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SPATIALLY EXPLICIT MODEL OF AREAS BETWEEN SUITABLE BLACK BEAR HABITAT IN EAST TEXAS AND BLACK BEAR POPULATIONS IN LOUISIANA, ARKANSAS, AND OKLAHOMA

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By

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Presented to the Faculty of the Graduate School of

Stephen F. Austin State University

In Partial Fulfillment

Of the Requirements

For the Degree of

Master of Science in Forestry

STEPHEN F. AUSTIN STATE UNIVERSITY

DECEMBER 2017

SPATIALLY EXPLICIT MODEL OF AREAS BETWEEN SUITABLE BLACK BEAR HABITAT IN EAST TEXAS AND BLACK BEAR POPULATIONS IN LOUISIANA, ARKANSAS, AND OKLAHOMA

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ABSTRACT

Although black bears (*Ursus americanus, Ursus americanus luteolus*) were once found throughout the south-central United States, unregulated harvest and habitat loss resulted in severe range retractions and by the beginning of the twentieth century populations in Oklahoma, Louisiana, Texas and Arkansas were nearing extirpation. In response to these losses, translocation programs were initiated in Arkansas (1958-1968 & 2000-2006) and Louisiana (1964-1967 & 2001-2009). These programs successfully restored bears to portions of Louisiana and Arkansas, and, as populations in Arkansas began dispersing, to Oklahoma. In contrast, east Texas remains unoccupied despite the existence of suitable habitat in the region.

To facilitate the establishment of a breeding population in east Texas, I sought to identify suitable habitat which bears could use for dispersal between known bear locations in Louisiana, Arkansas and Oklahoma and the east Texas recovery units. I utilized Maxent, a machine learning software, to model habitat suitability in this region. I collected known black bear presence locations (n=18,241) from state agencies in Louisiana, Oklahoma, Arkansas and east Texas and filtered them to reduce spatial autocorrelation (n=664). I also collected spatial data sets based on known black bear ecology to serve as environmental predictor variables. The model was developed at 30-m resolution and encompassed 417,076 km². The final model was selected to minimize

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model over-fitting while maintaining a high test Area Under the Receiver Operating Curve (AUC _{TEST}) score.

For final model interpretation and analysis, I used the 10th percentile training threshold available in Maxent which excludes the lowest 10% of predicted presence suitability scores from the binary predictive map, thus resulting in a more conservative predictive map. The final 10th percentile model predicted 43.7% of the pixels in the study area as suitable and 53.7 % percent of the pixels identified as potential recovery units by Kaminski et al. (2013, 2014) as suitable. To focus management efforts, I identified three movement zones with a high proportion of suitable habitat within which connectivity analyses were performed. Suitable patches greater than or equal to 12 km² were classified within ArcGIS as stepping stone patches. Buffers of 3,500 m were generated around these patches to determine the level of functional connectivity in each zone.

The final Maxent model confirmed that suitable bear habitat exists between source populations and the east Texas recovery units. The importance of percent of mast producing forest, percentage of cultivated crops and percentage of protected lands reflect what is known about basic bear biology and ecology. Furthermore, 153 stepping stone patches were identified within the movement zones, demonstrating that there is a reasonable chance of bears naturally dispersing to east Texas using the habitat identified in this study. Thus, protection of existing bear habitat and the stepping stone patches identified in this study should be a priority for managers seeking to facilitate natural bear recolonization of east Texas.

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ACKNOWLEDGMENTS

I would like to thank Stephen F. Austin State University and the Arthur Temple College of Forestry and Agriculture for providing the education and resources necessary to complete this research. I want to thank my major advisors, Dr. Chris Comer and Dr. Daniel Scognamillo for the time, effort and support they provided throughout my research. I very much appreciate the opportunity they gave me to work on this project. I also want to give a special thanks to Dr. Tanh Nguyen for his eternal optimism and confidence in me and my abilities when I came across roadblocks in my research. His advice and expertise throughout this process were invaluable to my research. I want to thank my committee members, Dr. Daniel Unger and Dr. Yanli Zhang for providing guidance and dedicating their time to helping me complete my research.

I want to thank the Texas Parks and Wildlife Department for providing funding for this research. Special thanks to Dave Holdermann for providing logistic support and advice during the interstate data collection phase of my research. Also, thank you to the Texas Black Bear Alliance for providing me opportunities to present my study to the public during their meetings.

Thank you to all my undergraduate professors at Louisiana State University for providing me the technical foundation I needed to be successful in a graduate program. Specifically, I want to thank Dr. Michael Kaller and Dr. Richard Stevens for encouraging me to apply to graduate school. I want to thank my supervisors at Advanced Ecology for their support and for allowing me the flexibility to take time off work to finish writing my thesis and prepare for my defense.

Thank you to my family and friends for their never-ending patience, understanding and encouragement throughout the graduate school process. Thank you to Tamara Wood, Bryce Gerlach and Ryan Jacques for their friendship and grad-student comradery. Lastly, thank you to my fiancé, Patrick Vines, for encouraging me to apply to this program, moving with me to Nacogdoches, patiently providing emotional support, and believing in me when I did not.

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CHAPTER I

Historically, the American black bear (*Ursus americanus*) was common throughout the continental United States, Canada, and northern Mexico (Pelton 1982). Habitat loss and overexploitation by early settlers led to considerable population declines across much of its range (Garshelis 1990). This was especially true in the southern United States, where indiscriminate logging practices, high demand for bear oil, and overhunting (Barker et al. 2005), caused a 90-95% range retraction in the late 1800's (Maehr et al. 1984, Wooding et al.1996). By the start of the twentieth century, black bears were nearing extirpation in Arkansas, Louisiana, Missouri, Oklahoma, and Texas (Bailey 1905, Smith and Clark 1994).

Translocation of individuals has been used as part of restoration efforts in different parts of the original species range. Various techniques exist for black bear restoration, including "hard-release" translocation, which involves the capture, transport and immediate release of individuals, without an acclimation period (Griffith et al. 1989, Shull et al. 1994). The Arkansas Game and Fish Commission implemented a hard-release translocation between 1958 and 1968 in an attempt to restore black bear populations in that state. Approximately 250 bears were captured and transported from Manitoba, Canada and Minnesota to regions of western and northern Arkansas over the ten-year period (Smith and Clark 1994). Within twenty years, populations had reached approximately 2,500 individuals, eventually leading to the natural re-colonization of black bears in southeastern Oklahoma (Smith and Clark 1994). Similar translocation programs occurred from 1964-1967 in Louisiana. These included 163 black bears that were captured in Minnesota and relocated to the Atchafalaya River Basin and Tensas River Basin in Louisiana, where small remnant populations were believed to exist (Black Bear Conservation Committee 1992). Statewide population numbers were estimated to have increased to 200-300 bears by 1991(Black Bear Conservation Committee 1992). In response to range reductions and perceived population declines, the U.S. Fish and Wildlife service designated the Louisiana black bear (*Ursus americanus luteolus*) as threatened under the Endangered Species Act on February 6, 1992 (USFWS 1995). The listing also extended protection to any free-living bears within the Louisiana black bear historic range, due to similarity of appearance (USFWS 1995).

Current Status

Louisiana

Currently, the Louisiana black bear has four breeding populations in Louisiana: 1) The Tensas River Basin (TRB) 2) Upper Atchafalaya River Basin (UARB) 3) Lower Atchafalaya River Basin (LARB) and 4) a recently repatriated population (REPAT) connecting the TRB and Atchafalaya populations (Davidson et al. 2015; Fig.1.1). The TRB is the largest of the four subpopulations, with estimates of female population ranging between 133 and 165 (Laufenberg and Clark 2014) and a positive annual growth rate of r=1.02-1.04 from 2002 to 2012 (Laufenberg and Clark 2014). Estimates of abundance may be low considering that private lands with bears were not included (Davidson et al. 2015). Genetic analyses of the TRB population indicated that there was connectivity between the individuals in the TRB and the White River National Wildlife Refuge, Arkansas as well as likely movement between the TRB and REPAT (Laufenberg and Clark 2014, Davidson et al. 2015).

Unlike previous translocation attempts which involved hard releases of captured bears during summer months, the repatriated subpopulation was established through winter translocations of 48 females and 104 cubs from the TRB to REPAT over an eightyear period (2001-2009) (Black Bear Conservation Coalition 2015). The goal was to facilitate connectivity, dispersal potential, and gene flow between the TRB and UARB as required in the USFWS recovery plan (Benson and Chamberlain 2007, Laufenberg and Clark 2014, USFWS 1995). Initial genetic research suggests that the subpopulation is operating as a stepping stone for bears between the TRB and UARB (Laufenberg and Clark 2014), with female survival of 1=0.93-0.97 and population growth rate of r = 0.99(Laufenberg and Clark 2014).

According to recent population parameter estimates, bear populations in Louisiana appear to be growing and expanding their respective ranges. Indeed, the UARB was estimated to have 41 individuals in 1999 (Triant et al. 2004), and a recent population study done in 2014 estimated the population to have increased to approximately 63 individuals (O'Connell-Goode 2014). Laufenberg and Clark (2014) found that females in this subpopulation had an annual survival rate of 0.84-0.90, which is slightly lower than estimates for the REPAT and TRB. Overall, likelihood of subpopulation persistence for the next 100 years was between 85% and 99% (Laufenberg and Clark 2014). In comparison to the same estimate for the TRB and REPAT, the outlook for this subpopulation is slightly better than that for REPAT (30%- 99%) while marginally lower than the TRB (\geq 95.8%) (Laufenberg and Clark 2014). These estimates are dependent on model assumptions, demographic and stochastic factors, and may change based on future research (Laufenberg and Clark 2014).

In 1999, the LARB was thought to have approximately 77 individuals (Triant et al. 2004); however, by 2013 estimates had increased to 138 (Troxler 2013). Despite this increase in numbers, annual female apparent survival was estimated between 0.81 and 0.84, making this the lowest survival rate among Louisiana subpopulations (Laufenberg and Clark 2014). Low survival in the LARB has been attributed to increased mortality from vehicular collisions and poaching (Davidson et al. 2015). U.S. Highway 90 and Louisiana Highway 317 reduce the LARB population by 10% annually as a result of vehicular mortality (Troxler 2013). Low genetic diversity and exchange (Troxler 2013, Laufenberg and Clark 2014) combined with low female survival in comparison to the other Louisiana subpopulations puts the LARB at risk in terms of future viability.

In addition to translocations, incentive based private land restoration programs significantly contributed to bear restoration by increasing available habitat. The Wetland Reserve Program permanently protected or restored 148,000 ac of habitat since 1992 and an additional 65,000 ac were protected or restored through other private groups such as

the Black Bear Conservation Coalition (USFWS 2015). The increased habitat acreage and influx of translocated individuals combined to meet the objectives outlined in the black bear recovery plan. Thus, on May 20, 2015 the U.S. Fish and Wildlife Service proposed delisting of the Louisiana black bear based on its current recovery status and in March of 2016 it was removed from the list.

Arkansas

Overall, approximately 2,500 bears existed in Arkansas and parts of Oklahoma and Mississippi by 1994 (Smith and Clark 1994), though numbers have likely increased since then. In Arkansas, black bears have been documented in all but three of the 75 counties (M. Means, Arkansas Game and Fish Commission, personal communication). The White River National Wildlife Refuge (WRNWR), Felsenthal National Wildlife Refuge (FNWR) and the Ouachita and Ozark mountains in Arkansas contain the four identified black bear populations in the state (Wear 2005, Black Bear Conservation Coalition 2015).

The WRNWR population was the last population remaining in Arkansas in the 1940's (Smith and Clark 1994). Currently, this population is expanding, indicating its' continued recovery and overall health (Black Bear Conservation Coalition 2015). Bear hunting is permitted in areas surrounding the refuge, thus harvest impacts survival rates within the refuge (Clark and Eastridge 2006). Clark and Eastridge (2006) determined that female survival decreased from 0.979, excluding harvest, to 0.923 including harvest data.

Continued monitoring of survival and population parameters is prudent to ensure harvest limits are at a healthy level for the population (Clark and Eastridge 2006).

FNWR is the location of the newest population of black bears in Arkansas (Wear et al. 2005). Over a six-year period (2000-2006), 46 females and 99 cubs were translocated from WRNWR to FNWR (Black Bear Conservation Coalition 2015). Average first-year survival rate of females following translocation (2000-2002) was estimated at 0.624 (Wear et al. 2005). Wear et al. (2005) documented two instances of successful breeding within the refuge, one in 2002 and one in 2003. There were eight adult female mortalities in the first two years, three of which were the result of poaching (Wear et al. 2005).

Bear hunting was reinstated in Arkansas in 1980 following the success of the translocation program (Smith and Pelton 1990). Archery, muzzleloader, modern gun and youth hunting seasons are currently permitted within the state (AGFC 2015). Hunting zones separate areas with differing quotas and regulations; however, there is a one bear per hunter combined limit amongst the different seasons and methods (AGFC 2015).

<u>Oklahoma</u>

Oklahoma also contains breeding bear populations within the eastern and southeastern regions of the state (Barker et al. 2005). Bales et al. (2005) studied an expanding population in the Oklahoma Ouachita Mountains. The population of 85 ± 30 individuals was relatively young and had an age structure consistent with recolonizing populations (Bales et al. 2005). The survival rate of adult females was estimated at 0.9,

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which is similar to estimates for Arkansas populations (0.98; Smith and Clark 1994; Bales et al. 2005). Overall population growth rate was estimated at 1.11±0.11/year, indicating an expanding population (Bales et al. 2005). The Oklahoma Department of Wildlife Conservation currently allows regulated archery and muzzleloader hunting seasons of bears (ODWC 2015). A 20 bear quota is enforced for muzzleloader season, and there is a combined season limit of 1 bear per hunter. At present, bear hunting is permitted in four counties (Latimer, Le Flore, McCurtain, and Pushmataha).

Recolonization of east Texas

Black bear dispersal from these source populations to east Texas is a distinct possibility due to several characteristics of black bear ecology. First, black bears are capable of traversing long distances in search of home range territory. Indeed, straightline dispersal distances range from 3-15 km for females and 13-219 km for males (Beck 1991, Elowe and Dodge 1989, Rogers 1987). Long range dispersal events are usually seen in sub-adult males as they emigrate from their natal home ranges due to mate and resource competition (Costello 2010), although female dispersal does occasionally occur (Rogers 1987, Shwartz and Franzmann 1992). As neighboring populations grow and competition increases, more bears are likely to disperse in search of mates and resources. Dispersal from the expanding neighboring state populations to east Texas, especially by males, is possible; however, it should be acknowledged that unless females are present in the area males may not establish permanent home ranges in the east Texas region. Although black bear populations are expanding in the southern U.S., large portions of the historic range remain unoccupied (Kaminski et al. 2013). East Texas contains some of the largest areas of unoccupied bear habitat in the region, which could hold opportunities for recolonization (Wooding 1994). The majority of available habitat in east Texas lies within the Pineywoods ecoregion (Fig 1.2; 60,864 km²), a matrix of pine, pine-hardwood, and bottomland hardwood forests stretching across rolling topography (Haggerty and Meuth 2015). The variation in forest type, cover, and food sources complements the generalist diet and adaptable nature of the black bear.

Reports of black bear sightings throughout this region have increased since 1977 (Barker et al. 2005), indicating the importance of this region for future black bear natural recolonization and population growth. In response to the increased activity of bears in the region, the Texas Parks and Wildlife Department developed the East Texas Black Bear Conservation and Management Plan in 2005. The report outlines the historic prominence of bears in Texas, and identifies the need for research focused on neighboring state dispersal, habitat, protection, and public and private support for bear recolonization (Barker et al. 2005). In response to the goals established in the plan, the East Texas Black Bear Task Force was created in 2005 to promote restoration of the black bear to the region through planning, outreach, habitat management, and research. To begin focusing management goals and encourage black bear recovery, the Task Force developed the North and South Black Bear Recovery Zones map (Barker et al. 2005). Recent studies utilizing habitat suitability indices (HSI's) have identified specific recovery units within those zones capable of supporting viable black bear populations (Kaminski et al. 2013, 2014). Four recovery units were identified in the South Recovery Zone (SRZ) and two units in the North Recovery Zone (NRZ) (Fig. 1.3 and 1.4). Recovery units were selected based on size and HSI score thresholds deemed necessary to support black bear populations (i.e., \geq 20,700 ha and mean HSI \geq 0.5; Kaminski et al. 2013). The identified recovery units depict the areas in east Texas that are likely to be the focus of natural bear recolonization from dispersing neighboring state populations.

Corridors provide landscape connectivity (Nelson et al. 2003, Dixon et al. 2006); however, the species in question must use the corridors to make them effective. Through genetic sampling and population assignment tests, researchers have documented successful movement of bears between two subpopulations in Florida using the regional Osceola-Ocala corridor (Dixon et al. 2006). To identify such functional corridors through modeling, Cushman et al. (2010) suggested that modelers focus on large-scale connectivity and least resistance paths, rather than the definition of corridors as small, linear bridges between unsuitable habitat patches. Furthermore, corridors should be representative of the needs of the target species and goals of the study (Clark et al. 2015). The Louisiana black bear recovery plan explicitly states the need for identifying and preserving dispersal corridors to maintain and grow future populations (USFWS 1995). Based on current literature and knowledge of black bear ecology, Clark et al. (2015) determined that roads, hydrology, and land cover type were important variables to consider for modeling Louisiana black bear connectivity at a large scale.

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Although HSI studies have documented the presence of suitable habitat in east Texas, there is a lack of information regarding the suitability of habitat occurring between breeding populations in neighboring states and suitable east Texas patches. The Louisiana Black Bear Recovery Plan specifically lists the "protection of the habitat and interconnecting corridors" of black bear populations as a priority criterion for recovery (USFWS 1995). The Black Bear Conservation Coalition also emphasizes the importance of forested corridors for black bear restoration throughout its historic range (Black Bear Conservation Coalition 2015).

Thus, in 2015 this study was initiated to identify suitable habitat corridors for natural black bear recolonization of east Texas from the current source populations in Louisiana, Arkansas, and Oklahoma. We used maximum entropy modeling, a machine learning approach, (Maxent version 3.4.1; Phillips et al. 2006) to create a landscape level habitat suitability map based on physical and human impact variables. The landscape scale evaluation of habitat for interstate black bear movement is an important step in restoring black bears to east Texas and will help inform conservation planning in the region.

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FIGURES



Produced 11/2014 by S. Murphy, Large Carnivore Biologist, Louisiana Department of Wildlife & Fisheries

Figure 1.1. Breeding populations of Louisiana black bear (*Ursus americanus luteolus*) in Louisiana as defined by the Louisiana Department of Wildlife and Fisheries in 2014.



Figure 1.2. The Texas Parks and Wildlife Departments map of Texas ecoregions. The Pineywoods ecoregion (shown in light blue) contains much of the black bear habitat in east Texas.



Figure 1.3. Potential black bear recovery units identified by habitat suitability models in the South Recovery Zone of northeastern Texas by Kaminski et al. (2013) in east Texas.



Figure 1.4. Potential black bear recovery units identified by habitat suitability models in the North Recovery Zone of northeastern Texas by Kaminski et al. (2014) in east Texas.

CHAPTER II: SPATIALLY EXPLICIT MODEL OF AREAS BETWEEN SUITABLE BLACK BEAR HABITAT IN EAST TEXAS AND BLACK BEAR POPULATIONS IN LOUSIANA, ARKANSAS, AND OKLAHOMA

INTRODUCTION

Black bears (*Ursus americanus*), including the Louisiana black bear (*Ursus americanus luteolus*) were once common across east Texas. However, by the early 1900's, unregulated harvest and habitat loss had caused significant population declines across the southern United States. By the 1940's, bears were considered extirpated from east Texas and by the early 1990's only three small remnant populations remained in Louisiana. Amongst growing concerns that bears were continuing to decline, the U.S. Fish and Wildlife Service listed the Louisiana black bear as Threatened under the Endangered Species Act of 1973 (USFWS 1995). This listing provided protection to all bears, including the American black bear, within the Louisiana black bear historic range due to similarity of appearance (USFWS 1995). In 1987, black bears were also declared a state endangered species in Texas (Barker et al. 2005).

Despite similar historic population declines, neighboring states (e.g. Louisiana, Arkansas, & Oklahoma) have been successful recovering their black bear populations and many of these populations appear to be expanding (Barker et al. 2005). Indeed, since 1977 black bear sightings in east Texas have been increasing, with 3 class I sightings confirmed as recently as August 2016 (Barker et al. 2005, Dave Holdermann, Texas Parks and Wildlife Department, personal communication). In response to these early sightings, the East Texas Black Bear Task Force was created in 2005 with the goal of promoting restoration of the black bear to the region. To this end, they developed the North and South Black Bear Recovery Zones map (Barker et al. 2005). Within these zones, six recovery units were identified as being capable of supporting black bear populations (i.e., \geq 20,700 ha and mean HSI \geq 0.5; Kaminski et al. 2013). Although most east Texas sightings are likely solitary, transient males (Barker et al. 2005), the presence of bears in the region combined with the six recovery units identified by Kaminski et al. (2013, 2014), are indicative of the potential for a breeding population to establish in east Texas.

Natural black bear recolonization of east Texas is a long-term, regional process which, to be successful, requires the identification and protection of important movement corridors between source populations in neighboring states and areas in east Texas with potential to support viable populations of black bears (Kaminski et al. 2013, 2014). Due to technological advancements (e.g. GIS, online databases) increasing the availability and accessibility of species occurrence and environmental data (Graham et al. 2004, Franklin 2014), species distribution modeling (SDM) has become a popular method for generating spatially explicit predictive maps of habitat suitability and species distribution (Franklin 2014). Such maps can be applied to a variety of problems including reserve design and conservation planning (Thorn et al. 2009), reintroduction efforts (Hirzel et al. 2004), invasive species risk assessments (Peterson and Robbins 2003), and climate change impacts (Iverson et al. 2008). Generally, SDM's create statistical models (Franklin 2014), which allow for exploration of a target species' current and potential distribution through extrapolating environmental data in space and time. Several modeling frameworks (e.g. Generalized Linear Models, Resource Selection Functions) exist for implementing SDM's (Phillips et al. 2006, Phillips & Dudik 2008). These include Maxent, a machine learning method that operates on the principle of maximum entropy which states that "a probability distribution with maximum entropy (the most spread out), subject to known constraints, is the best approximation of an unknown distribution" (Franklin 2014). The unknown distribution in an SDM context is the multivariate distribution of suitable habitat of a target species and the constraints are the environmental conditions associated with the species presence locations (Philips et al. 2006). Background points provide a sample of the available environmental conditions across the study area to compare with those at presence points. To reach a final solution, Maxent finds the model which can best differentiate presences from background points.

The main advantages of Maxent over other modeling options are that it does not require absence data when generating predictions and it is robust to small sample sizes (Franklin 2014). Often, absence data cannot be or are not collected because of the extensive time and money required; thus, presence-only datasets are more readily available (Zaniewski et al. 2002). In addition, Maxent is able to process extremely large datasets at a faster rate than other software packages such as R Statistical Computing software, making it ideal for landscape scale studies (e.g. black bear recolonization of east Texas). Furthermore, Maxent consistently outperforms other presence-only and
presence-absence techniques (e.g. GLM's, GARP, ENFA, BIOCLIM) in terms of predictive accuracy (Elith et al. 2006, Phillips et al. 2006, Elith and Graham 2009). Due to the advantages mentioned above, the use of Maxent for SDM analyses is widespread in the conservation literature, with over 1,000 publications since 2006 (Merow et al. 2013).

Considering the expansion of black bear populations in neighboring states, the known existence of large expanses of suitable habitat in east Texas (Wooding et al. 1996, Kaminski et al. 2013, 2014), and the increased activity (sightings) of black bears in east Texas, it is reasonable to assume that black bears have a reasonable probability of naturally recolonizing parts of their historic range. Based on this evidence, we initiated a two-phase research project to identify and describe corridors and likely movement paths for dispersal of black bears from source areas in Louisiana, Arkansas and Oklahoma to suitable habitats in east Texas. This study represents Phase I, the main goals of which were to 1) model suitable black bear habitat within the study area and 2) identify habitat zones which could be used for dispersal from source populations in Louisiana, Oklahoma and Arkansas to east Texas. Phase II of the project will utilize the habitat suitability map created in Phase I to identify the most likely movement path bears will take to reach quality habitat in east Texas. Results of this study could be used to facilitate black bear recolonization through informing habitat management decisions and aiding in the selection and designation of protected habitat patches important to bear movement.

STUDY AREA

Our study area covers 417,076 km² extending from east Texas into Louisiana, Oklahoma, and Arkansas (Fig. 2.1). The study area was bounded by the north and south recovery units in east Texas, and known black bear presence locations in Louisiana, Oklahoma, and Arkansas. Four broad forest categories fall within the study area; 1) Eastern Deciduous, 2) Southern Oak-Hickory-Pine, 3) Southern Floodplains and 4) Southeastern Coastal Plains Forests (Kershner et al. 2008). Although sub-groupings exist, these land-scape scale categories best match the scale of our study area.

The eastern deciduous forest type is the second largest in North America, extending from Texas and Louisiana, east to Georgia, and north to Minnesota, Maine, and Quebec (Kershner et al. 2008). A broadleaf canopy with few conifers and moderately dense understory are characteristic of this forest type (Kershner et al. 2008). Gums *(Nyssa* sp.), sweetgum *(Liquidambar styraciflua)*, oaks *(Quercus* sp.), maples *(Acer* sp.), ashes *(Fraxinus* sp.), elms *(Ulmus* sp.) and hickories *(Carya* sp.) are common (Kershner et al. 2008). Southern Oak-Hickory-Pine forests are a variant of the eastern deciduous forest type, differing primarily in the prevalence and occasional dominance of several pine species including loblolly *(Pinus taeda)* and shortleaf *(Pinus echinata*; Kershner et al. 2008).

Southern floodplain forests occur at low elevations along rivers and other waterways. Historically, these communities experienced regular flooding events; however, construction of levees and dams has significantly altered the natural flood regimes and has allowed for conversion to agriculture (Kershner et al. 2008). Baldcypress (Taxodium distichum) and water tupelo (Nyssa aquatica) are the dominant tree species; Sweetgum, American sycamore (*Platanus occidentalis*), American hornbeam (Carpinus caroliniana), and hickories, ashes, elms and oaks also can also be found (Kershner et al. 2008). Although the southeastern coastal plains forests are similar to southern floodplain forests in terms of geographical location, they vary considerably in species composition and importance of fire (Kershner et al. 2008). Unlike the hardwood dominated southern floodplains, pine uplands with few patches of hardwoods are characteristic of the southeastern coastal plains. A subgroup within the southeastern coastal plains is the longleaf pine (*Pinus palustris*) upland forest, which extends from eastern Texas east to Virginia (Kershner et al. 2008). Once covering 36,421,707 ha this forest type has been drastically reduced due to logging and human expansion. Longleaf pine upland communities are fire dependent, and therefore rely on prescribed burning to maintain their natural fire regime (Kershner et al. 2008). Common understory species are persimmon (*Diospyros virginiana*), turkey oak (*Quercus laevis*) and bluestem grasses (Andropogon sp.), among others (Kershner et al. 2008).

METHODS

I used a SDM approach in program Maxent version 3.4.1 (Philips et al. 2006) to model the likely distribution of black bear habitat across the described areas of Arkansas, Louisiana, Oklahoma, and Texas. The Maxent approach requires only known locations (presences) within the area of interest and derives a probability distribution based on comparisons between these presences and background locations. Thus, the process consisted of four primary steps: gathering presence data, collection of environmental data that potentially influence bear occurrence, model construction and evaluation, and model analysis.

Presence Data Collection and Processing

Presence points are locations where black bears have been known to occur within the study area. These points are used by Maxent to determine the environmental characteristics that are found concurrently with black bear presence. I compiled black bear presence locations from Texas, Louisiana, Oklahoma and Arkansas (n= 18,241) available from state and federal agencies. Presence data took several forms depending on the data collected by the relevant state agency or research effort in each state. For Texas, I obtained all confirmed class I black bear sightings in east Texas since the 1970's (Texas Parks and Wildlife Department, unpublished data). The Texas Parks and Wildlife Department has collected black bear sightings in their region since the early 1970's and classified them by the reliability of the sighting. Class I sightings are considered the most reliable and consist of verifiable tracks or scat, photo evidence or black bear carcasses (Barker et al. 2005). Presence points for Louisiana were a combination of GPS radio telemetry data and capture locations collected by the Louisiana Department of Wildlife and Fisheries (LDWF) from 1992 to 2014 (Laufenberg and Clark 2014, LDWF, unpublished data). The Arkansas presences were VHF and GPS radio telemetry locations obtained by the Arkansas Game and Fish Commission from 1993 to 2014 (AGFC, unpublished data). Lastly, Oklahoma presences were derived from bait station lines maintained annually by the Oklahoma Department of Wildlife Conservation (ODWC). A total of eighteen station lines with 348 stations (e.g., approximately 20 per line) were monitored for black bear visitation from 1999 to 2014. Because I did not have precise bait station locations, I randomly generated points along station lines with at least one detection based on ODWC's site descriptions and methodology (i.e. 20 stations per line, at least 0.80 km apart and 18 meters from the line). All location data were cleaned for duplicates and errors.

Spatially auto correlated presence points can falsely inflate model evaluation metrics (e.g. Area Under the Curve) and result in over fitting (Boria et al. 2014). To reduce the influence of spatial autocorrelation and bias in the model I implemented spatial filtering of the presence points. This technique has been successful in reducing sampling bias and improving model performance by reducing the chances of having nonindependent presence points in the analysis (Boria et al. 2014, Fourcade et al. 2014). I spatially filtered the data by creating a fishnet of grid cells the same size as the average female black bear home range in the southern U.S. (e.g. 12 km²; Benson and Chamberlain 2007) and randomly selecting one presence point per cell using the Sampling Design script tool (Fourcade et al. 2014) in ArcGIS 10.5 (ESRI 2017). This subset of point locations (n=664) was then exported to an Excel file for input to Maxent. Of the filtered locations, 391 were in Louisiana, 135 were in Arkansas, 100 were in Oklahoma, and 38 were in Texas.

Because the presence data came from a variety of sources with differing sampling efforts and methodologies, we needed to take steps to further alleviate sampling biases. Common sampling biases include clustering of the sample points within a species range (e.g., over or under sampling certain areas within species range), and variation of sampling intensity across the range (Fourcade et al. 2014). If unaddressed, sampling biases can result in misleading outcomes such as under sampled habitats being classified as unsuitable. Therefore, I created a bias file which defined where Maxent would select background points. In Maxent, background points are used to compare the available environmental conditions in the study area with those environmental conditions selected by the target species at presence points (Merow et al. 2013). One method to mitigate bias is to "factor it out" by selecting background points with the same bias associated with the presence data (Dudik 2005, Elith 2010, Syfert et al. 2013). Bias files instruct Maxent to select background points from certain places based on estimated sampling effort, rather than randomly across the study area. To generate the bias file, I assumed that survey

effort was limited to counties and parishes with at least one presence. Within ArcMap, these counties and parishes were selected and exported as a separate shapefile and assigned a sampling effort value of 1 while the rest of the study area had sampling effort values of 0 (Young et al. 2011). Thus, the background samples were all selected from the counties or parishes assumed to have been sampled and therefore suffered from similar biases as our presence points.

Variable Data Collection and Processing

I selected the initial set of environmental variables (Table 2.1) based on black bear ecology and habitat preferences in the region (Clark et al. 2015, Brown 2008). Quality black bear habitat typically consists of large tracts of mast producing forest with little human disturbance (Rudis and Tansey 1995, U.S. Fish and Wildlife Service 1995, Benson and Chamberlain 2007). The presence of agricultural fields (Benson and Chamberlain 2007) and streams (Brown 2008) have also been associated with increased black bear presence. In contrast, high proximity to roads and human development appears to negatively influence bear presence (Quigley 1982, Brody and Pelton 1989) and survival due to the increased chances of human-bear contact (Apps et al.2004).

To account for these habitat characteristics and factors in our model, I compiled the most recent, representative GIS datasets available. We used the National Land-Cover Database (NLCD) 2011 (Homer et al. 2015) as the basis for our land-cover variables, and reclassified the original 16 cover types in ArcGIS (Table 2.2) to create a mast-producing forest variable consisting of the deciduous forest, woody wetland and mixed forest cover types (Clark et al. 2015). Due to the prevalence of pine forests in east Texas, I also created an evergreen forest variable. The human development variable consisted of the low, medium, and high development intensity (i.e. percent of impervious surfaces) landcover classes. Cultivated crops and open water land-cover types were also extracted through reclassification. I obtained protected habitat from the Protected Areas Database of the United States (USGS Gap Analysis Program, 2016) which includes mostly public lands at both federal and state levels (e.g. National Forests, Wildlife Management Areas, state parks). Federal and state lands were the predominant focus as these areas have substantial long-term protection and ownership and management stability (Gantchoff & Belant 2017). Some lands protected by long term lease agreements and easements are also included if they were documented in an agency management plan. I used TIGER/Line shapefiles to create the rivers and roads variables (U.S. Bureau of the Census 2011). I reclassified the hydrology shapefile to contain only the "Stream/River" feature class type (natural flowing waterways). Canals, aqueducts and other human-made hydrological features were excluded from the analysis. Primary and secondary roads were reclassified as one variable (roads).

Cushman et al. (2010) suggested that animals experience land-cover types (e.g., categorical data) as environmental gradients that vary based on the species' perception of the habitat. Thus, converting categorical raster variables to some form of meaningful gradient at the scale the species experiences their surroundings may be more informative

(Cushman et al. 2010). I converted our categorical raster variables into gradient or continuous variables, specifically Euclidean distance to and percent of each individual variable. In ArcGIS, I estimated distance to our land cover variables by calculating for each raster cell the Euclidean distance from the center of the cell to the nearest target land cover class. Percent of each land cover class was calculated using the Percent Class tool in ArcGIS by specifying a moving window radius of 1,000 m within which the percent of a given land cover class was calculated and that value was assigned to the central pixel of the window. Additionally, we tested all input variables for high collinearity ($R^2 \ge 0.70$; Kalle et al. 2013) using the Band Collection Statistics tool in ArcGIS prior to use in the model. Lastly, the black bear presence shapefile and all variables were processed to have the same projection (NAD_83_Albers) and all variables were converted to raster format (ASCII) with the same cell size (30-m) and extent, as required by Maxent.

Modeling Procedure

To build our models, I used Maxent 3.4.1, with cloglog (complimentary log log link) output, which provides a probability of presence (i.e., habitat suitability) map ranging from 0-1 (Philips et al. 2006, Philips and Dudik 2008, Fourcade et al. 2014). In machine learning algorithms such as Maxent, predictor variable covariates and their mathematical transformations are referred to as "features" (Elith et al. 2010). Maxent is capable of building models based on highly nonlinear features by fitting the predictor data to different feature classes (linear, hinge, quadratic, product, or threshold) (Elith et al. 2010).

al. 2010, Merow et al. 2013). By default, Maxent determines which feature classes to use based on the number of presences (Merow et al. 2013). In our case, we had more than 80 presence points after spatial filtering (n=664), thus all feature classes were used (Philips and Dudik 2008, Elith et al. 2010).

Maxent utilizes regularization multipliers to select the individual features for each predictor that contribute most to model gain (Merow et al. 2013). It restricts model complexity and protects against overfitting by ensuring model constraints are not fit too closely and by penalizing for large feature coefficients (Philips et al. 2006, Anderson and Gonzalez 2011). Thus, it essentially smooths the model with larger numbers increasing the level of smoothing (Young et al. 2011, Merow et al. 2013). The default regularization setting of 1 was based on extensive model testing and performance evaluation across many taxonomic groups; however, species-specific tuning is recommended when modeling single species (Philips and Dudik 2008, Elith et al. 2010). Increasing the regularization relaxes model constraints and results in a more generalized prediction, thereby ensuring the predicted suitable habitat does not fit the observed presences too closely. We tested 10 different regularization parameters (e.g., 1 through 10), with default feature classes, and randomly selected 30 percent of our presences to set aside for model testing.

Model Selection and Evaluation

To evaluate and select our final model I used threshold-independent measures (Radosavljevic and Anderson 2014, Muscarella et. al 2015). Specifically, I used area under the receiver-operator curve (AUC) which measures overall predictive accuracy by determining the probability that a random presence location is ranked higher than a random background point (potentially un-sampled location; Philips et al. 2006). AUC scores can range from 0-1 with 1 indicating optimal discrimination and values less than 0.5 meaning model discrimination is no better than random (Ward 2007). Models with AUC values above 0.75 are generally considered to be useful or "sufficiently discriminatory" for most modeling efforts (Elith 2002). However, because AUC is calculated based on the area of suitable habitat available, model comparisons using AUC are only valid for models run with the same species and study area (Lobo et al. 2008, Radosavljevic and Anderson 2014). I selected the final model based on maximum test AUC (AUC TEST). Although AUC is a widely used measure of model fit in the Maxent literature (Philips et al. 2006, Merow et al. 2013, Elith 2002), there is a lack of consensus regarding the best way to evaluate ecological niche models, including whether AUC is appropriate as a stand-alone measure (Lobo et al. 2008, Warren & Seifert 2011). Therefore, I utilized the AUC differential (AUC DIFF) which is the difference in test and train AUC (AUC TRAIN) scores. This provides another evaluation method that has been used in conjunction with AUC TEST, to aid in evaluating potential over fitting of the

models (Philips 2006, Ward 2007, Radosavljevic and Anderson 2014, Muscarella et al. 2015).

Calculating AUC _{DIFF} provides a threshold-independent measure of overfitting (Warren and Seifert 2011, Radosavljevic and Anderson 2014). Models with high AUC _{TRAIN} but low AUC _{TEST} are likely over fit to the training data; therefore, minimizing that difference lessens the risk of an over fit model (Warren and Seifert 2011). I followed the model selection protocol used in Radosavljevic and Anderson (2014) to identify the final model. Specifically, I considered the best models to be those which 1) minimized AUC _{DIFF}; and 2) maintained a high AUC _{TEST} score (Radosavljevic and Anderson 2014). Once the final model settings were selected, I performed 4 iterations of the model and used the average of those runs as our final map. Standard deviation of AUC _{TEST} was calculated to provide an indication of how consistent the model performance was over multiple runs.

Model Analysis

To aid in model interpretation and analysis I implemented thresholding rules which generate binary prediction maps (i.e. suitable or unsuitable). Pixels greater than or equal to the threshold are considered suitable. I used the 10th percentile training threshold available in Maxent which utilizes the suitability threshold of the training presence record below which 10 percent of presence records suitability's fall. This results in a more conservative predictive map by excluding the lowest 10% of predicted presence suitability scores from the binary predictive map. I also compared my model predictions to the east Texas recovery units to determine what percentage of the recovery unit pixels identified by Kaminski et al. (2013, 2014) were also predicted as suitable pixels in my model. To better understand which variables were most important to the model I utilized the permutation importance percentages provided in the Maxent output files. Permutation importance is calculated by randomly permuting the values for each variable on training and background data and measuring the drop in AUC_{TRAIN}. A larger drop in AUC_{TRAIN} indicates that the variable is particularly important to the model (Young et al. 2011). The permutation importance values are then normalized to percentages. I also analyzed the variable response curves and various jackknife tests of variable importance graphs provided in the Maxent output files. The jackknife tests systematically exclude each variable and runs a model with the remaining variables. They also create a model with each variable in isolation, thus providing an additional measure of variable importance.

To identify potential dispersal zones from Louisiana, Oklahoma and Arkansas to east Texas, I created buffers of 3,500m (approx. half the average female black bear home range size) around the 10th percentile threshold habitat suitability patches and selected zones with high suitable habitat connectivity between source populations and the Texas border. Within each identified movement zone, I ran class level analyses in FRAGSTATS (McGarigal et al. 2012) to quantify the proximity of suitable patches to one another and the level of connectivity in each zone. Specifically, I focused on the mean proximity index (PROX) and connectivity index (CONNECT) metrics. PROX measures the average level of isolation and fragmentation of a specific patch type by summing the area of the patch type and dividing it by the nearest edge-to-edge distance between the focal patch and patches of the same type within a specified search radius (McGarigal et al. 2012). In this case, patch type was all "suitable habitat" cells from the 10th percentile threshold map and the search radius was 3,500 m. PROX is a unitless index, with PROX=0 for patches with no other patches falling within the search radius and increasing as patches become closer and less fragmented (McGarigal et al. 2012).

CONNECT calculates a percentage representing the degree of connectivity among specified patch types (McGarigal et al. 2012). It is calculated by summing the number of functional connections between all patches of a specific type divided by the total number of possible connections between all patches of the same type, multiplied by 100 to convert to a percentage (McGarigal et al. 2012). To be considered functionally connected the patches must fall within a specified distance of one another, in this case 3,500 meters. Connectivity values range from 0 to 100 with higher percentages indicating a higher degree of connectivity (McGarigal et al. 2012).

To gain a deeper understanding of the dispersal and functional connectivity potential in the study area, I identified "stepping-stone" patches within each zone. Suitable patches greater than or equal to 12 km² were selected and classified within ArcGIS as stepping-stone patches which may provide short-term resting and refuge areas for bears during dispersal events while also providing long-term habitat for several dispersing individuals (Almasiah et al. 2016). (Almasiah et al. 2016). Lastly, buffers of 3,500 m were generated around each of these patch types to determine the level of functional connectivity in each zone.

In addition, I was interested in examining how future urbanization and human development may impact potentially important bear habitat. Therefore, I obtained raster layers from the SLEUTH Urban Growth Model (Southeast Regional Assessment Project). This model predicts urbanization risk for up to 100 years into the future based on specific urban growth rules (e.g., spontaneous growth, new spreading urban centers, edge-growth and road-influenced growth). I overlaid these maps with our habitat suitability map and extracted the cells which overlapped with our suitable habitat predictions to identify areas which may be at risk of future human development and urbanization.

RESULTS

Model Selection and Variable Analysis

Based on the evaluation criteria, the model with a regularization parameter of 8 was selected as our final model (Fig. 2.2). This model had the lowest AUC $_{DIFF}(0.01)$ (Fig. 2.3), indicating low overfitting, and maintained an acceptable average test (0.788) and training (0.802) AUC values (Fig.2.4) implying good overall model performance (Fig.2.5). The standard deviation of AUC_{TEST} over four replicates of the model was 0.013 indicating the predictions were relatively consistent. None of the variables was highly correlated ($R^2 \le .70$), thus all 16 predictor variables were input and retained by the model. The percentage of mast producing forest variable contributed the most to the model according to permutation importance (42.9%), followed by percentage of cultivated crops (32.8%), and percentage of protected lands (9.2%; Table 2.3). The jackknife test of variable importance on regularized training gain revealed that percentage of mast producing forest increased model gain the most when used alone, followed by distance to and percent of protected areas and percent of evergreen forest (Fig.2.6). Percent mast producing forest also decreased model gain the most when it was omitted, indicating it had the most information not present in the other variables. The same jackknife test using AUC on test data rather than model gain revealed that distance to protected areas, distance to and percent of mast producing forest areas increased AUC_{TEST} the most when used in isolation (Fig. 2.7). However, percentage of protected areas and percentage of

mast producing forest decreased AUC_{TEST} equally when individually excluded. The response curves (Fig. 2.8) generated by Maxent show how the prediction changes when the model is generated using only individual variables. The response curves show that predicted suitability for percent cultivated crops follows a bell curve and begins to decline at 50% cultivated crops. Suitability increases as percentage of mast producing forest and protected areas increases.

Anthropogenic variables (e.g. percent of and distance to roads and human development) contributed about 3 percent (2.8%) to AUC_{TRAIN} gain of the model (sum of individual variables permutation importance). The most important anthropogenic variable alone was percent human development (2.4% contribution) followed by distance to human development (0.4% contribution). Analysis of these variable response curves show that predicted suitability is low near human development, and then increases sharply at 2,000 m before leveling out. Suitability decreased with increased percentage of human development, decreased with increased percentage of roads and was relatively unaffected by distance to roads. Analysis of the SLEUTH model revealed that 4.3% of the suitable cells predicted in my 10th percentile model will be at risk of urbanization by 2100 (Fig.2.9).

Habitat Suitability and Movement Zones

The 10th percentile suitability threshold of the model was 0.23, therefore, only suitability scores above 0.23 were mapped in the binary prediction. This means 90% of

our presences had a suitability score greater than 0.23. This binary map predicted 43.7% percent of the pixels in the study area as suitable (Fig. 2.10). In addition, 53.7 % percent of the pixels identified as potential recovery units by Kaminski et al. (2013, 2014) were considered suitable in the model (Fig. 2.11). Based on proportion of suitable habitat and location, I identified three zones with the potential to provide habitat linkages for black bear dispersal extending between known bear locations in neighboring states and the Texas border (Fig. 2.12). Zone 1 encompasses 16,142 km² between breeding populations in south-central Louisiana and the Lower Sabine recovery units lying along the southeast Texas border. Although the majority of Zone 1 is unprotected, my model predicted large areas of suitable habitat within it that bears could use to disperse, thus this region was delineated as a movement zone (Fig. 2.13). Zone 2 was derived based on the location of the Repatriated and Upper Atchafalaya River Basin black bear populations and the Upper Sabine River recovery units in east Texas (Fig. 2.14). This zone, covering 32,125 km², was chosen in part because of the presence of the Kisatchie National Forest and several state wildlife management areas which are likely to be important refuges for dispersing individuals. Zone 3 lies between the breeding population in southeast Oklahoma and Sulphur River recovery units located along the Sulphur River in Texas (Fig. 2.15). Aside from having a high proportion of suitable predicted habitat, this zone was also selected to include portions of the Ouachita National Forest which provides an important connection to bear populations in Arkansas.

Of these zones, Zone 1 had the highest CONNECT score at 0.99 followed by Zone 2 (0.44) and Zone 3 (0.38) (Table 2.4). Zone 1 also had the highest PROX score (224,367.5) while Zone 3 had the second highest score (41,400.6) followed by Zone 2 (24,101.5) (Table 2.4). I also calculated mean suitable patch size for each zone. Zone 1 had the largest mean patch size (3.23 km²) while Zone 2 had the second largest (2.68 km²) and Zone 3 had the smallest (2.35 km²) (Table 2.4). The number of stepping-stone patches were also aggregated by zone (Table 2.4). Zone 2 had the most stepping-stone patches (58), while Zone 1 had the fewest stepping stone patches (17) of the three zones.

DISCUSSION

Current literature on black bear habitat suitability and connectivity in the southcentral United States can be grouped into two categories; small scale, regional habitat suitability studies (Kaminski et al. 2013, 2014) and broad population connectivity analyses (Clark et al. 2015, Gantchoff and Belant 2017). Though informative, a combination of landscape-scale habitat suitability and connectivity analysis techniques is needed to adequately assess where bear habitat exists at a landscape level and how bears may use said habitat for dispersal and re-colonization. This study presents phase one of the first multistate, landscape scale habitat suitability and connectivity analysis for Louisiana and American black bears in the region.

The final Maxent model prediction of suitable habitat (HSI≥ 0.76) largely coincided with known black bear distributions in Louisiana, Oklahoma and Arkansas (see Fig. 2.11, Fig. 2.16). The variable importance outputs produced by Maxent generally reflected established facets of bear ecology and biology associated with habitat suitability such as the importance of mast producing forests, cultivated crops and protected areas (Black Bear Conservation Coalition 2015, Benson and Chamberlain 2006, Weaver 1999, USFWS 1995). The importance of cropland and forested areas may also be influenced by the majority of our presences coming from Louisiana populations which occurred predominantly within a matrix of agriculture and croplands. Despite this potential effect, it was determined that the predictions generated by Maxent were still representative of bear habitat due to the generalist nature of bears and the documented use of such habitats in the literature. However, the distance to and percent of roads and rivers variables contributed very little to the models' AUC _{Train} score and had very little influence on suitability even though these variables are usually reported as strong predictors of black bear habitat suitability (Clark et al. 2015, Simek et al. 2015, Black Bear Conservation Coalition 2015). This is likely an effect of the spatial resolution of the variables used in this model. The relatively coarse resolution (30-m x 30-m cells) used in the model may not be ideal for representing small linear features, such as roads and streams. Such large grid cells cause linear features to be aggregated and values averaged across the cell, meaning that the spatial accuracy of these features is reduced (Vuilleumier and Metzger 2006). Thus, the accuracy of the species' responses to these variables is also affected. Future research should consider multi-scale HSI modeling of the region to determine how scale influences suitable habitat predictions.

It is also plausible that although roads may increase mortality risk for bears they are not actively avoiding them. Indeed, black bears in the Ocala National Forest in Florida exhibited frequent road crossings, most of which were successful (Cunningham et al. 2001). Furthermore, smaller, low traffic, residential and ATV roads exhibit positive relationships with black bear occurrences possibly by allowing for easier movement (Drasher 2017). Thus, from a black bear occurrence perspective, roads may not necessarily be a negative factor.

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Despite differences in scale, variables and methodology the model was also able to confirm the presence of suitable bear habitat within the black bear recovery units previously identified in east Texas (Kaminski et al. 2013, 2014). Although female bears are typically philopatric, male bears will disperse up to 218 km from natal home ranges to establish their own ranges (Rodgers 1987, Barker et al. 2005). Therefore, identification and affirmation of suitable, unoccupied bear habitat (i.e. east Texas recovery units) within dispersal distance of existing populations is pivotal for providing new areas for young males to establish home ranges. However, in terms of re-colonization, male-biased dispersal can become problematic by limiting mating options and reducing the odds of establishing a breeding population. Indeed, no confirmed sightings of females with cubs have been documented in east Texas suggesting that most bear sightings are likely transient males dispersing from expanding populations in neighboring states (Barker et al. 2005).

Stepping-stone populations have been shown to facilitate both female and male dispersal by allowing population establishment or resting points within functionally connected patches of suitable habitat (Almasieh et al. 2016, Clark et al. 2015). The three movement zones, habitat patches, and buffers delineated in this study allow for a deeper understanding of dispersal and functional connectivity potential across the landscape. Zone 1 extends east from the southeastern Texas-Louisiana border to Lafayette and St. Landry parishes in Louisiana (Fig. 2.13). Although this region achieved the highest CONNECT and PROX scores of the three zones, it was also the smallest with the least number of suitable patches. The low number of suitable patches available directly influences the CONNECT score calculations by reducing the divisor (potential connections), thus resulting in a higher number. Similarly, this zone also had the largest mean patch size, causing the PROX score to be larger due to the contiguity of the patches. Of the suitable patches in the zone, 17 were classified as stepping stone patches (Fig. 2.17). These stepping stone habitats create functional habitat linkages from known bear locations in Louisiana to the Texas border (Fig. 2.17). The main linkage connecting the eastern and western portions of the zone is dependent on two stepping stone patches (patch 7 and 8). These patches shorten the travel distance between larger patches and may provide temporary refuge to dispersing bears, thereby providing them a reasonable chance of reaching east Texas. However, pockets of high human development occurring within the zone, such as Lake Charles (Calcasieu Parish), may impede bear movement. In fact, Calcasieu Parish is one of the last parishes bears must cross through in this Zone to get to the Texas border, yet it contains relatively few suitable habitat patches (Fig. 2.17). Thus, prioritizing protection of existing suitable habitat within Calcasieu Parish, particularly the stepping stone patches identified in this study, as well as educating the public about human-bear coexistence may be necessary to facilitate bear dispersal to the border.

Zone 2, situated north of Zone 1, extends northwest from upper Avoyelles, central Concordia and southwestern Tensas parishes into Shelby, Panola, Harrison, Marion and Cass counties in east Texas. Zone 2, the largest of the three zones, had the second highest CONNECT score (44%) and the lowest PROX score which can be attributed to the relative isolation of patches across this zone. Nonetheless, functional connectivity exists amongst the 60 stepping stone patches identified in the zone. As in Zone 1, several of the patches were essential to creating functionally connected habitat linkages from Louisiana to east Texas and should be considered high conservation priorities (Fig. 2.18). Within this zone, many of the stepping stone patches also fell within protected areas such as the Kisatchie National Forest and Lake Ophelia NWR (Fig 2.18). Due to the stability in ownership and management, these protected areas are particularly valuable to long-term black bear habitat suitability and connectivity. National Wildlife Refuges are required to develop Comprehensive Conservation Plans (CCP) every 15 years and those within Louisiana black bear range, such as Lake Ophelia NWR, specifically focus on black bear management (USFWS 2015). Additionally, these protected areas may provide refuge from busy urban areas (e.g., Alexandria, Natchitoches and Shreveport) as bears move west from the Repatriated and Tensas River Basin populations in Louisiana towards Texas. However, Interstate 49, which runs diagonally across Zone 2, may be problematic for bears attempting to disperse west (Fig. 2.18). Determining where bears are likely to attempt crossings and installing tunnels or overpasses may help to mitigate the problem while facilitating recolonization (Black Bear Conservation Coalition 2015).

Zone 3 focuses on the Texas-Oklahoma and Oklahoma-Arkansas border. It encompasses most of Bowie, Red River and Lamar counties in northern Texas and extends up to Pushmataha, McCurtain and Atoka counties in Oklahoma. In the east it extends into Polk, Sevier and Little River counties in Arkansas. Although Zone 3 had the highest number of suitable habitat patches it had the lowest CONNECT score (38%). This indicates that the number of functional connections amongst the patches was small in comparison to the total number of potential connections. However, the buffer analyses of the 58 stepping stone patches show strong functional connectivity (Fig. 2.19). This discrepancy may be due to the prevalence of small (< 12 km²) habitat patches inflating the number of potential connections (i.e. the divisor) in the CONNECT calculations. Of the three zones, this zone had the second most stepping-stone patches and was the only zone to achieve functional connectivity using patches greater than or equal to 50 km². As bears continue to expand from populations in Arkansas and Oklahoma, the availability of these stepping-stone patches will be integral in facilitating female dispersal and population establishment in east Texas. In fact, the concentration of class I bear sightings recorded in Red River and Lamar counties suggests that bears are already utilizing this zone for movement.

Although black bears are adaptable, further habitat loss, fragmentation and development would undoubtedly impact their ability to disperse and recolonize east Texas. Analysis of the overlap between the SLEUTH model and the Maxent model revealed that 4.3% of the suitable cells predicted in the 10th percentile model will be at risk of urbanization by 2100 (Fig.2.9). Although the majority of at risk habitat was predicted as unsuitable by the model, the increased human activity predicted around suitable regions may negatively affect the quality of those habitats in the future.

Specifically, Tensas Parish, which contains the Tensas River Basin population of black bears, is predicted to see several pockets of new and expanding development throughout the Parish. Such development in this region would reduce the quantity and quality of existing suitable bear habitat in Louisiana. For successful re-colonization of east Texas to occur, the current bear populations must be vigilantly protected against future fragmentation, degradation and decline. Encouragingly, Oklahoma, southwest Arkansas and northeast Texas appear to have a relatively low risk of development according to the SLEUTH model.

The results of this study demonstrate that substantial suitable habitat does exist between the east Texas recovery units and source populations in Louisiana, Oklahoma and Arkansas. The identification of stepping-stone patches based on the HSI map offers managers a concrete tool for understanding which areas hold potential for regional connectivity and where conservation and public relations efforts need to be focused. Garnering public support in areas with suitable habitat through education and coexistence strategies may facilitate natural re-colonization by helping to ensure safe passage for dispersing bears. The next phase of this research will identify the most likely paths bears will take to reach east Texas based on the continuous habitat suitability map created in this study as well as provide a timeline estimating how long the re-colonization process may take. As humans continue to expand and develop natural lands in black bear territory, it is increasingly important to identify and protect essential habitats and bear populations from further fragmentation and isolation. The findings in this study contribute to that end by identifying areas of conservation interest and providing a model of suitable habitat which can be utilized to improve connectivity and increase the probability of restoring the American and Louisiana black bear to a portion of their historic range.

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FIGURES

Figure 2.1. Extent of study area used for modeling black bear movement corridors in Arkansas, Louisiana, Oklahoma and Texas. The study area is bounded by the recovery units in east Texas and known black bear locations in Louisiana, Arkansas and Oklahoma.



Figure 2.2. Continuous black bear habitat suitability map generated by Maxent for the area between source populations in Louisiana, Arkansas and Oklahoma, and recovery units in east Texas.



Figure 2.3. Comparison of model-overfitting using the Area Under the Receiver Operating Curve differential (AUC_{DIFF}) evaluation criteria across ten Maxent models built with different regularization parameters. Low AUC_{DIFF} indicates less over-fitting.



Figure 2.4. Comparison of black bear habitat suitability model performance using the Area Under the Receiver Operating Curve (AUC) evaluation criteria across 10 Maxent models built with different regularization parameters. A higher AUC indicates better predictive accuracy and discrimination.


Figure 2.5. Evaluation of the final black bear habitat suitability Maxent model performance using Area Under the Receiver Operating Curve (AUC). AUC of the final model (shown in red) is above the random prediction line (shown in black) indicating the model performed better than random. False positive rate (specificity) is shown on the X-axis and True positive rate (sensitivity) is shown on the Y-axis.



Figure 2.6. A jackknife test of variable importance to mean regularized training gain of the final continuous black bear habitat suitability model generated by Maxent. Percentage of mast producing forest increased model gain the most when used alone, followed by distance to and percent of protected areas and percent of evergreen forest. Percent mast producing forest decreased model gain the most when it was omitted, indicating it had the most information not present in the other variables.







Figure 2.8. Variable response curves of the final continuous black bear habitat suitability model generated by Maxent. Variable response curves indicate the dependence of predicted suitability on each variable.



Figure 2.9. Proportion of suitable habitat (shown in yellow) predicted by the 10th percentile threshold Maxent model which is at risk of urbanization by 2100 according to the SLEUTH Urban Growth Model.



Figure 2.10. Proportion of suitable black bear habitat (shown in red) predicted by the 10th percentile threshold model generated by Maxent from bear presence locations in Louisiana, Oklahoma, Arkansas and Texas.



Figure 2.11. Proportion of black bear recovery zones in east Texas (shown in red) that were also identified as suitable habitat in the 10th percentile threshold habitat suitability model generated by Maxent from bear presence locations in Louisiana, Oklahoma, Arkansas and Texas.



Figure 2.12. Delineation of three black bear movement zones (shown in blue, green and black) identified from the 10th percentile habitat suitability map generated by Maxent. These zones extend from source populations in LA, AR, and OK to east Texas recovery units.



Figure 2.13. Delineation of black bear movement Zone 1, identified from the 10th percentile habitat suitability map generated by Maxent. Zone 1 extends from the Lower Sabine Recovery unit in east Texas to known black bear presences in south-central Louisiana.



Figure 2.14. Delineation of black bear movement Zone 2, identified from the 10th percentile habitat suitability map generated by Maxent. Zone 2 extends from the Upper Sabine Recovery unit in east Texas to known black bear presences in south-central Louisiana.



Figure 2.15. Delineation of black bear movement Zone 3, identified from the 10th percentile habitat suitability map generated by Maxent. Zone 3 extends from the Sulphur River recovery unit in east Texas to known black bear presences in southern Oklahoma.



Figure 2.16. Identification of highly suitable habitat predicted by the final continuous habitat suitability map generated by Maxent which overlaps with known black bear breeding populations in Louisiana.



Figure 2.17. Functional connectivity buffer zones, stepping stone patches identified in movement zone 1 based on the 10th percentile black bear habitat suitability map generated by Maxent. The positional importance and possible hindrance of Calcasieu Parish (shown in dark blue) and Lake Charles for bears dispersing into east Texas is also depicted.



Figure 2.18. Functional connectivity buffer zones, stepping stone patches identified in movement zone 2 based on the 10th percentile black bear habitat suitability map generated by Maxent. Zone 2 contained a prevalence of stepping-stone patches within the Kisatchie National Forest (shown in black) and Lake Ophelia NWR (shown in red) as well as I-49 which may act as a barrier to dispersal through the zone.



Figure 2.19. Functional connectivity buffer zones, stepping stone patches identified in movement zone 3 based on the 10^{th} percentile black bear habitat suitability map generated by Maxent.

TABLES

Table 2.1. Variables used to develop black bear habitat suitability models in Maxent. All variables were based on 30-m cell sizes.

Variable (units)	Source	Procedure
Distance to mast-producing forest (m)	2011 National Land Cover Database, combined woody wetlands, deciduous forest, and mixed forest	Calculated Euclidean distance to nearest mas- producing forest
Percent of mast-producing forest (%)	2011 National Land Cover Database, combined woody wetlands, deciduous forest, and mixed forest	Neighborhood analysis in 1,000 m radius focal area
Distance to human development (m)	2011 National Land Cover Database, combined high, medium and low development	Calculated Euclidean distance to nearest human development
Percent of human development (%)	2011 National Land Cover Database, combined high, medium and low development	Neighborhood analysis in 1,000 m radius focal area
Distance to open water (m)	2011 National Land Cover Database	Calculated Euclidean distance to nearest open water
Percent of open water (%)	2011 National Land Cover Database	Neighborhood analysis in 1,000 m radius focal area
Distance to crops (m)	2011 National Land Cover Database	Calculated Euclidean distance to nearest cropland

Percent of crops (%)	2011 National Land Cover Database	Neighborhood analysis in 1,000 m radius focal area
Distance to evergreen forest (m)	2011 National Land Cover Database	Calculated Euclidean distance to nearest evergreen forest
Percent of evergreen forest (%)	2011 National Land Cover Database	Neighborhood analysis in 1,000 m radius focal area
Distance to protected areas (m)	2016 Protected Areas of the United States Database	Calculated Euclidean distance to nearest protected area
Percent of protected areas (%)	2016 Protected Areas of the United States Database	Neighborhood analysis in 1,000 m radius focal area
Distance to roads (m)	2016 TIGER/Line Data	Calculated Euclidean distance to nearest road
Percent of roads (%)	2016 TIGER/Line Data	Neighborhood analysis in 1,000 m radius focal area
Distance to rivers (m)	2016 TIGER/Line Data	Calculated Euclidean distance to nearest river
Percent of rivers (%)	2016 TIGER/Line Data	Neighborhood analysis in 1,000 m radius focal area

Table 2.2. NLCD	2011 land-cover	classifications	and descriptions	of each land-cover
class.				

NLCD 2011 Land-cover Classifications	Description
Open Water	Areas of open water, generally with less than 25% cover of vegetation or soil.
Perennial Ice/Snow	Areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
Developed, Open Space	Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover.
Developed, Low Intensity	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
Developed, Medium Intensity	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover.
Developed, High Intensity	Highly developed areas where people reside or work in high numbers. Impervious surfaces account for 80% to 100% of the total cover.
Barren Land	Areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Deciduous Forest	Areas dominated by trees generally greater than 5 meters tall. More than 75% of the tree species shed foliage in response to seasonal change.

Evergreen Forest	Areas dominated by trees generally greater than 5 meters tall. More than 75% of the tree species maintain their leaves all year.
Mixed Forest	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrub/Scrub	Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation.
Grassland/Herbaceous	Areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation.
Pasture/Hay	Pasture/hay vegetation accounts for greater than 20% of total vegetation.
Cultivated Crops	Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
Woody Wetlands	Areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
Emergent Herbaceous Wetlands	Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Variable	Permutation Importance
Percent mast producing forest	42.9
Percent cultivated crops	32.8
Percent protected areas	9.2
Percent evergreen forest	6.6
Distance to mast producing forest	1.3
Percent human development	2.4
Distance to open water	0
Percent rivers	1.4
Distance to evergreen forest	0.6
Distance to cultivated crops	1.4
Percent open water	0.5
Distance to protected areas	0.3
Distance to human development	0.4
Distance to rivers	0.2
Percent roads	0
Distance to roads	0

Table 2.3. Variable permutation importance to the final continuous black bear habitatsuitability model generated by Maxent.

Table 2.4 Summary of the connectivity characteristics of the three black bear movement
zones identified within the habitat suitability map generated by Maxent for Louisiana,
Oklahoma, Arkansas and east Texas.

Tone	Area (km²)	Total number of suitable natches	Mean patch size (km²)	PROX Score	CONNECT Score	Number of stepping-stone natches (> 50 km²)
1	16,412	2,155	3.23	224,367.50	66.0	17
2	32,125	3,388	2.68	24,101.60	0.44	60
ŝ	25,116	4,176	2.35	41,400.60	0.39	58

VITA

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Journal of Wildlife Management style manual

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