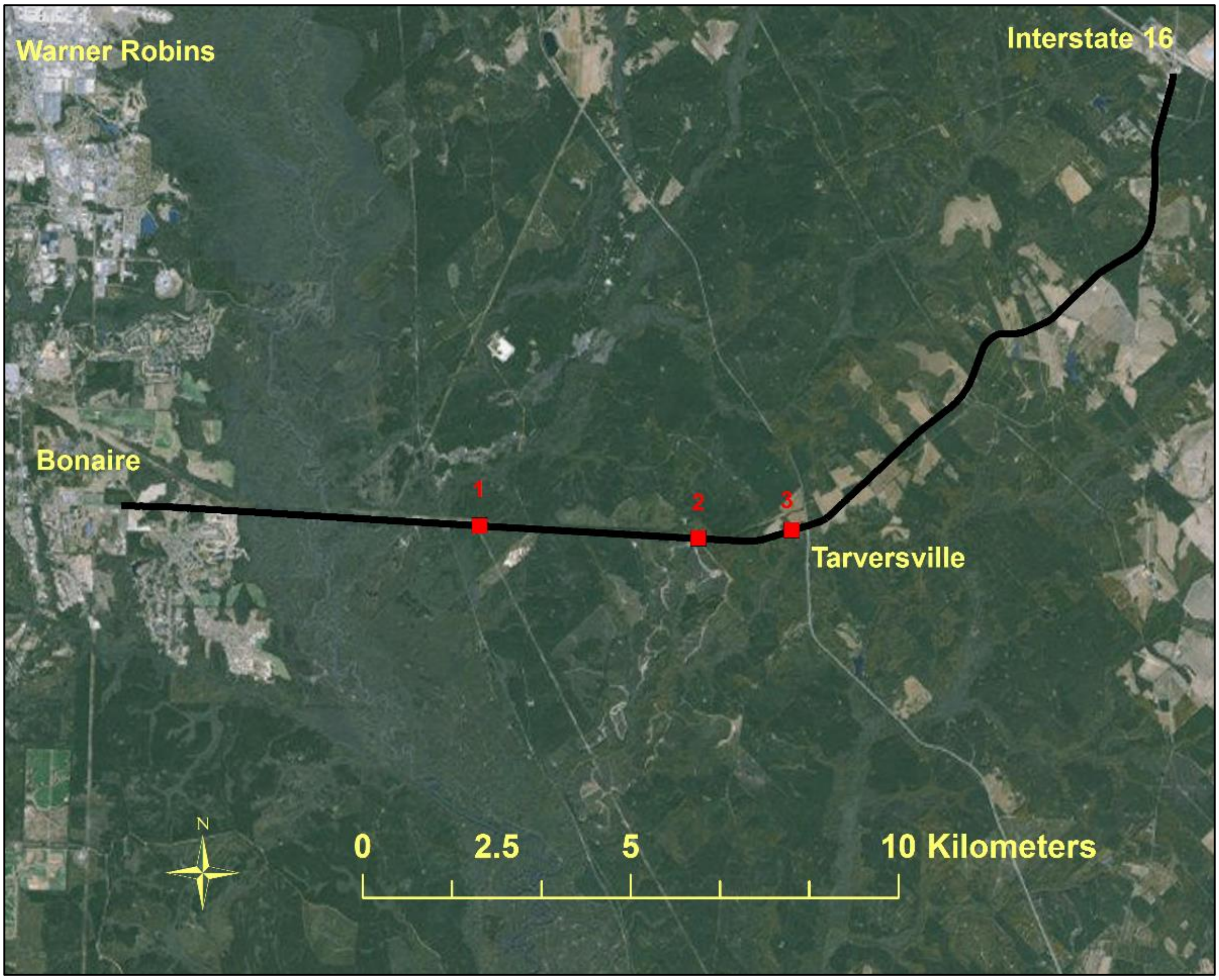


Figure 5. Segment of SR 96 (black line) used to evaluate black bear highway crossings with depiction of virtual fence (yellow shaded area), Central Georgia Black Bear Study, Georgia, USA, 2012–2014.

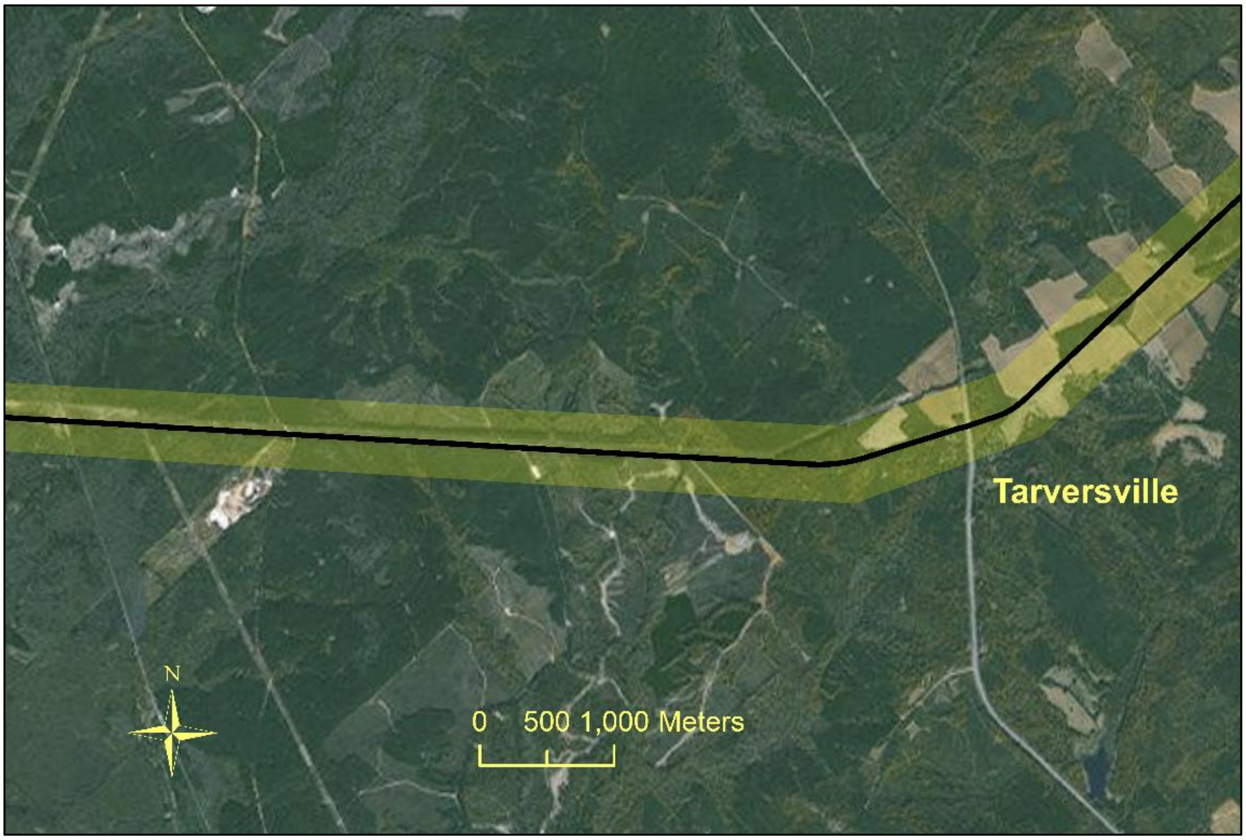


Figure 6. Schematic view of camera system used to monitor bear activity under SR 96 bridges, Central Georgia Black Bear Study, Georgia, USA, 2012–2014.

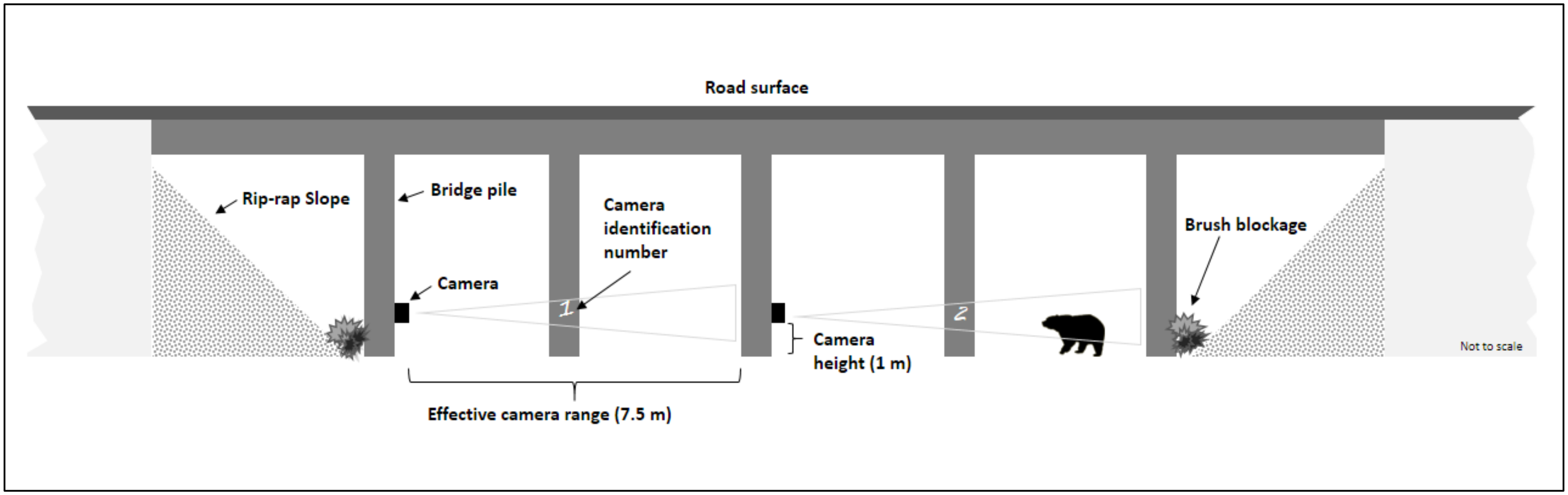


Figure 7. Segment of SR 96 (black line) and examples of black bear location data exhibiting bear activity directly adjacent to but not crossing SR 96, Central Georgia Black Bear Study, Georgia, USA, 2012–2014.

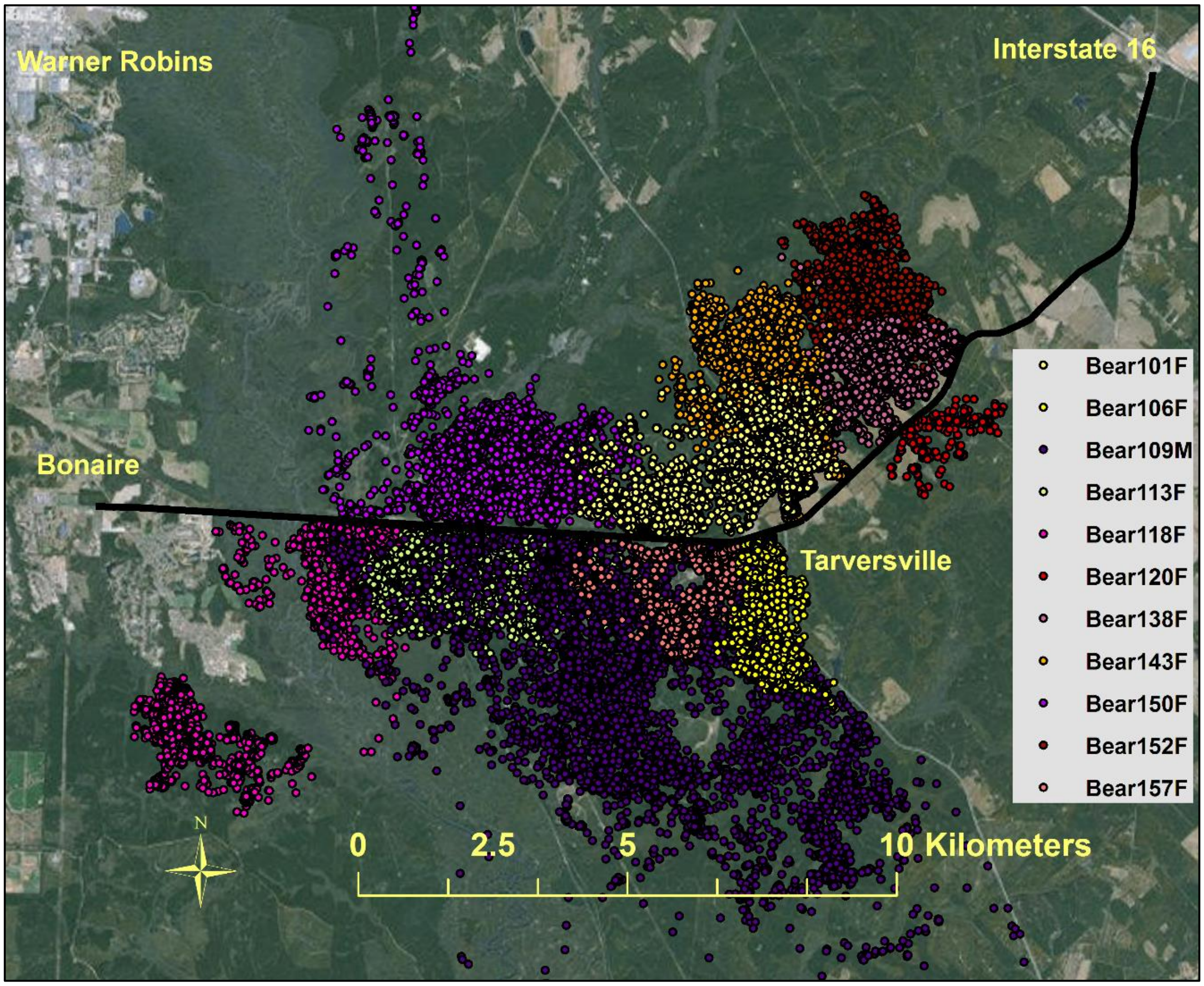


Figure 8. Segment of SR 96 (black line) and GPS location data of female Bear 117 exhibiting crossing of SR 96 during 2012 (top), and no crossings of SR 96 during 2013 (middle) and 2014 (bottom), Central Georgia Black Bear Study, Georgia, USA, 2012–2014.

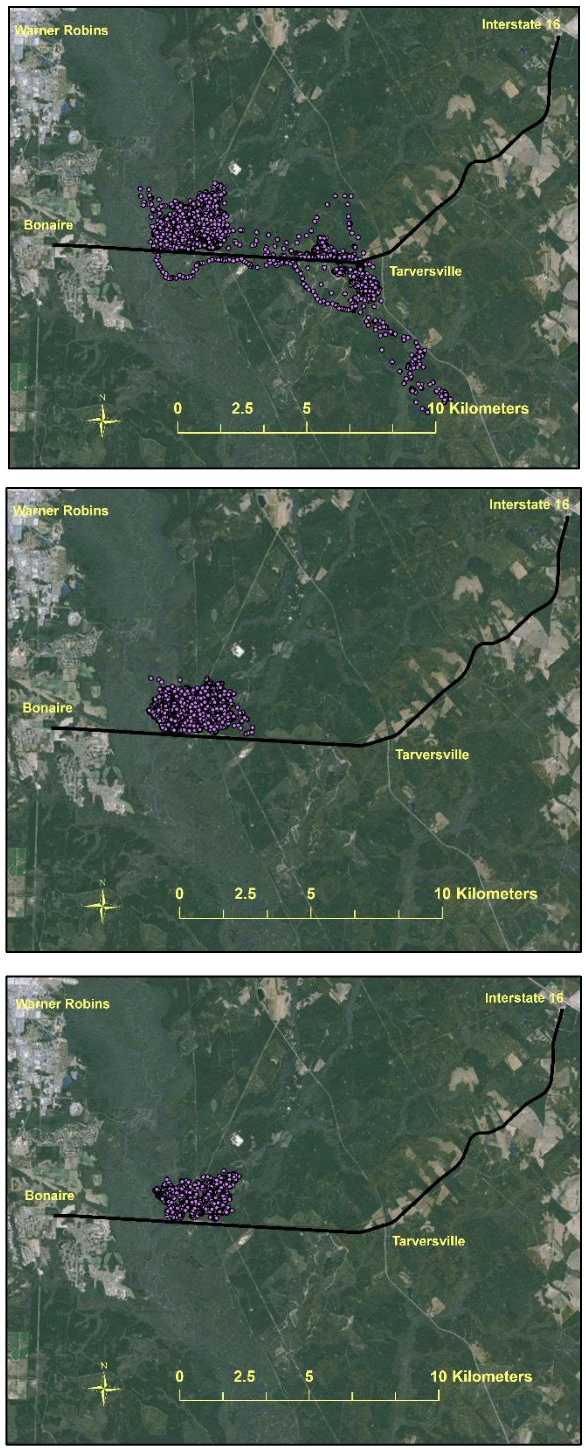


Figure 9. Segment of SR 96 (black line) with crossing locations of 11 GPS-collared black bears , inset shows concentration of crossings in road segment west of Tarversville, Central Georgia Black Bear Study, Georgia, USA, 2012–2014.

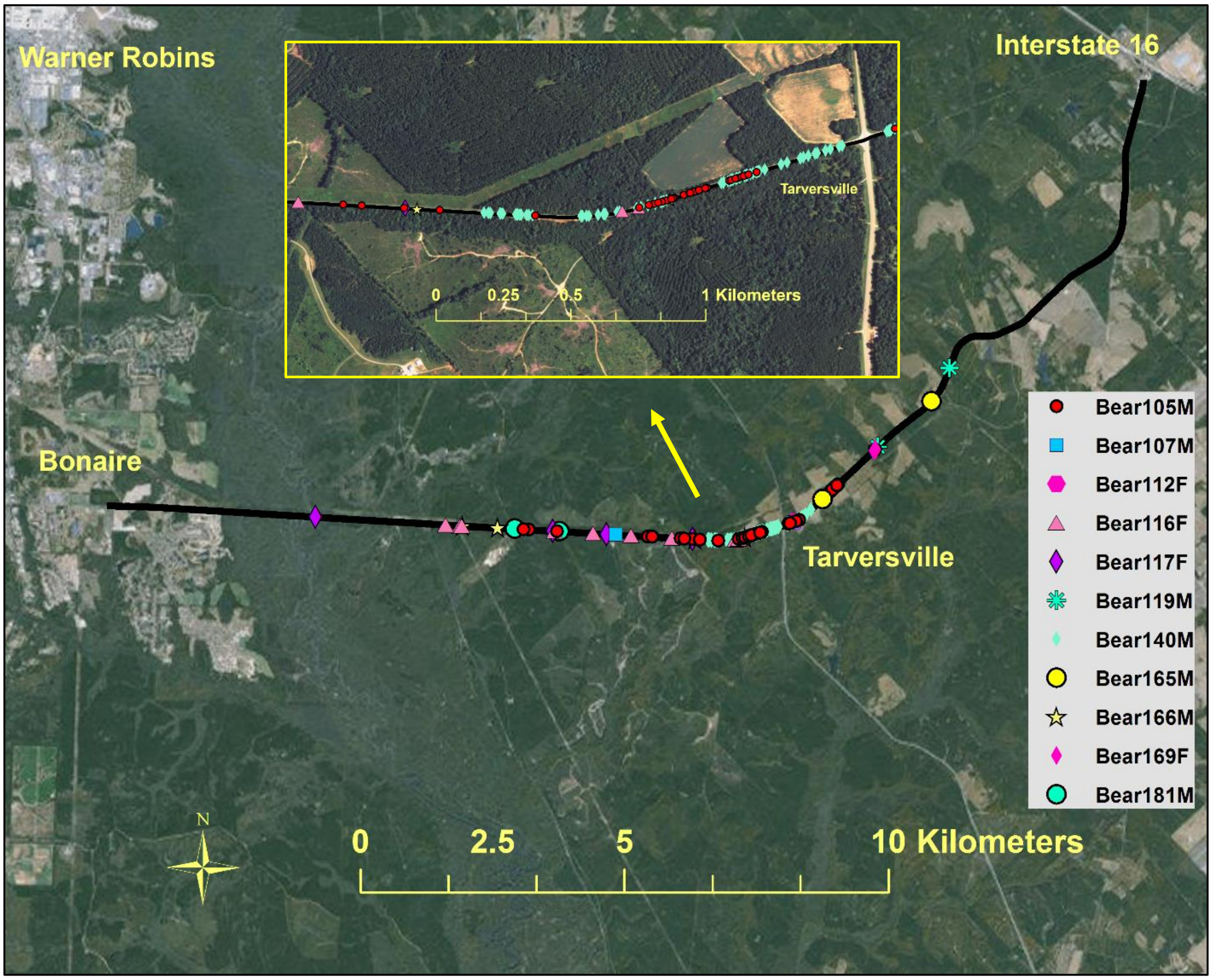


Figure 10. SR 96 road segment lengths defined by dynamic Brownian Bridge Movement Model 95 % Utilization Distributions of bear movement paths, Central Georgia Black Bear Study, Georgia, USA, 2012–2014

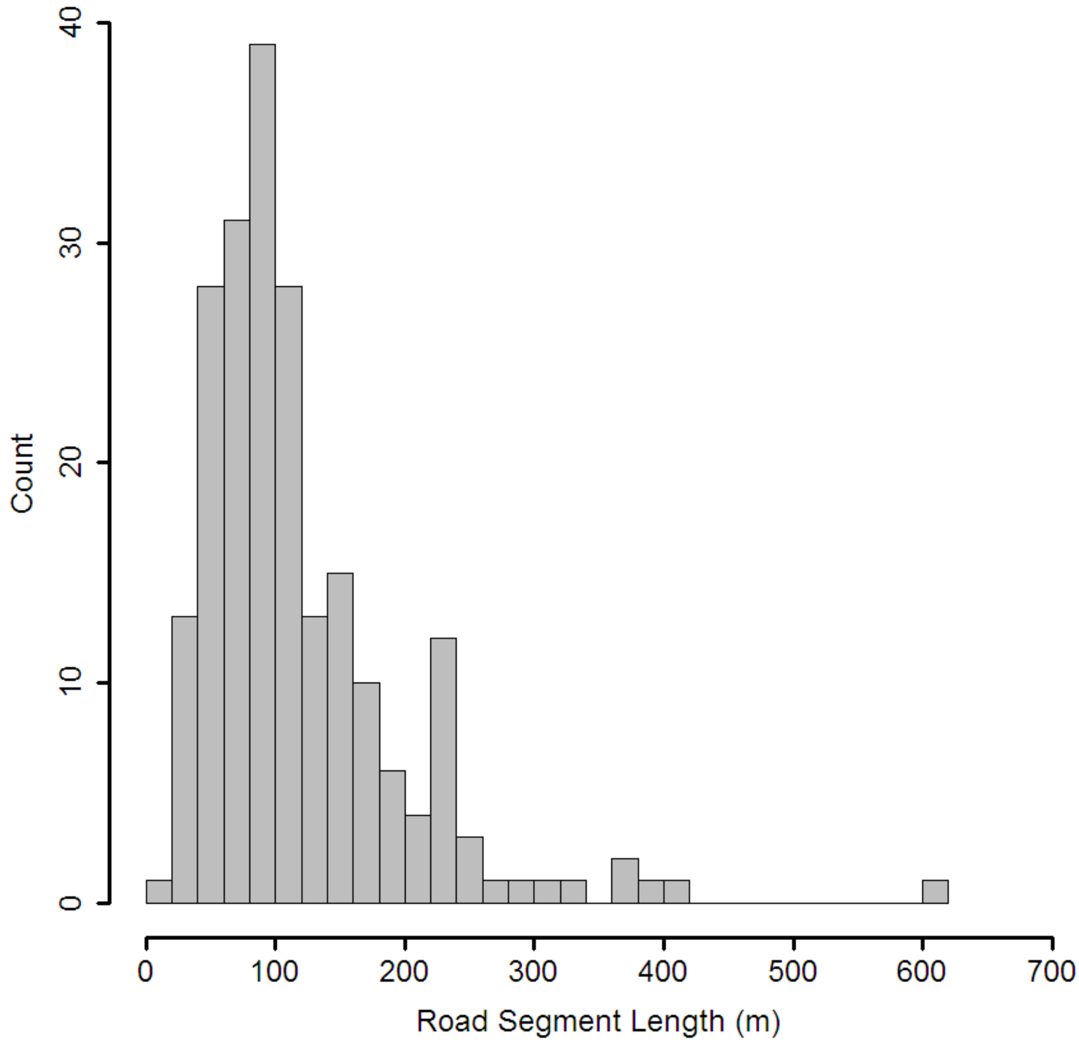
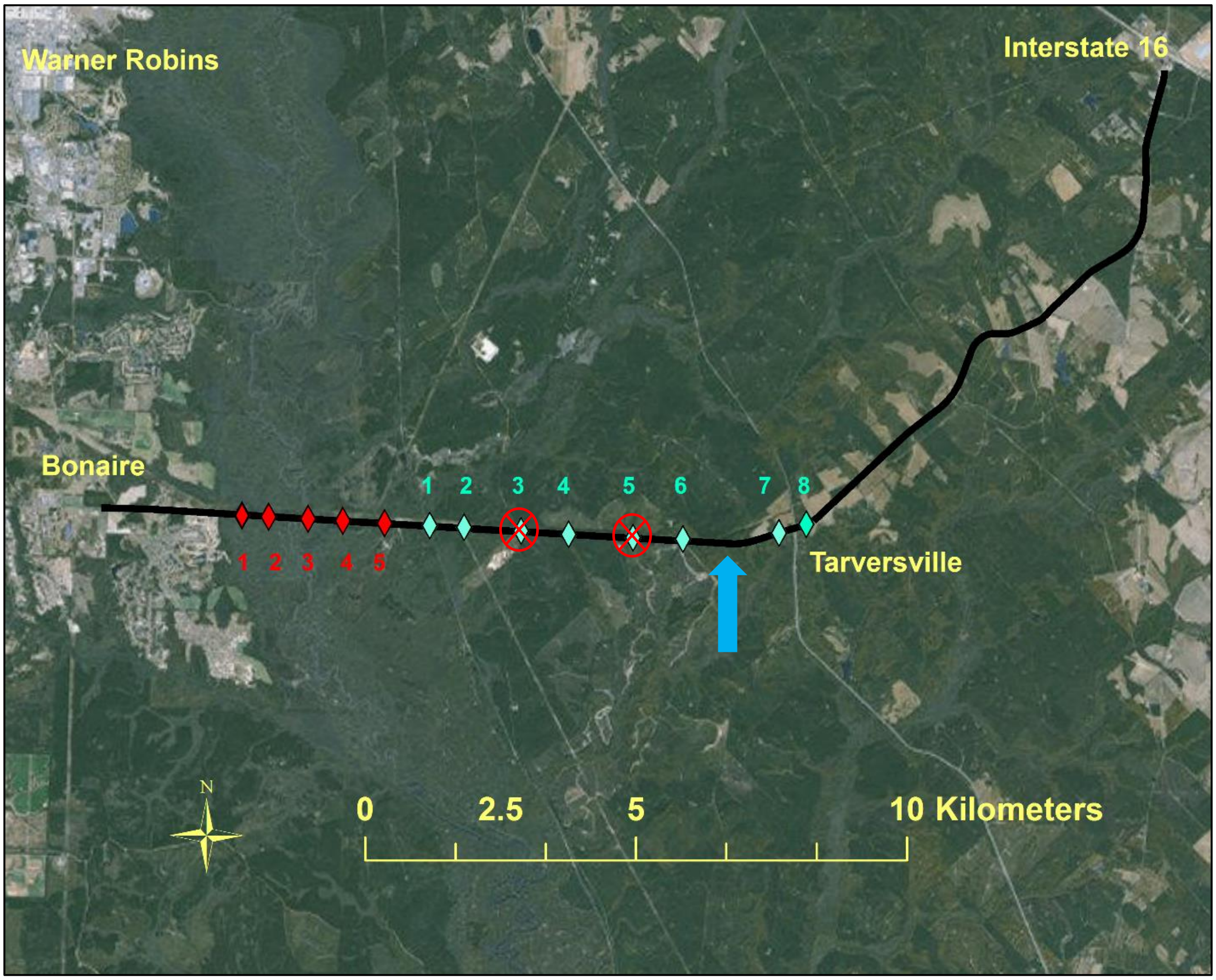


Figure 11. Segment of SR 96 (black line) used to evaluate black bear highway crossings with existing bridges (red diamonds), proposed underpasses (tourmaline diamonds), proposed underpasses which can be dropped from consideration (red circles), and road segment which should be considered for a proposed underpass (blue arrow), Central Georgia Black Bear Study, Georgia, USA, 2012–2014.



Evaluation of Currently Proposed Wildlife Underpasses on State Route 96

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Robert J. Warren, Ph.D. – Cooperating Investigator

Karl V. Miller, Ph.D. – Cooperating Investigator

At the request of the Georgia Department of Transportation, members of the University of Georgia's Middle Georgia bear research project reviewed fine-scale GPS data of black bear movement along the Highway 96 corridor between Bonaire, GA and the intersection of State Route 96 and Interstate 16. Of interest were the specific locations where bears had crossed State Route 96 during the field seasons of 2012, 2013, and 2014. We evaluated these crossing data relative to the proposed underpass locations and the proposed roadside fence design. After review of the data, we make the following recommendations:

1. The 13 proposed underpasses are appropriate and will offer bears (and other wildlife) potential safe passage under the State Route 96 corridor.
2. It is our recommendation, however, that 1 additional underpass be located within a stretch of Highway 96 that experienced the highest number of bear crossings both in terms of the number of different bears that crossed State Route 96 and the number of crossings for some individual bears. We propose that this additional underpass be located at or near the location noted in the provided figure (Figure 1). This portion of the roadway is about 0.5 miles long and does not currently have an underpass proposed in the design for the 4-lane segment of State Route 96. If possible the underpass could be located at the site of an existing culvert. In the absence of an appropriate existing culvert, a site should be selected that will allow for maintenance of road-side vegetation as described below.
3. We also recommend that vegetation management be taken into consideration for enhancing the potential of bears using underpasses and avoiding the highway in areas without underpasses. Based on the bear movement data we reviewed, bears were more likely to cross State Route 96 if there was forest habitat directly adjacent to the highway. Conversely, bears were less likely to approach (and therefore cross) the highway in areas with little or no forested cover directly adjacent to the highway. Therefore, removal of forest habitat adjacent to those segments of State Route 96 that do not include underpasses should discourage bears from crossing over the roadway. Furthermore, we recommend adding shrub and forest habitat leading up to the underpasses on State Route 96. Bears are more likely to remain in this vegetative cover on both sides of the highway where underpasses are located, which will enhance the likelihood that they will be "funneled" into the underpasses.
4. With regards to the roadside fencing, we recommend that fencing not be implemented at this time. We make this recommendation based on several factors. First, as described in Recommendation #3 above, we believe vegetation management will be equally effective as fencing in helping "funnel "bears into the underpasses. Second, given the number and locations

of the proposed fence breaches (i.e., driveways that intersect State Route 96) it is unlikely that the proposed fence design would greatly decrease the potential of a bear getting onto the roadway surface. Third, some of the proposed breaches are not paired. That is, a fence breach on the north side of the highway does not have a corresponding breach on the south side of the roadway or vice versa. Thus, the current fencing proposed for State Route 96 has the potential for bears to become “entrapped” within the roadway right-of-way, and may increase the chance of a bear-vehicle collision if the bear is unable to easily escape from the roadway.

5. If GDOT decides to eliminate the fencing from the design for State Route 96 as described in our recommendations #3 and #4 above, then we also recommend that a follow-up bear research project be conducted after construction of the 4-lane segment of State Route 96. This research project could specifically monitor movements of GPS-instrumented bears adjacent to this portion of State Route 96 to determine the efficacy of the vegetation management and underpasses in “funneling” bears under the roadway, in the absence of fencing.

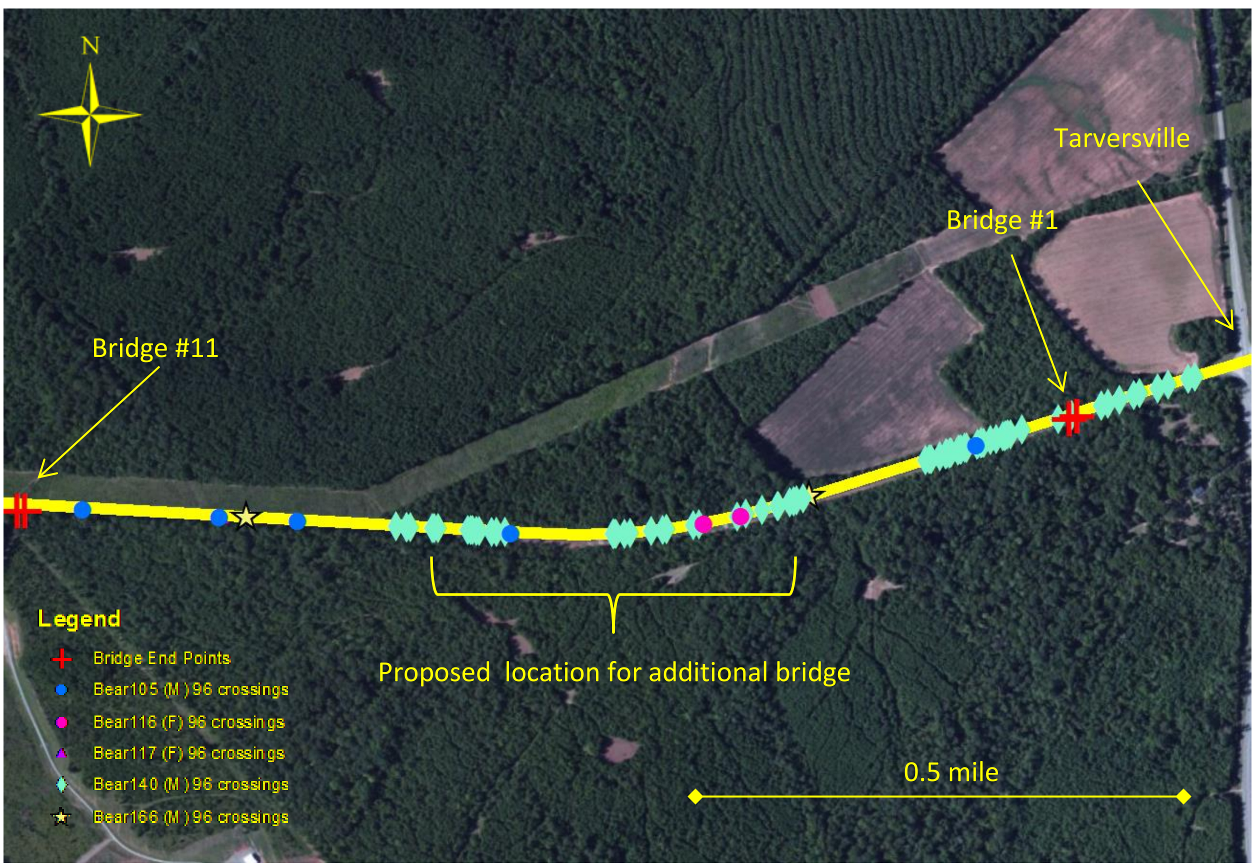

Fig. 1. Proposed location for additional underpass, State Route 96 widening project, State Route 96, Twiggs County, Georgia, USA.

Evaluation of Currently Proposed Wildlife Underpasses on State Route 96

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GDOT Project Numbers: STP00-0155-01(022) and STP00-0155-01(023)

GDOT PI Numbers: #322460 (the project west of SR 87) and #322470 (the project east of SR 87)

At the request of the Georgia Department of Transportation (GDOT), members of the University of Georgia's Middle Georgia Bear Research Project reviewed fine-scale GPS and photographic data of black bear activity along the State Route 96 corridor between Bonaire, GA and the intersection of State Route 96 and Interstate 16. Of interest were the specific locations where bears had crossed State Route 96 during the field seasons of 2012, 2013, and 2014. We evaluated these crossing data relative to existing and proposed bridge locations. We then met with GDOT officials in Macon, GA on February 13, 2015 to discuss the proposed bridge locations, specifically in comparison to our bear movement data to identify those bridges that would or would not likely be used by bears after highway construction was completed. At GDOT's request we also offer suggestions regarding the use of right-of-way vegetation management to enhance the likelihood of bears and other wildlife species locating and utilizing the bridges to safely pass under State Route 96.

1. After reviewing our data with GDOT officials, and considering the existing and proposed bridges individually, we provide the following recommendations:

- The existing bridges (Bridges # 1-5) serve hydrologic function and we have documented bears crossing beneath 3 of these 5 bridges. We also documented extensive use of these bridges as underpasses by deer, feral swine, and mesocarnivores. We recommend that these bridges remain in the new highway design.
- Proposed Bridge #6, the bridge over the existing railroad track, is necessary but will likely be of little value as a wildlife underpass due to the presence of the railroad track as well as human disturbance in that area.
- Proposed Bridge # 7, we believe, has strong potential to be used as an underpass by wildlife. We documented several crossings of GPS-collared bears in the vicinity of the proposed location of Bridge #7 and we photographed a bear at the mouth of a culvert which is currently at the location of the proposed bridge. We recommend retaining Bridge #7 in the new highway design.
- Proposed Bridge # 8, the bridge designed to overpass West Lake Road, would likely have little use as a wildlife underpass due to the presence of West Lake Road and its concomitant vehicle traffic and human disturbance. In addition, we documented very few GPS-collared bear

crossings in the vicinity of the proposed location of Bridge #8. We recommend that Bridge #8 be eliminated from the new highway design.

- Although it is located in an area with little demonstrated bear crossing activity, proposed Bridge # 9 is equidistant between proposed Bridges # 7 and 11. Given our recommendation to remove from consideration Proposed Bridges #8 (see above) and #10 (see below), we recommend retaining Bridge # 9 in the new highway plan because it will provide an opportunity for bears to cross under State Route 96 at distances of < 1 mile along the length of the highway.
- Proposed Bridge # 10 would be located in an area that demonstrated little GPS-collared bear crossing activity. Therefore, we recommend eliminating proposed Bridge # 10 from consideration in the new highway design.
- Proposed Bridge # 11 will be in a location where several GPS-collared bears crossed State Route 96; some of them crossed multiple times. A nearby stand of hard-mast bearing trees make this location attractive to bears. For these reasons, we recommend that Bridge # 11 be retained in the new highway design.
- Proposed Bridges # 1 and 2 (PI#322470) are both in areas where GPS-collared bears have demonstrated heavy crossing activity. Both of these bridges should remain in the new highway design.
- Lastly, we recommend the inclusion of at least 1 bridge in the area between Bridge # 11 and Bridge #1 (PI#322470, Figure 1). The topography in this area lends itself well to the placement of a bridge, and this area demonstrated high GPS-collared bear crossing activity.

2. With regards to the roadside fencing, we recommend that fencing not be implemented at this time. We make this recommendation based on several factors. First, we believe vegetation management will be equally effective as fencing in helping "funnel "bears into the underpasses (See Item #3 below). Second, given the number and locations of the proposed fence breaches (i.e., driveways that intersect State Route 96) it is unlikely that the proposed fence design would greatly decrease the potential of a bear getting onto the roadway surface. Third, some of the proposed breaches are not paired. That is, a fence breach on the north side of the highway does not have a corresponding breach on the south side of the roadway or vice versa. Thus, the current fencing proposed for State Route 96 has the potential for bears to become "entrapped" within the roadway right-of-way, and may increase the chance of a bear-vehicle collision if the bear is unable to easily escape from the roadway.

3. In our previous memo that we submitted to GDOT in December 2014 (entitled "Evaluation of Currently Proposed Wildlife Underpasses on State Route 96"), we recommended that fencing not be included as a feature in the State Route 96 project. In that memo, we provided justification for the elimination of fencing and also recommended that vegetation be planted and maintained at strategic locations along State Route 96 to help attract bears to the underpasses. GDOT officials requested that we provide detailed recommendations regarding this vegetation. Therefore, we reviewed our bear movement data and published literature regarding bear use of wildlife underpasses as a basis for the following specific suggestions:

- Vegetative cover should be planted and maintained in the right-of-way adjacent to each bridge (Figure 2). Where possible, this vegetation should extend all the way from the underpass opening to the existing forest at the edge of the right-of-way. Where there is no forest adjacent to the right-of-way (e.g., north of the highway beneath the high-voltage transmission lines), cover vegetation should still be planted within the highway right-of-way. These patches of cover, while not connected to forest, will potentially attract bears that are crossing open ground as they approach the highway and, thereby, will help lure them to the underpass openings.

- The width of the planted area (Figure 2) where it meets the underpass opening should be at least as wide as the opening. The width of the planted area where it meets the tree line of existing forest stands should be a minimum of twice the width of the corresponding opening. The outside edges of these planted areas should be comprised of densely planted shrubs that will function as a natural 'fence'. Within the planted area, trees and shrubs should be planted at a density that will provide adequate cover to animals within the area but not so densely as to impede access by animals. If the patch of cover is to stand alone and not be connected to an existing forest stand, then the 'fence' of shrubs along the edges is of less importance.
- Shrubs should be 4 to 6 feet tall at maturity.
- Trees within the planted area should be a minimum 8 feet tall at maturity. Trees do not have to be as tall as nearby forest trees but could be shorter near the underpass opening and taller near the existing forest edge (Figure 3).
- After review of GDOT's plant species list we recommend the planting of redbud (*Cercis canadensis*) and/or fringetree (*Chionanthus virginicus*) for the trees, and waxmyrtle (*Myrica cerifera*) and/or holly (*Ilex attenuata*) for shrubs.
- Gaps between bridge underpasses within the median should be blocked with wildlife-proof fencing and shrubs to prevent wildlife from exiting the underpasses into the median. Fencing should be similar in design to the originally proposed road-side fencing, 10ft in height and topped with out-riggers facing toward the underpass. The ends of the fence should adjoin the underpass walls as to prevent animals from traveling between the fence and the underpass opening.
- The ground surface within the underpasses should be of natural material.

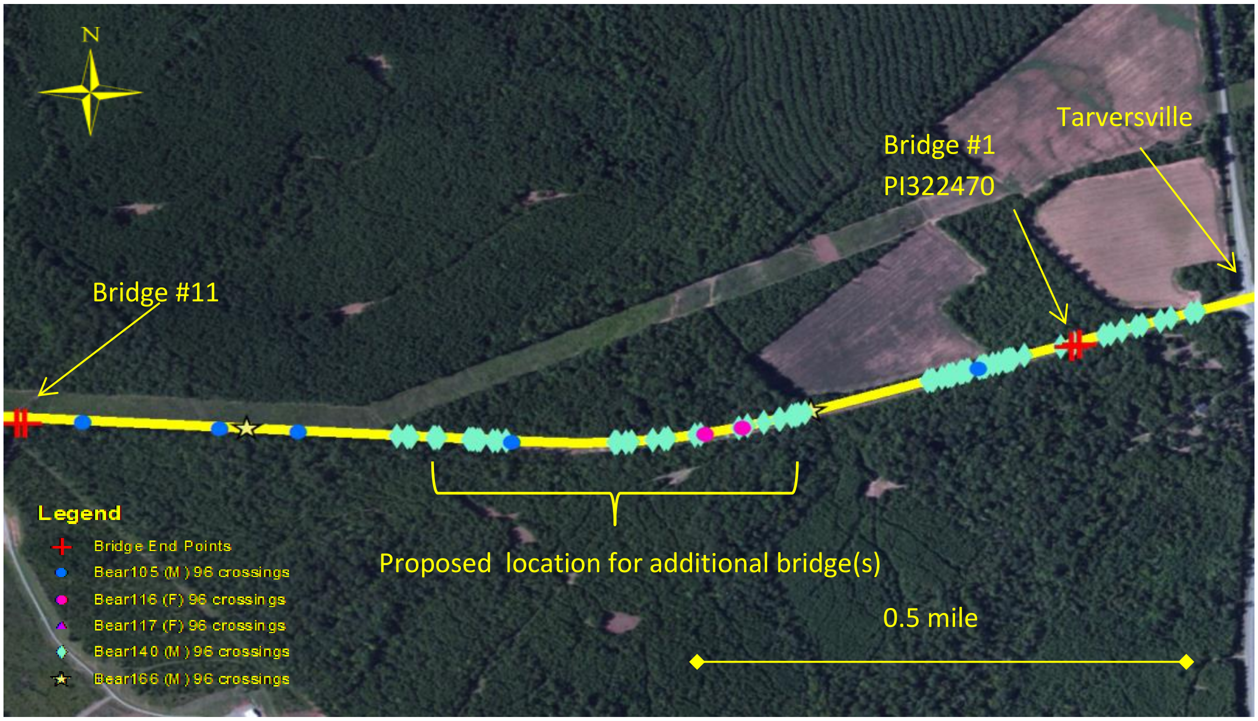

Fig. 1. Proposed location for additional underpass, State Route 96 widening project, State Route 96, Twiggs County, Georgia, USA.

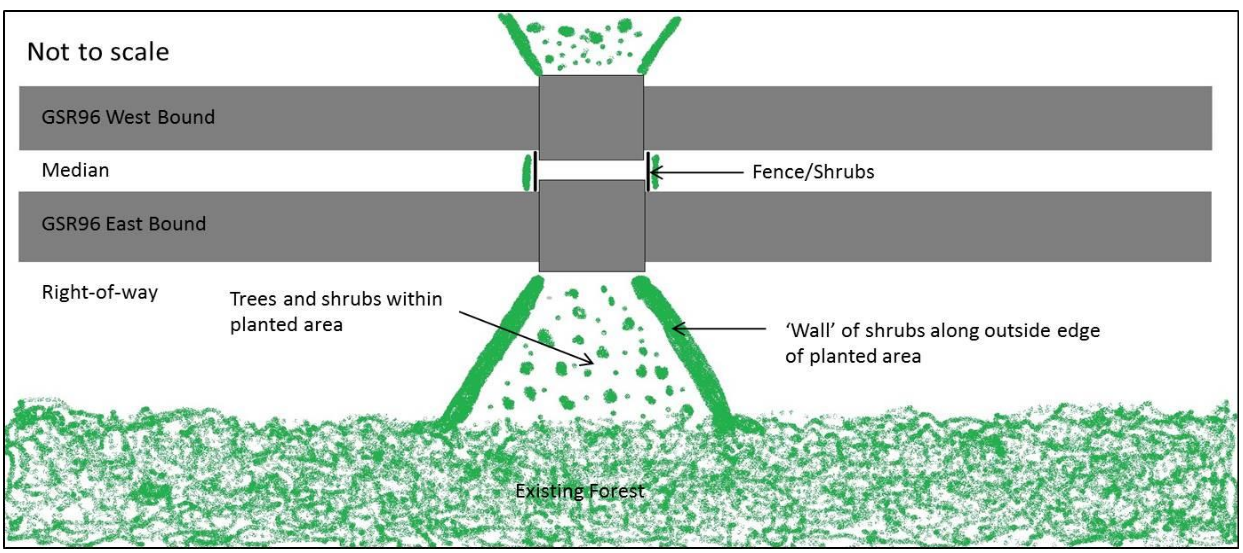

Fig. 2. Proposed vegetation plan for wildlife underpasses, State Route 96 widening project, State Route 96, Twiggs County, Georgia, USA.

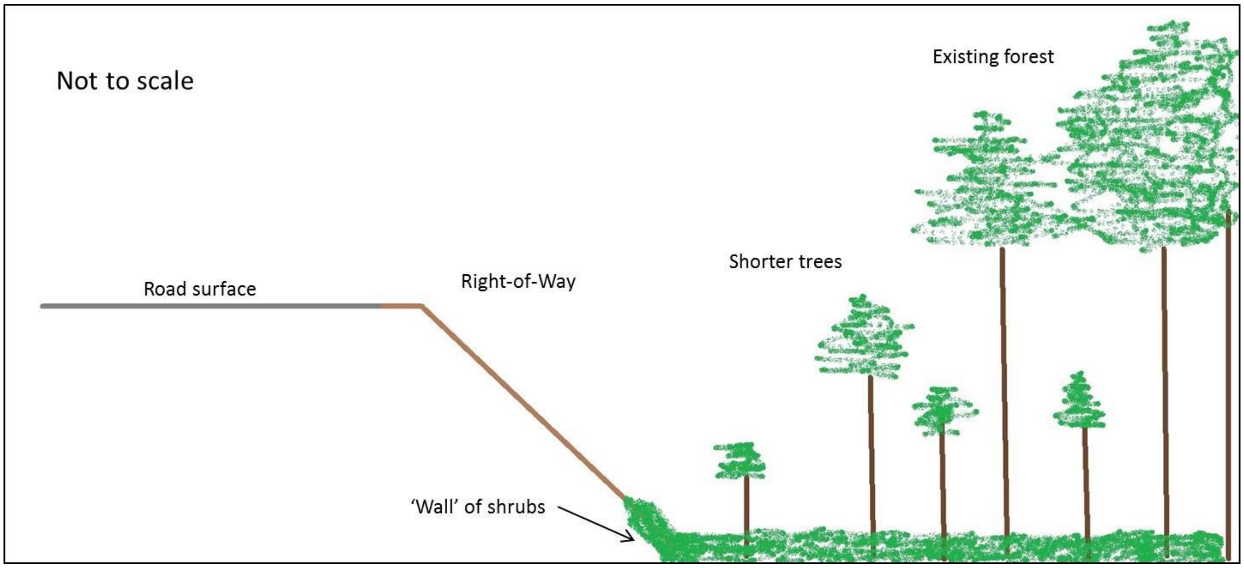

Fig. 3. Profile of proposed vegetation plan for wildlife underpasses, State Route 96 widening project, State Route 96, Twiggs County, Georgia, USA.