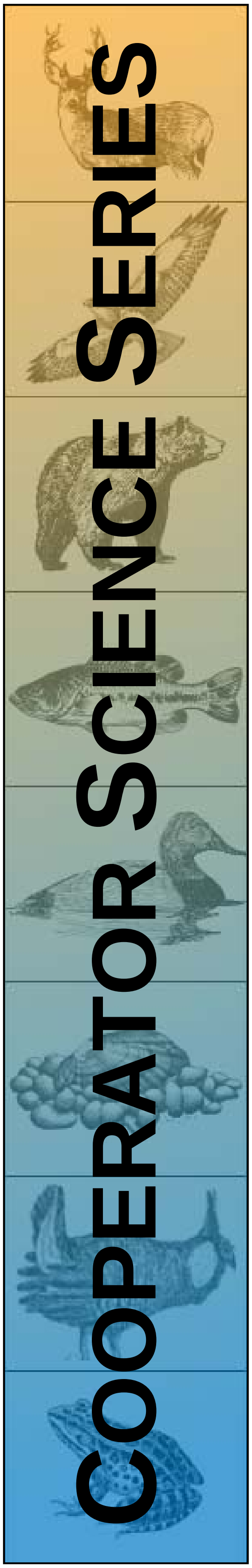

U.S. Fish and Wildlife Service

Prioritizing Landscapes For Longleaf Pine Conservation

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PRIORITIZING LANDSCAPES FOR LONGLEAF PINE CONSERVATION

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SUMMARY

We developed a spatially explicit model and map, as a decision support tool (DST), to aid conservation agencies creating or maintaining open pine ecosystems. The tool identified areas that are likely to provide the greatest benefit to focal bird populations based on a comprehensive landscape analysis. We used NLCD 2011, SSURGO, and SEGAP data to map the density of desired resources for open pine ecosystems and six focal species of birds and 2 reptiles within the historic range of longleaf pine east of the Mississippi River. Binary rasters were created of sites with desired characteristics such as land form, hydrology, land use and land cover, soils, potential habitat for focal species, and putative source populations of focal species. Each raster was smoothed using a kernel density estimator. Rasters were combined and scaled to map priority locations for the management of each focal species. Species' rasters were combined and scaled to provide maps of overall priority for birds and for birds and reptiles. The spatial data can be used to identify high priority areas for conservation or to compare areas under consideration for maintenance or creation of open pine ecosystems.

INTRODUCTION

We developed a decision support tool (DST) to aid decisions about where creating or maintaining open pine ecosystems is likely to provide the greatest benefit to focal bird populations based on a comprehensive landscape analysis. Our DST relies on key principles of conservation biology and reserve design to enhance conservation benefits for birds and other wildlife. We developed the DST based on habitat requirements for focal species of birds, but we demonstrate how additional taxonomic groups can be incorporated, and argue that because the

[1]Deceased.

land cover type and configuration requirements are similar, the results using birds as focal species for planning are applicable to the protection of many other species (Margules 2000). Our objectives were to develop a model for the prioritization of the landscape for open pine conservation and longleaf restoration based on ecosystem requirements of focal bird species following the principles of strategic habitat conservation (SHC; USFWS 2008), and to compare the resulting priorities to the distribution of suitable habitat for two representative species of reptiles (Gopher Tortoise, *Gopherus polyphemus*) and Black Pine Snake, *Pituophis melanoleucus lodingi*).

We defined open pine ecosystems, including uneven-aged longleaf pine (*Pinus palustris*), as forests dominated by southern pines (*Pinus* spp.) with low tree density, open canopy, open midstory, and diverse herbaceous understory maintained by frequent fires. Our basic assumption is that availability, stand structure, and spatial context of open pine ecosystems are principal factors limiting the abundance of species associated with these systems. Therefore, we also assume that through protection from conversion, widespread reforestation, and enhancement of stand conditions, populations of focal species of wildlife can be achieved and maintained. We further assume that the spatial context and quantity of habitat is of great importance to the value of open pine for conservation.

Significant financial and human resources have been applied to the conservation of longleaf and other open pine systems. Federal, State, and non-governmental entities have established partnerships in the form of groups like America's Longleaf (2009), Longleaf Alliance (2013), East Gulf Coastal Plain Joint Venture, Atlantic Coast Joint Venture, West Gulf Coastal Plain Joint Venture, and Gulf Coast Joint Venture to pool support and resources to restore longleaf and other native pine ecosystems. Each of these groups has different restoration objectives, but all at least include benefits to wildlife associated with longleaf ecosystems. The DST was created to aid these partnerships by prioritizing the landscape for open pine conservation following the principles of the first two elements of Strategic Habitat Conservation (National Ecological Assessment Team 2006): biological planning and conservation design.

Biological planning consists of three primary elements: (1) defining the ecological context of a particular region of interest, including major threats and limiting factors, (2) articulating population objectives and (3) modeling species-habitat relationships. With adequate biological planning, conservation design is the next step in implementing strategic habitat conservation. Conceptually this step also consists of three primary elements: (1) defining the amount of habitat required to meet the population objectives for species, (2) describing the desired configuration (landscape) of suitable habitat including the patch size for long-term sustainability and the relationship between patches required for connectivity of populations, and (3) determining where on the landscape these habitats should occur to best support population objectives. Numerous approaches to conservation planning and decision making exist, and almost all have analogous elements in their development.

Areal habitat objectives can be calculated from population objectives when coupled with an understanding of the areal habitat requirements for focal species. Utilizing GIS, areal habitat objectives can be spatially defined and specific areas of the landscape prioritized according to their conservation potential. Throughout this document, assumptions and uncertainties inherent to each data layer and the resultant model are articulated. The articulation of assumptions is critical to transparent model development and designing applied research to validate or improve model performance and outcomes from conservation activities.

ACKNOWLEDGMENTS

This project was conducted to address a high priority need identified by partners in the East Gulf Coastal Plain Joint Venture including the State agencies responsible for the management of bird populations and the habitats they require in Alabama, Mississippi, Florida, Tennessee, and Kentucky. Representatives from those agencies participated in numerous workshops and conference calls that helped shape this document. Several individuals including Amy Silvano, Catherine Rideout, and Allison Vogt contributed constructive comments to early versions of this document. Kevin Kleiner my co-author passed away before the analysis and this document could be completed, and we miss him still. I sincerely appreciate the work of Allison Webber, who worked diligently to assemble and process the spatial data for this effort and produced the figures presented here. Funding for this project was provided by U.S. Geological Survey and Auburn University. Any use of trade, firm or product names in this document is for descriptive purposes only and does not imply endorsement by the U.S. Government. Although these data

have been processed successfully on a computer system at Auburn University, no warranty expressed or implied is made regarding the display or utility of the data on any other system or for general or scientific purposes, nor shall the act of distribution constitute any such warranty. The USGS or the U.S. Government shall not be held liable for improper or incorrect use of the data described and (or) contained herein.

BIOLOGICAL PLANNING

ECOLOGICAL CONTEXT

The DST was developed to guide the strategic conservation of open pine ecosystems within the boundaries of the historic range of longleaf pine (Figure 1) (Little and others, 1971). By some accounts, open pine systems in the form of longleaf pine Flatwoods and Uplands once covered 88 million acres (>356,000 km^2) in the Southeastern United States from Texas to Virginia. Up to 52 percent of all Uplands and 36percent of the entire southeastern U.S. landscape may once have been dominated by longleaf, but this ecosystem has undergone drastic declines (Frost 1993). Mesic Pine Flatwoods and Savannas, hereafter referred to as Flatwoods, and Pine Uplands and Sandhills, hereafter referred to as Uplands, were the principal natural ecosystems for a large portion of the southeastern coastal plain. These are open, fire-dependent forest ecosystems. Flatwoods are wetter environments and typically occur in near coast areas. Uplands are drier and occupy from the northern boundary of the historic range of longleaf pine south to the northern extent of the range of Flatwoods (Comer and others, 2003). Based on 2011 National Land Cover Data (Homer et. al 2015), within the historic range of longleaf east of the Mississippi River, pine-dominated and mixed pine systems accounted for over 26percent (127,949 km^2) of all land cover (490,316 km^2) and 74percent of all upland forest cover (171,293 km^2) (Grand unpublished).

THREATS TO NATURAL SYSTEMS

Alteration of natural fire regimes and widespread conversion to systems dominated by loblolly pine (*P. taeda*) and slash pine (*P. elliottii*) have drastically altered many of the original longleaf pine ecosystems across the region; as a result, many species associated with the system are imperiled or in decline (Van Lear and others, 2005). These declines have sparked widespread interest and debate over the conservation of what is considered one of the most critically endangered ecosystems in the U.S. today. Uplands and Flatwoods are impacted by a similar suite of threats. Alteration of the natural fire regime and forestry practices that significantly alter the composition and structure of both Flatwoods and Upland ecosystem types are the dominant drivers in decline of these ecosystems (Florida Fish and Wildlife Conservation Commission, 2005; Mississippi Museum of Natural Science, 2005; Wildlife and Freshwater Fisheries Division, Alabama Department of Conservation and Natural Resources, 2005).

Fire frequency in Flatwoods and Uplands is naturally high and in pre-Columbian times fire frequency is thought to have ranged from one to eight years (Florida Natural Areas Inventory and Florida Department of Natural Resources, 1990; Wildlife and Freshwater Fisheries Division, Alabama Department of Conservation and Natural Resources, 2005). A combustible leaf litter and grassy understory carried fires important to the flowering and seed and fruit production of understory vegetation (Fish, 2005; Mississippi Museum of Natural Science, 2005). Without fire, canopy closure increases and a dense growth of hardwoods, shrubs, and vines pervades and the normally diverse native grasses and forbs are shaded out (Fish, 2005; Wildlife and Freshwater Fisheries Division, Alabama Department of Conservation and Natural Resources, 2005).

An increase in road density, human dwellings, and lack of public support due to current concerns over air quality are impediments to managing pine ecosystems with fire (Dellasala and others, 2004). Application of fire management during the dormant season does not effectively control stem proliferation of shrubs and hardwoods relative to growing season fires (Mississippi Museum of Natural Science, 2005). State Wildlife Conservation Strategies from Louisiana, Mississippi, Alabama and Florida identify numerous threats to the availability of pine Uplands and Flatwoods including: altered fire regime, conversion to pine species other than longleaf, intensification of forestry practices (heavy stocking densities), urban and agricultural expansion, altered hydrology due to drainage ditches, raised roadbeds, exotic or invasive species, and erosion from mechanized vehicle trails (Fish 2005, Louisiana Department of Wildlife and Fisheries 2005, Mississippi Museum of Natural Science 2005, Lester and others, 2005, Wildlife and Freshwater Fisheries Division Alabama Department of Conservation and Natural Resources

2005).

In stark contrast to a landscape that was once dominated by open, low-density stands of longleaf pine, a 2001 land cover analysis suggested that disturbed pine ecosystems, including pine plantations and dense stands with closed canopies, account for 86 percent of all pine-dominated forests in the region. Uplands and Flatwoods in a 'natural' condition account for a mere 4.3 and 9.6 percent, respectively, of all pine-dominated forests (USGS-GAP 2010). However, imperiled, open pine ecosystems still support a suite of birds and other wildlife of high conservation concern (Means 2005, Repenning and others, 1985, Allen et al 2006).

ARTICULATING POPULATION OBJECTIVES

Prioritizing Bird Species

At least 86 species of birds occurred in open pine communities; of these, 35 were year-round residents, 29 are only present in nesting season, and 22 were strictly winter residents (Engstrom 1993). Partners in Flight proposed a priority list of pine-dependent birds and management recommendations (see Woodrey and others, 1998). From that list, Mississippi Sandhill Crane (*Grus canadensis pulla*), Red-cockaded Woodpecker (*Picoides borealis*), Brown-headed Nuthatch (*Sitta pusilla*), and Bachman's Sparrow (*Aimophila aestivalis*) ranked among the highest priority, and are largely sympatric with longleaf pine. Furthermore, these species commonly used a variety of micro-habitats, such as bogs and freshwater marshes, which were interspersed within pine-dominated communities. Other high priority species within the southeastern coastal plain discussed in Woodrey and others, (1998) included Northern Bobwhite (*Colinus virginianus*), Chuck-Will's-Widow (*Caprimulgus carolinensis*), and Eastern Kingbird (*Tyrannus tyrannus*), as well as non-breeding species such as Henslow's and LeConte's Sparrows (*Ammodramus henslowii, A. leconteii*). We further elicited expert reviews of these species and their habitat requirements from partner members of the East Gulf Coastal Plain and West Gulf Coastal Plain Joint Ventures.

A total of 6 bird species were identified as focal species for this study. They included Bachman's Sparrow, Brown-headed Nuthatch, Henslow's Sparrow, Northern Bobwhite, Red-cockaded Woodpecker, and Red-headed Woodpeckers (*Melanerpes erythrocephalus*) as potential focal species. Red-headed Woodpecker was added due to its requirements for large old trees without the patch-size requirements of Red-cockaded Woodpecker. Mississippi Sandhill Cranes were not considered because they only occur in a small portion of the former range of longleaf. We assumed that the resulting list of species represented the full range of avian habitat niches within open pine systems and selected them as focal species for conservation planning (Roberge and Angelstam 2004).

Population Objectives

We developed population objectives for the focal species breeding in the EGCP because establishing population objectives and monitoring progress towards them are critical to SHC. We started with continental population objectives identified by Partners-in-Flight for each species (Rich and others, 2004). We then determined the portion of the population expected to occur within the historic range of longleaf within the EGCP to scale the population objective to the area of interest (AOI). Thus, the AOI and the population objectives apply to the historic range of longleaf within the EGCP boundary. Rich and others, (2004) did not provide a population objective for Red-cockaded Woodpeckers, so we derived one from the recovery plan (U.S. Fish and Wildlife Service. 2003). As explained below, in order to scale the continental objectives to the AOI, we used the ratio of population density within the AOI to the total population density based on data from the North American Breeding Bird Survey (http://www.mbr-pwrc.usgs.gov/bbs/geographic_information/Instructions_abundance_grid.htm accessed: 15SEP15). BBS estimates density as the mean number of birds expected on a typical 25-mi BBS route. This value is calculated for each species in each cell of an approximately 25km^2 grid covering North America. We summed the density across the cells intersecting the AOI and divided by the total of the density estimates for the entire range of each species. This portion was multiplied by the continental objective for the species to obtain the population objective (Table 2).

In addition to well-documented assumptions of the BBS estimates of breeding bird density and trends (O'Connor and others, 2000, Link and Sauer 1994), our methodology assumes the AOI provides an appropriate scale for sub-setting BBS data, and perhaps more importantly that the current distribution reflects the desired distribution of the population.

The continental population objectives call for substantial increases for all five of the focal species. In every case the goal is to increase the population by at least 50percent. For three of the focal species, Bachman's Sparrow, Brown-headed Nuthatch, and Red-cockaded Woodpecker the AOI represents the majority, over 60percent, of the population counted on BBS surveys continent-wide. Thus, assuming the current distribution of the population based on the BBS is appropriate and adequate, the majority of the increase in population size must come from within the AOI.

SPECIES-HABITAT RELATIONSHIPS

We used the habitat relationship models developed for the Southeast Regional Gap Analysis Project (SEGAP) to determine where potential habitat existed for each species (Rubino and Williams 2012. These models are based upon species-specific habitat requirements that were determined by literature review and expert opinion (Table 3). The habitat requirements were reduced to those that could be mapped at landscape scales, such as land cover, hydrology, and distance to water, road density, elevation, and slope. Spatial queries of the resulting GIS were used to map the potential habitat within the known range of each species at 30m resolution for the entire southeastern United States. The range maps used to limit species' distributions were derived from published sources and reviewed by regional experts. In addition to land cover, GAP models used the following inputs to model potential habitat: land cover metrics (patch size, edge density, and forest interior area), hydrography (stream type, stream flow, and salinity), road density, elevation, and landform.

In addition to the maps of potential habitat from SEGAP, for Gopher Tortoises we incorporated priority soils data. Soil type is an important determinant of site suitability for gopher tortoise (Jones and others, 1995, Epperson and Heise 2001, and U.S. Fish and Wildlife Service) (Table 4).

CONSERVATION DESIGN

Habitat quantity

We estimated the amount of occupied habitat required to meet the population objectives using published estimates of home range size and density for each of the focal species. Where multiple published estimates of home range or density existed we use the median value (Table

5). Assuming that on average these density estimates are correct, we calculated the areal habitat requirements for each species based on their territorial behavior. For species that normally form territorial pairs we use the desired number of pairs (half of the population objective) multiplied by the mean territory size. We used this method to estimate the area of required habitat for Bachman's Sparrow, Brown-headed Nuthatch, and Red-headed woodpecker. For territorial species that are cooperative breeders (e.g., Red-cockaded Woodpecker), we divided the population objective by the average group size and multiplied the result by the mean territory size. For non-territorial species (for example, Northern Bobwhite), we divided the population objective by the mean density (birds/unit area). We realize that these estimates do not consider differences in density across habitats or landscapes, nor do they consider minimum patch size requirements or structure of populations (for example, covey size for Northern Bobwhite). We recognize the need for additional complexity to capture more of the spatial heterogeneity in population distributions, encourage others to pursue more sophisticated models incorporating spatial heterogeneity and uncertainty in population density, but argue that our estimates are robust and useful.

Habitat configuration

Having defined the ecological context of the open pine systems, identified priority birds and described their habitats, developed population objectives, modeled species-habitat relationships, and estimated the quantity of habitat required; we developed a model to describe the desired configuration of habitat to achieve the population objective as well as goals for sustainability of populations. We started by estimating the minimum viable population size (MVP) for each species. We used MVP to calculate the minimum dynamic area (MDA, Pickett and Thompson 1978) necessary to support the MVP. We assumed that MDA was the smallest patch able to serve as a source for colonization of new or enhanced patches of suitable habitat. We then prioritized the landscape based on existing land cover data to map the locations where potential habitat and putative source populations occurred, areas where the landform was likely suitable for open pine ecosystems, areas where the use of prescribed fire as a management tool would be relatively uninhibited, and areas that were managed for open pine, would not likely be converted for other uses.

We developed the prioritization through the use of two-dimensional kernel density surfaces (KDS) with a normal kernel (Silverman 1986). Kernel densities are estimated by applying a weight across the cells in a grid representing the domain of interest based on the distance from each occurrence of a resource of interest (for example, potential habitat). The normal kernel applies the weight using a sigmoid decay function in which approximately 66percent of the weight is distributed among cells within the radius of the kernel. In our application each surface represents the density of a desired resource, for example potential habitat, or putative source population) mapped across a grid of 200-m square cells.

Sustainable Populations

Using the concept of minimum viable population size (MVP), we defined a sustainable population as one large enough to have a $\geq$95percent probability of maintaining $\geq$ 25 individuals, the quasi-extinction level below which populations are not expected to recover, over a 50-year time period. We used stochastic simulations based on uncertainty in population trends (Appendix 1) to determine the required number of individuals in a population of each focal species to meet these requirements given North American Breeding Bird Survey estimates of population trend and variance (Table 5). Our simulations projected populations, starting with 25 individuals for 50 years using the BBS trend estimate, 1000 times. We then determined the probability of quasi-extinction based on the percentage of projections that fell below 25 individuals. If the probability of quasi-extinction was >0.05 we increased the initial population size until we established the initial population size that resulted in less than 5percent probability of quasi-extinction. We used this estimate as the MVP.

We estimated the patch size required to hold the MVP for each species based on the concept of minimum dynamic area (MDA, Pickett and Thompson 1978). This we calculated as the product of either the mean territory size, or mean density of each species and the functional group size of the population. For territorial breeding birds (for example, Bachman's Sparrow) this was one pair, for Red-cockaded Woodpeckers this was mean group size, and for Northern Bobwhites this was breeding density (Table 6). For example, a species (i) with a mean group size (d_i) of 4.5 birds and an average territory of 500 ha (a_i), and MVP of 250 birds:

$$MDA_i = (a_i/d_i)*MVP_i$$

$$= (500/4.5)*250$$

$$= 27{,}778\text{ha}.$$

This approach assumes that territory size and density are interchangeable, and that an average density figure can be applied across the landscape to determine the habitat objective even though population density varies among locations within that landscape.

Prioritizing the landscape

We developed five KDS that correspond to objectives for prioritization that could be translated into spatial models reflecting characteristics of the desired landscape. The objectives of this conservation design were to prioritize areas where there is likely to be a high density of: 1) appropriate and desirable (suitable) sites for longleaf pine restoration, 2) lands that can be managed with prescribed fire, 3) areas with long-term commitment to conservation, 4) potential habitat for priority species, and 5) source populations of priority species to colonize, enhance, or rescue populations in areas where habitat is created or enhanced. We combine KDS to create a single priority value for each 200m cell within the range of longleaf that represents areas that have the highest density of the desired characteristics of sites for longleaf restoration.

Appropriate sites to restore and maintain longleaf pine

We created a KDS map of suitable sites for longleaf restoration based on the historic range limits, land cover, and land form. We created a binary raster (matrix) of cells based on suitable land form, a digital elevation model (DEM) derivative that integrates slope and landscape position. We used land form data, developed for the SEGAP project (http://www.basic.ncsu.edu/segap/). Landforms we deemed suitable for longleaf included classes: 12 (Slope Crest), 13 (Upper Slope), 14 (Flat Summit/ridge), 20 (Sideslope –N/NE), 23 (Cove/Ravine – S/SW), and 30 (Dry Flat). We excluded sites outside of the historic range of longleaf (Little 1971), those classified as open water, developed open space, or developed (Homer and others, 2015) and created a binary raster of locations where suitable land forms occurred. We used this binary to create a KDS of suitable sites for longleaf using a kernel size calculated by the normal scale rule (Silverman 1986) (Figure 2).

Management with prescribed fire

To identify areas where prescribed fire could be used regularly, we mapped the density of urban areas using data extracted from the 2011 National Land Cover Database (Homer and others, 2015) (Figure 3). We used a binary map of developed areas and created a KDS with kernel of 1600m based on expert opinion, which indicated that at distances greater than 1600m smoke management concerns were minimal (Grand pers. comm.). We subtracted the resulting estimates of density from 1.0 to produce the inverse of urban density. The result was a surface that assigned highest values to areas with the greatest density of undeveloped sites, which we assume is a good index to the ability of managers to use prescribed fire to maintain open pine ecosystems.

Long-term conservation intent

We extracted public conservation lands, nature preserves, and permanent easements with a mandate for long-term conservation of any type from the U.S. Protected Areas Database version 1.3 (PAD-US, Gergely and McKerrow 2013). For the KDS, we subjectively chose a large, normal kernel (25,000m) because we wanted to assign higher priority to areas with the potential to improve connectivity of even widely separated areas that were in long-term conservation (Figure 4).

Potential habitat for priority species

Under the assumption that the SEGAP animal distribution layers provide useful information with regard to the distribution of sites that are or could be suitable for priority species, we calculated KDS of sites classified as potential habitat for each species using the normal scale rule (Figure 5). The map thus reflects the density of suitable sites with relatively little smoothing.

Because gopher tortoise distributions are closely tied to soil conditions we also included soils in the region using the Natural Resources Conservation Service's State Soil Geographic data (STATSGO, Schwarz and Alexander 1995). We created three binary soil maps based on soil families: prime, suitable, and marginal (Jones and others, 1995, Epperson and Heise 2001, and U.S. Fish and Wildlife Service). We created three binary matrices from the soils data corresponding to cells with prime soils only, cells with primary or suitable soils, and cells with primary, suitable, or marginal soils calculated KDS for each binary matrix, summed them, and divided them by the largest value. The result is a binary raster that we believe reflects the density and suitability of soils for use by gopher tortoise.

Putative source populations for focal species

We filtered the map of potential habitat for each species to remove patches smaller than MDP. We then calculated a KDS using a normal kernel size based on the estimated dispersal distance for each respective species (Figure 6, Table 7). Dispersal distances (D_i) were determined from the literature or estimated from the allometric equation:

$$D_i = 2.1M_i^{0.18}$$

for omnivores, where M_i is average body mass (kg) (Sutherland et. al 2000).

Modeling conservation priority

We combined KDSs to create a single priority value for each 200m cell within the range of longleaf that represents areas with the highest density of the desired characteristics of sites for longleaf restoration. We allow for tradeoffs among the objectives in the spatial analysis based on the presumption that areas where there is a high density of sites suitable for longleaf restoration ($\mathbf{S}$) and management using prescribed fire ($\mathbf{F}$) are highest priority and that the density of potential habitat ($\mathbf{H}_i$), stewardship ($\mathbf{L}$) and source populations ($\mathbf{P}_i$) is secondary, but each is of equal importance. Thus, we estimate species (i) priority ($\mathbf{V}_i$) by combining the KDS matrices using the following equation:

$$\mathbf{V}_i = \mathbf{S}*\mathbf{F}*(\mathbf{P}_i+\mathbf{L}+\mathbf{H}_i).$$

Each of the $\mathbf{V}_i$ was rescaled such that the maximum value was equal to 1.0 (Figures 7, 8) using:

$$\mathbf{V}_i = \mathbf{V}_i/\max(\mathbf{V}_i)$$

We then calculated overall priority by:

$$\mathbf{V} = \Sigma\mathbf{V}_i$$

for only the focal bird species (Figure 9A), and birds and reptiles (Figure 9B)**.**

RESULTS AND DISCUSSION

Our goal was to develop a spatially explicit DST that illustrated where desired landscape conditions for restoration and conservation of longleaf pine ecosystems are most likely to occur or be achieved. The priority surfaces we created are based on the relative value of each 200m cell based on the spatial models we developed. They can be used to guide decisions regarding the comparative value of potential sites for conservation implementation or in the identification of focal areas, which if restored should provide sustainable populations of the priority species and their associated flora and fauna.

PRIORITIZATION

Our objective was to develop a model and map of conservation priority under the assumption that areas assigned the highest priority are likely to provide the greatest contribution to conservation objectives and should be the target of conservation delivery. That is, we attempted to map the landscape conditions that would lead to efficient use of resources to meet the desired populations of priority birds. Our approach often assigns the highest priority to lands that already meet the desired conditions. We suggest that the maintenance of these areas is the highest priority for conservation, and they serve as building blocks for larger, less fragmented, more connected, and more secure habitat for priority species.

We develop the prioritization through the use of two-dimensional kernel density surfaces (Silverman 1986). Kernel densities have been widely used in the ecological literature to map the spatial relationships among observations (for example, survey observations Ramsey and others, 1987), desirable resources (for example spatial hotspots Nelson and Boots 2008), or hostile areas (i.e. resistance Compton and others, 2007). We combine appropriate density surfaces to create a single priority value for grid cell within the range of longleaf. The spatial data sets we used represent the state of the landscape with respect to the desired conditions for longleaf conservation. The density of sites meeting the desired conditions is necessarily higher in areas where the important characteristics occur in larger, more connected, less fragmented concentrations. For example, it is intuitive that if we could accurately map the distribution of longleaf pine, the highest densities would occur in existing large, contiguous patches and lowest densities would occur where longleaf is absent, and moderate densities would occur where the longleaf forests are less than contiguous. The result is a density surface that conforms to the basic tenets of reserve design suggested by Diamond (1975) and many other authors since, all of which are rooted in the theory of Island Biogeography (MacArthur and Wilson 1967).

Diamond (1975) suggested six important characteristics for the design of reserves based on theories of Island Biogeography that directly result from our use of KDSs. 1) He suggested that larger reserves (i.e. patches of ecosystem) are better than smaller ones. Because KDSs are the cumulative weights of surrounding cells with desired characteristics, the highest densities occur where more of the desired resources exist even when local densities are equal. 2) Diamond also suggested that contiguous (unfragmented) areas are better than segmented ones. Given the same resources, KDSs will indicate highest densities in areas where desired resources are tightly clustered because they have more of the desired resources per unit area than less tightly grouped clusters. 3) Another of Diamond's suggestions was that if segmented, patches that are nearer to one another are preferred. Because KDSs are based on weights that decline in value with distance from the desired resource, even clusters of equal size and shape will receive higher density values when they are nearer together. 4) Diamond offered that clusters of patches that minimize the inter-patch distance are better than those with greater inter-patch distances. Since the kernels we used were elliptical, and points equidistant from each resource were weighted equally, patches that are equidistant will have greater density than patches that are not. 5) Diamond suggested that patches that are connected are better than unconnected patches. Because the areas between patches are also weighted in KDS, clusters of patches that are connected by corridors receive higher density values and sites that would contribute to corridor formation are given higher values that sites that are equidistant to a patch but not between it and other patches. 6) Finally, Diamond asserted that round patches with smaller edge:area ratio are better than those with greater edge:area ratio. Again because we used elliptical kernels with weights that declined with distance from desired resources (for example, potential habitat for focal species), higher value is assigned to clusters that are round versus those with equal amounts of desired resources in other configurations.

Appropriate sites to restore and maintain longleaf pine

In addressing this objective, we were attempting to prioritize areas based on the density of sites that were within the historic range of longleaf, and were potentially suitable for restoration as functional longleaf or open pine systems. Thus, it was important to first identify areas that historically would have been dominated by longleaf. This is important because we did not want to promote the establishment of longleaf in areas where it is unlikely to grow well or be managed as a functional open pine ecosystem. However, climate change may alter the future range of longleaf and may require consideration in future updates to the model.

Longleaf probably occurred throughout the historic range on upland sites that were subjected to frequent disturbance. Although longleaf will tolerate a wide variety of conditions from wet to xeric sites, it may have been out-competed on sites that were not frequently disturbed by fire and those where soils were not sufficiently deep and penetrable to the species' long tap-root. Despite the large-scale availability of coarse-filter soils data (STATSGO), they lack the thematic resolution to accurately map sites suitable for growing longleaf. Fine-scale soil maps (SSURGO) are inconsistent in their precision and accuracy and thus are not useful at large spatial extents (for example the entire range of longleaf). Accurate, precise maps of soils, and landform would improve the resolution of maps of suitable sites.

Management with prescribed fire

Our objective was to prioritize areas where the use of fire as a management tool would not be limited substantially. Historically, natural fires were a dominant factor shaping the structure and function of longleaf ecosystems (Frost 1990). When fire is suppressed in these systems, hardwoods and shrubs become established which reduces herbaceous and grass diversity and biomass and eventually leads to hardwood stand replacement (Haywood 2012, Hiers and others, 2007,). Although grazing and herbicides can slow this succession, fire has proven to be the only management technique capable of fully maintaining biodiversity. Thus, the ability to regularly manage with fire is a crucial component in deciding where open pine systems can be maintained and restored.

However, managing with fire can be problematic, primarily because of smoke. If it does not disperse sufficiently, smoke can be an annoyance, a health hazard, and a driving hazard (Mobley 1990). In many instances concern over human safety due to the smoke from fire has inhibited land managers from burning on a schedule which they would otherwise prefer. Although there is active research on modeling smoke dispersal, it is very site and condition specific. Therefore, we took a much simpler route based on the assumption that the density of urban areas was inversely related to the ability to use fire as a management tool.

We recognize that ours is a very simplistic approach to identifying fire management potential. Two areas that will likely be pursued in future iterations are high priority areas and wind/topography. High priority areas for the exclusion of smoke include hospitals, schools, bridges, airports, and other places where smoke presents a hazard to human health. Other factors which potentially could affect the use of fire include attainment areas, urban growth, and local policies. Non-attainment areas are locales that the EPA has identified as currently having relatively poor air quality (https://www3.epa.gov/airquality/greenbook/index.html accessed 24 May 2016). These typically include large urban areas. The locale is required by the EPA to keep concentrations of pollutants below set levels and penalties are levied on days that minimum standards are not met. Urban growth is also a factor that could significantly impact the ability to manage with fire. A location that is easily burned today because it is rural may be more difficult to burn in the future when the surrounding area has urbanized. Finally, local policies and opinions can affect the ability to burn. When there is strong local opposition to any burning, the likelihood of burning sufficiently for restoration is reduced in the long term. The majority of smoke-sensitive sites fall within developed areas mapped by the National Land Cover Dataset (Homer and others, 2015), thus, they are considered in our analysis. However, it may also be desirable to consider predominant wind direction in combination with large scale topography in large scale models predicting where fire can be used with fewer restrictions resulting from smoke abatement concerns.

Long-term conservation intent

Another objective of the DST was to prioritize areas in or near the largest tracts of land that could be managed for long-term conservation of bird populations. This objective is essential to the goal of sustainable bird populations. Thus, we used the stewardship data developed in PAD-

US, the most recent database of conservation stewardship for the region. We extracted public conservation lands, nature preserves, and permanent easements included in the database that indicated a mandate for long-term conservation of any type. While these data are relatively current, they do not include many private conservation lands, particularly those in easements. In calculating the density of these sites, we subjectively chose a large, normal kernel (25 km) because we wanted to assign higher priority to areas with the potential to improve connectivity of even widely separated areas that were in long-term conservation (Figure 4). Our choice of kernel size was admittedly arbitrary, and the effect of using alternative kernel sizes should be explored.

Potential habitat for priority species

This objective was included to ensure that conservation and restoration efforts would take place in proximity to larger tracts of habitat for the priority bird species. The coarse-filter habitat relationship models used in GAP have widely been criticized for their inaccuracy (Conroy 1996, Peterson and others, 2002, but see McClure and others, (2012). However, for most species including the focal species selected for use by the experts few alternatives exist. Predictions based on highly parameterized, fine-scale models are usually based on studies conducted at limited scope and scale; thus they are often affected by sampling bias and underestimate uncertainty. This severely limited their applicability to coarse-scale problems at large extents such as the one we are addressing here (Rastetter and others, 1992). Further, the information required to apply fine-scale models (for example, understory structure) is often unavailable over large extents such as the historic range of longleaf pine. We suggest that interpreting the GAP models not as estimates of species occurrence, but as locations that are or have the potential to become suitable habitat is the correct and perhaps best use of those data. Further we assert that the smoothing that occurs when applying KDS compensates for error that occurs in the misclassification of remotely-sensed data (Kleiner 2007; Kleiner et. al 2007).

Under the assumption that the SEGAP animal distribution layers provide useful information with regard to the distribution of sites that are or could be suitable for the priority species, we used the density of sites classified as potential habitat for each species to prioritize areas for conservation and management of open pine systems. We mapped the density of these sites using a kernel density estimator with a kernel size calculated using the normal scale rule (Figure 5). The map thus reflects the density of suitable sites with relatively little smoothing.

Putative source populations for focal species

We used the maps of potential habitat to determine where putative self-sustaining, source populations could exist. These were expected to occur where patches of contiguous potential habitat were large enough to contain a sustainable population of a priority species. This approach assumes that territory size and density are interchangeable and that an average density figure can be applied across the landscape to determine the total habitat objective even though density varies among habitats within that landscape. If models based on landscape-scale data to predict the heterogeneity in species' density were available, the size and location of putative source populations would vary. Landscape scale models have been shown relatively ineffective for predicting the local abundance of birds (LeBrun and others, 2012).

We estimated the amount of suitable habitat required to sustain populations of our priority species at or above the objective levels. Conservation theory tells us that to be sustainable a population must be persistent (Shaffer 1981). For the purposes of this exercise we defined a population as a group of animals of the same species living in one relatively contiguous block of suitable habitat. We defined contiguity as being within the estimated average dispersal distance of that animal. Populations of many species of concern are declining in abundance, therefore given a stable environment they may inevitably become extinct; stochastic environments may make extinction more likely (Leigh 1981, Pimm and others, 1988). Further, even for populations that are stable or increasing the possibility exists that some sequence of events could lead to their demise; particularly if annual fluctuations in population size are large. Additionally, populations in stochastic environments have lower average annual growth rates, which contribute to the likelihood of their extinction. Theory also tells us that if populations become too small (defined as quasi-extinction) they may decline even more rapidly thus extinction becomes inevitable, due to Allee effects (Allee 1931). Populations that fall below this quasi-extinction threshold are for all practical purposes extinct. However, Island Biogeography and Metapopulaton Theory suggests that if populations are not closed to the processes of emigration and immigration and local extinctions occur, a species may re-colonize suitable habitat (MacArthur and Wilson 1967; Hanski 1999). The probability of colonization is directly related to dispersal distance, but inversely related to the distance from source populations. The nature of this relationship depends upon species-specific behavior and dispersal capabilities, but could be irrelevant for species that do not demonstrate strong site fidelity or natal philopatry.

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APPENDIX 1

Although ths script has been processed successfully on a computer system at the U.S. Geological Survey (USGS), no warranty expressed or implied is made regarding the display or utility of the data on any other system or for general or scientific purposes, nor shall the act of distribution constitute any such warranty. The USGS or the U.S. Government shall not be held liable for improper or incorrect use of the script described and/or contained herein.

MATLAB® SCRIPTS FOR CALCULATING MVP OF FOCAL SPECIES

MVP50-v2

```
% MVP50 -v2 – calculates minimum viable population size and 95% CLs based on trends

% and 95% CLs in population size.  MVP is based on <5% probability that the population % will
fall below quasi-extinction level of 25 individuals during 50 years.  Stochastic

% simulations begin with 25 individuals and increase the population size until MVP

% criteria are met.

clear; clc

iname = 'USBBSSppTrends.xls'; % Excel table of species trend data from BBS

sname = 'BBS_2012_SEGCP' % worksheet containing trend and 95% CLs for each species (inputs)

osname = 'MVP SEGCP results_2012' % worksheet for storing results

[bbsnum,bbstxt,bbsraw] = xlsread(iname,sname);% load species names trends and CLs obtained
from BBS

bbsraw = bbsraw(2:end,:);

vnames = bbsraw(1,:);

for i = 1:size(vnames,2)
```

```
 if ischar(bbsraw{2,i})==0
   bbsnum(i)=1;
   eval([char(vnames{i}) ' = cell2mat(bbsraw(2:end,' num2str(i) '));'])
 end
end
grate = log(1+(Trend./100)); % mean ln(lambda)
sdgrate = abs((log(1+(UCL./100))-log(1+(LCL./100)))/4).^.5; % sd of ln(lambda)
qext = 25; % quasiextinction level
pext = 0.05; % acceptable probability of quasi extinction
time = 50; % time window for projections
fig = 0;
inc = 1;
ptxt = num2str(pext);

for k = 1:size(bbsnum,1) % for each species
   spp = k;
   % get variable names from Excel table & change where necessary



   iter = 1000; % number of trials per simulation
```

```
  sim = 100; % number of simulations

  fname = [char(bbsraw(spp+1,2)) ' mvp ' num2str(time) ' qext ' num2str(qext) ' pext ' ptxt(end-
1:end)] % name for graphic output



  for j = 1:sim % each simulation

     i=1; cont=1; % flags for stopping rules

     n0 = qext; % initial population size

     prext = []; % initialize probability of extinction

     flag = 0; % another flag

    while cont==1 % continues until MVP found

       [prext(i)]=probnvp(n0(i),qext,iter,grate(k),sdgrate(k),time,fig); % calls function to project
and calculate p(ext)

%        fprintf('%s MVP running: simulation: %g of %g, searching: %g, n(0) %g\n',
char(bbsraw(spp+1,2)), j, sim, i, n0(i));

       if and(prext(i)<=pext,flag==0) % detect whether criteria for probability of extinction is met.

          mvp(j)=n0(i);

          flag=1;

       end

       if prext(i)>0.5*pext;

          n0(i+1)=n0(i)+inc;

          i = i+1;
```

```
      else

         cont=0;

      end



    end

  %    prmvp(j)=prext(i);

  end

  fprintf('%s done.\n\n',char(bbsraw(spp+1,2)));  % write to console

  FigOut % generate graph

  smvp = sort(mvp);

  outstat = [mean(mvp) std(mvp) mode(mvp) smvp(round(0.025*sim))
smvp(round(0.975*sim))];

  fprintf('\n%s MVP stats:\n\n   mean: %6.4f, std: %6.4f, mode: %g, lcl: %g, ucl: %g, n: %g \n\n',
char(bbsraw(spp+1,2)),outstat,sim)

%    save(fname)

  % write output to Excel

  header = {'Species' 'mean' 'std' 'mode' 'lcl' 'ucl' 'n'};

  xlswrite(iname,header,osname, 'a1');

  xlsrng = ['a' num2str(spp+1)];

  xlswrite(iname,[(bbsraw(spp+1,2)) num2cell([outstat sim])],osname, xlsrng);
```

end

User-defined function – probnvp()

```
function [prext]=probnvp(n0,qext,iter,grate,sdgrate,time,fig)

% [prext]=probnvp(n0,qext,iter,grate,sdgrate,time,fig)

% Calculates the probability of extinction for a stochastic population

% based on initial population size (n0), quasiextinction level (qext),

% growth rate 1-lambda (grate), STDDEV of growth rate (sdgrate) based on MC

% methods with many trials (n=iter), over time period (time).  Set toggle

% fig=1 to display a plot of the first 10 trials.

r = randn(time,iter); % generate random normal variate

lambda = exp(grate+(sdgrate*r));  % calculate random normal variate around population growth rate

n = zeros(time+1,iter);

 % routine to project population

n(1,:) = n0;

for t = 1:time

   n(t+1,:) = n(t,:).*lambda(t,:);

end



% find populations that crashed
```

```
[row,col]=find(n<20);

nvp = size(unique(col),1);

prext = nvp/iter;

 if fig ==1 % graph the results of first 10 trials.

    plot(n,'LineWidth',2)

    hold on

    plot(ones(time,1)*qext,'r','LineWidth',2);

    hold off

end
```

TABLES

Table 1. Focal species selected for open pine ecosystems and characteristic habitat requirements in the East Gulf Coastal Plain.

Habitat Attribute	Bachman's Sparrow	Brown-headed Nuthatch	Henslow's Sparrow	Northern Bobwhite	Red-cockaded Woodpecker	Red-headed Woodpecker	Gopher Tortoise	Pine Snake
Low percent Canopy Cover[1]	X		X	X	X			
Diverse and Herbaceous Understory[2]	X		X	X			X	
Low Basal Area/ Tree Density[3]	X		X	X	X			
Significant component of old trees[4]		X			X	X		
Presence of Dead Trees[5]		X			X	X		
Large Patch Size[6]					X	X		
High Fire Frequency[7]			X	X				
Growing Season Fire[8]	X							
Presence of Bare Ground				X			X	
Duff layer								X
Soil texture							X	X

[1]low <10 to 30percent; high = >50percent

[2]Understory is dominated by forbs, herbs, and grasses. Few woody shrubs; little hardwood or pine regeneration.

[3]Basal area below 50 square feet per acre is acceptable (one 14" diameter breast height (dbh) tree = 1 sq. ft. BA) (i.e., 50-14" dbh trees on one acre = 50 BAA). Tree spacing or density may be a better measure because 80 BA of 22" dbh trees is reasonably open with 30 stems per acre

approximately 38 feet apart. Eighty BA of 6 in dbh trees is something altogether different with 408 trees per acre spaced 10 ft apart.

[4]On average, 6-10 trees per ac greater than 80 yr old.

[5]1-2 per acre across a stand should be sufficient. Some larger areas of insect or fire killed trees would be nice in a larger landscape context.

[6]5000 acres of contiguous upland pine habitat is necessary for a viable population of Red-cockaded woodpeckers.

[7]Interval of fire ranges between 1 yr and 4 yr with an average between 2 yr and 3 yr.

[8]15 March through 30 September.

Table 2. Continental population estimates and objectives, percentage of breeding population within the East Gulf Coastal Plain planning boundary (EGCP) and historic range of longleaf east of the Mississippi River (AOI) and the population objectives for focal species in open pine ecosystems.

Species	Continental estimate[1]	Continental Objective[2]	EGCP percent	EGCP Objective	AOI percen t	AOI Objective	AOI Increase
Bachman's sparrow	200,000	Increase 100percent	22	88,000	72	290,000	145,000
Brown-headed nuthatch	1,100,000	increase 50percent	13	208,000	60	986,000	329,000
Northern bobwhite		5,800,0001	36	208,000	13	735,000	
Red-cockaded woodpecker	15,000		10	2150 groups[4]	72	62,000	51,352
Red-headed Woodpecker	1,200,000	Increase 100percent	30	301,000	13	301,000	151,000

[1] PIF database estimates (http://rmbo.org/pifpopestimates/Database.aspx). Estimate is number of individuals. (Accessed 15SEP15).

[2] PIF plan (Rich and others, 2004).

[4] Species recovery plan (U.S. Fish and Wildlife Service 2003.).

Table 3. Land cover units and ancillary variables used in the SEGAP[1] habitat models for the focal species.

Species	Land cover	Contiguous	Elevation	Urban avoid
Bachman's sparrow	Successional, longleaf pine, prairie, pine Flatwoods	3 ha	NA	NA
Brown-headed nuthatch	All pine and mixed forest except plantation	NA	< 762 m	NA
Henslow's sparrow	Longleaf pine, successional, herbaceous, pine Flatwoods	NA	NA	NA
Northern bobwhite	Pasture, successional, developed open space, all pine forest except plantation, prairie	8 ha	<975 m	medium
Red-cockaded woodpecker	All pine except plantations	40 ha	NA	NA
Red-headed woodpecker	Pine and hardwood forests including wetlands, anthropogenic types except medium and high intensity developed,	NA	< 762 m	NA
Black Pine Snake	All pine except plantations, anthropogenic bare sand and soil	NA	NA	NA
Gopher Tortoise	Pasture, successional, developed open space, all pine except plantation, unconsolidated shoreline, dunes and associated grasslands	NA	NA	medium

[1]Southeast Gap Analysis Project at http://www.basic.nscu.edu/segap accessed: 17 May 2016.

Table 4. Compiled soils series by priority for GOTO (Jones and others, 1995, Epperson and Heise 2001, and U.S. Fish and Wildlife Service).

Preferred	Suitable	Marginal
Alaga	Apopka	Alphalpha
Alpin	Bama	Basin
Astatula	Benndale	Baxterville
Bigbee	Bonneau	Bibb-Ponzer
Blanton	Cuthbert-Bowie-Sunsweet	Bibb-Susquehanna
Candler	Dothan	Boswell
Eustis	Faceville	Canaveral
Kureb	Fuquay	Daleville
Lakeland	Harleston	Escambia
Lakewood	Heidel	Falkner
Nugent	Izagora	Florala
Paola	Lucedale	Freest
St. Lucie	Lucy	Freestone
Troup	Norfolk	Grady
Wadley	McLaurin	Immokalee
	Orangeburg	Leefield
	Orlando	Lorman
	Pomello	Lynchburg
	Quitman	Malbis
	Ruston	Mashulaville
	Shubuta	Myatt
	Smithdale	Ocilla
	Suffolk	Osier
	Sunsweet	Poarch
	Tavares	Prentiss
	Wagram	Saucier
		Savannah
		Susquehanna

Table 5. Population trend (average percent annual change), standard error, and minimum viable population size (MVP) for priority species inhabiting open pine systems in the East Gulf Coastal Plain based on analyses of BBS data through 2012 (Citation).

			95percent Confidence Limits			95percent Confidence Limits	
Common name	n[1]	Trend[2]	LCL	UCL	MVP[3]	LCL	UCL
Bachman's Sparrow	265	-3.2	-4.3	-2.3	290	278	298
Brown-headed Nuthatch	493	-0.4	-0.9	0.1	58	56	60
Northern Bobwhite	1979	-4.2	-4.5	-3.9	332	325	339
Red-cockaded Woodpecker	62	-3.5	-6.5	-0.7	611	554	623
Red-headed Woodpecker	1737	-2.6	-2.9	-2.3	146	143	151

[1]Number of routes.

[2]Percentage change per year from North American Breeding Bird Survey.

[3] MVP – minimum population size with >95percent chance of remaining above 25 individuals (quasi-extinction) over a 50-year time period.

Table 6. Density estimates and occupied habitat required to meet population objectives for priority birds used in species modeling.

		Occupied		Habitat Objective (km^2)	
Species	Density Estimate (ha/breeding pair)	EGCP	AOI	EGCP	AOI
Bachman's sparrow	3[1]	660	9,855	1,320	4,350
Brown-headed nuthatch	2.8[2]	1,946	9,198	2,910	13,800
Northern bobwhite	20.0[4]			20,800	73,500
Red-cockaded woodpecker	93[6]	677	5,045	4,190	28,830
Red-headed woodpecker	1.0[5]	242	753	240	1,510

[1] Home range, (Dunning and others)

[2] Breeding territory (Withgott and Smith 1998).

[3] Home range (Bechtoldt and Stouffer 2005) .

[4] Breeding territory (Parnell and others, 2001).

[5] Winter territory (Moskovits 1978)

[6] Median of sizes reported by Hooper and others, 1982, Repasky 1984, Blue 1985, DeLotelle and others, 1982)

Table 7. Dispersal distances used for open pine system umbrella species in the East Gulf Coastal Plain.

Species	Dispersal Distance (km)	Body Mass	Trophic Type
Bachman's sparrow	3.01[2]		
Brown-headed nuthatch	0.92[1]	10.1 g[4]	omnivore[4]
Henslow's sparrow	0.96[1]	12.8 g[5]	omnivore[6]
Northern bobwhite	1.81[3]	NA	NA
Red-cockaded woodpecker	8.0	NA	NA
Red-headed woodpecker	1.0	66.4 g[7]	NA

[1]Dispersal distance estimated via allometric equations (Sutherland et. al 2000).

[2]Dunning et. al (1995).

[3] Dimmick (1992).

[4] Norris (1958).

[5]Skipper (1998).

[6]Hyde (1939).

[7]Murray (1964).

FIGURES

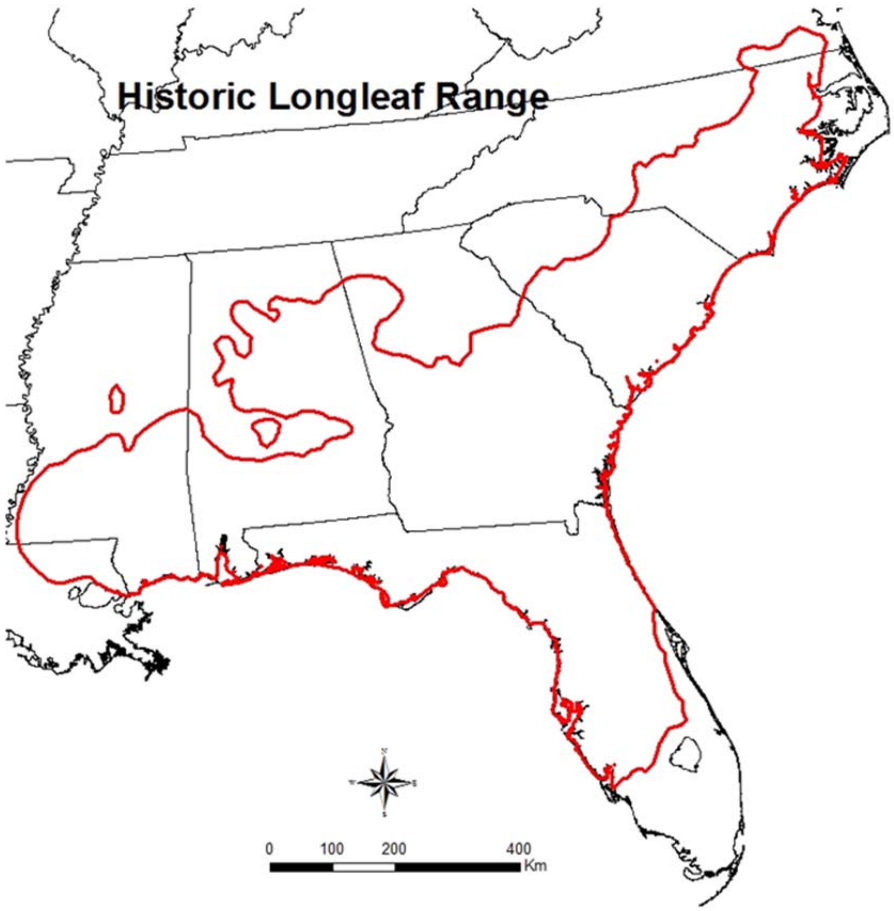


Figure 1. The historic range of longleaf pine east of the Mississippi River (Little 1971).

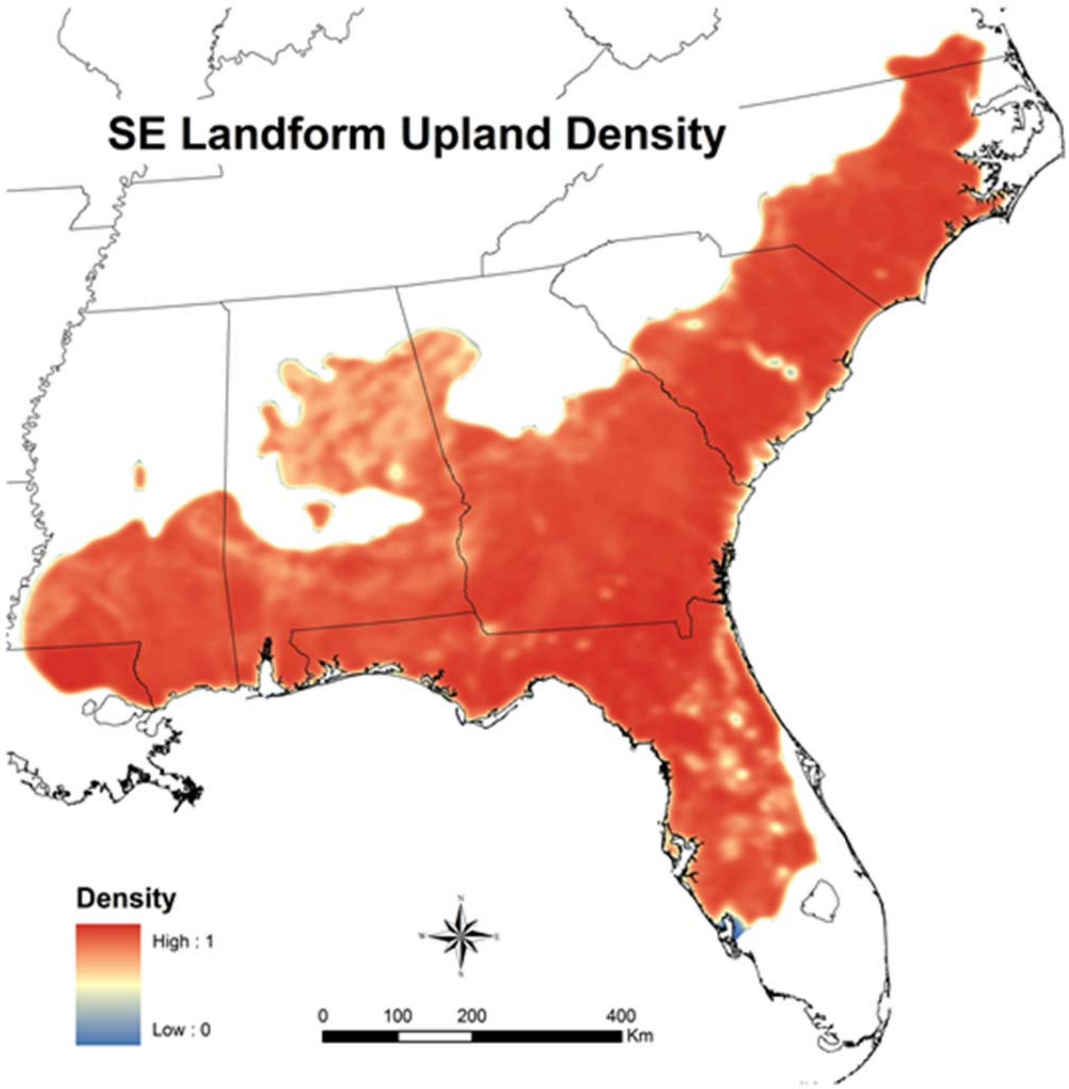


Figure 2. Density of suitable land forms (dry flat, flat summit and ridge, and moist flat sites) for longleaf pine within the species' range.

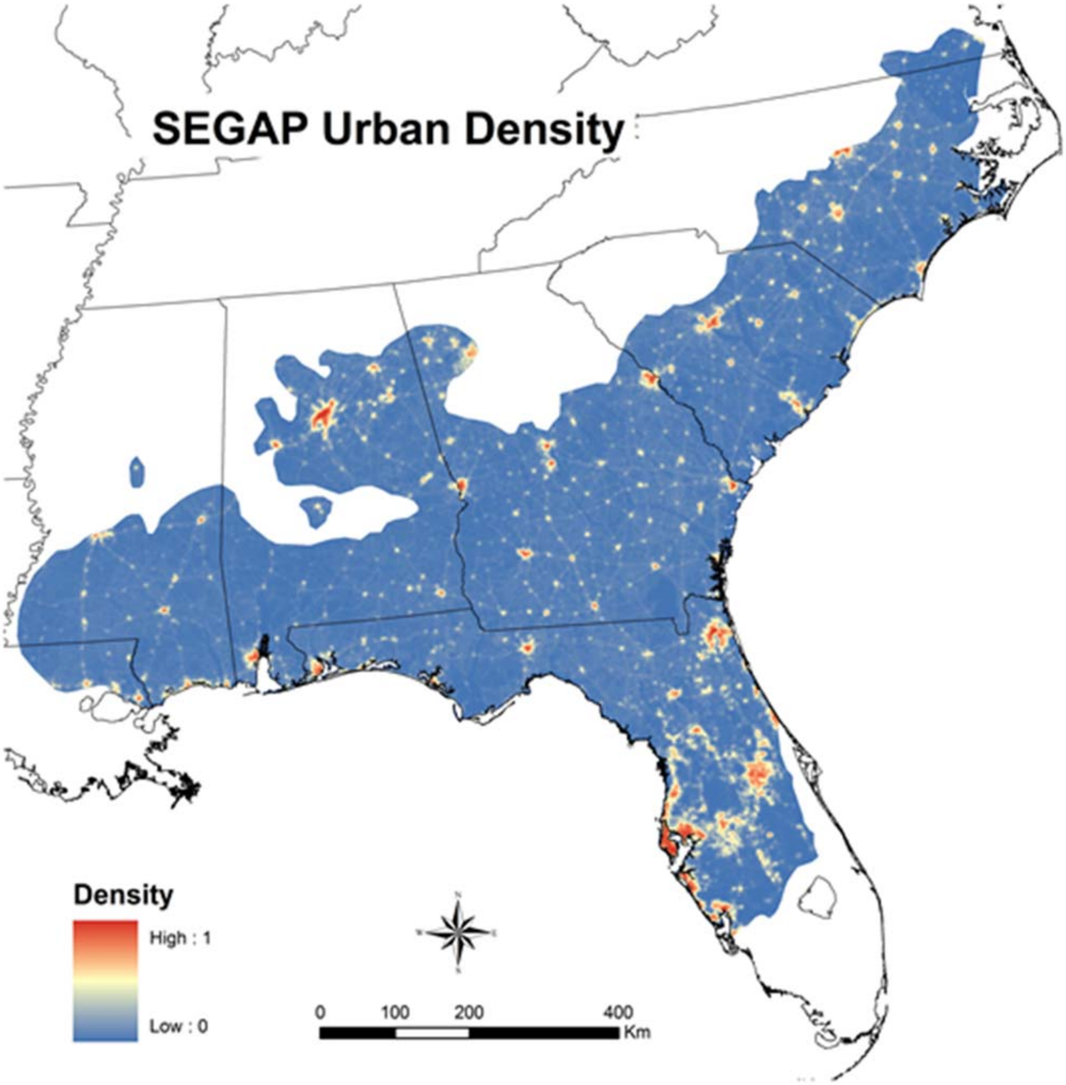


Figure 3. Density of developed land based on NLCD 2011 within the range of longleaf.

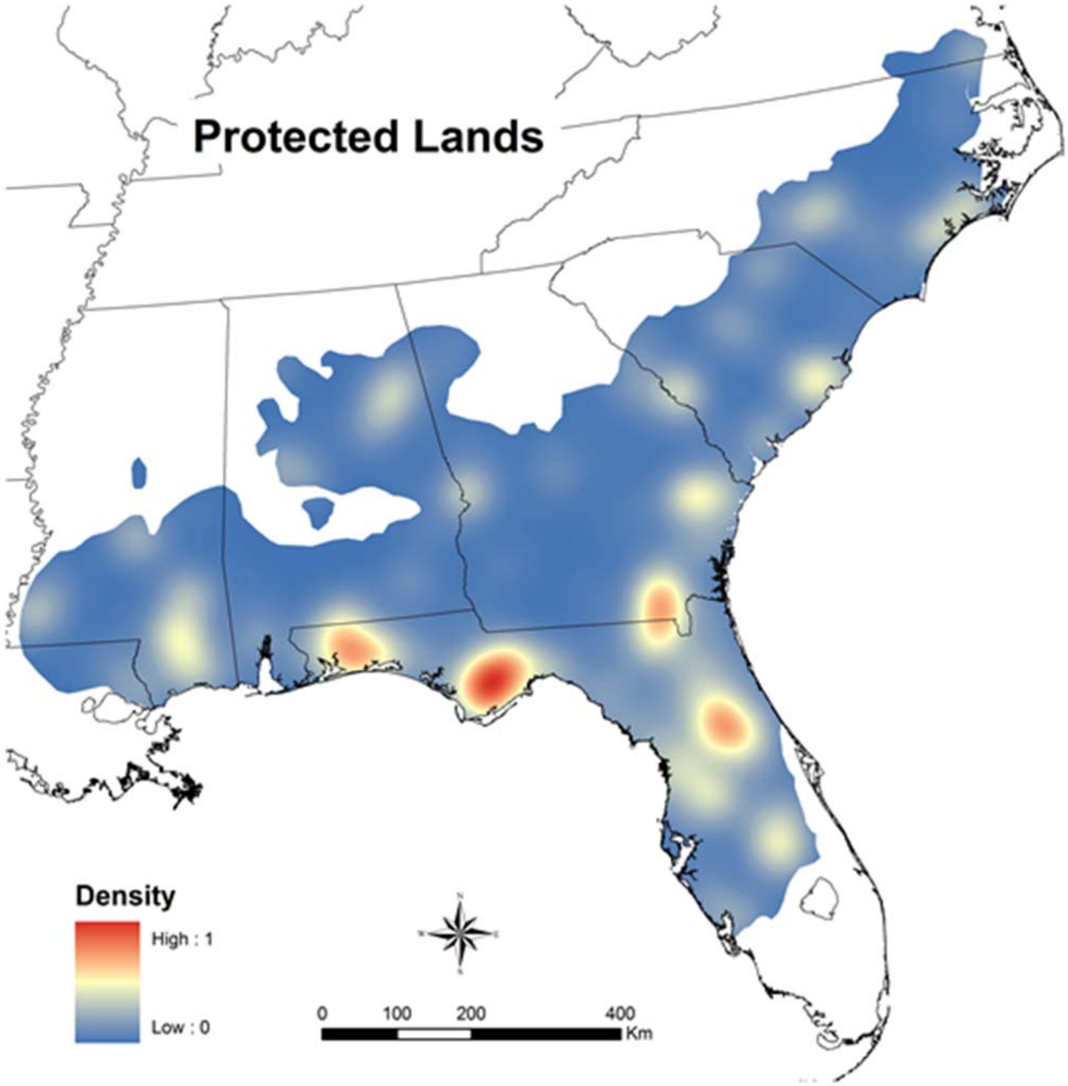


Figure 4. Density of lands in public ownership or land trusts within the range of longleaf pine circa 2001.

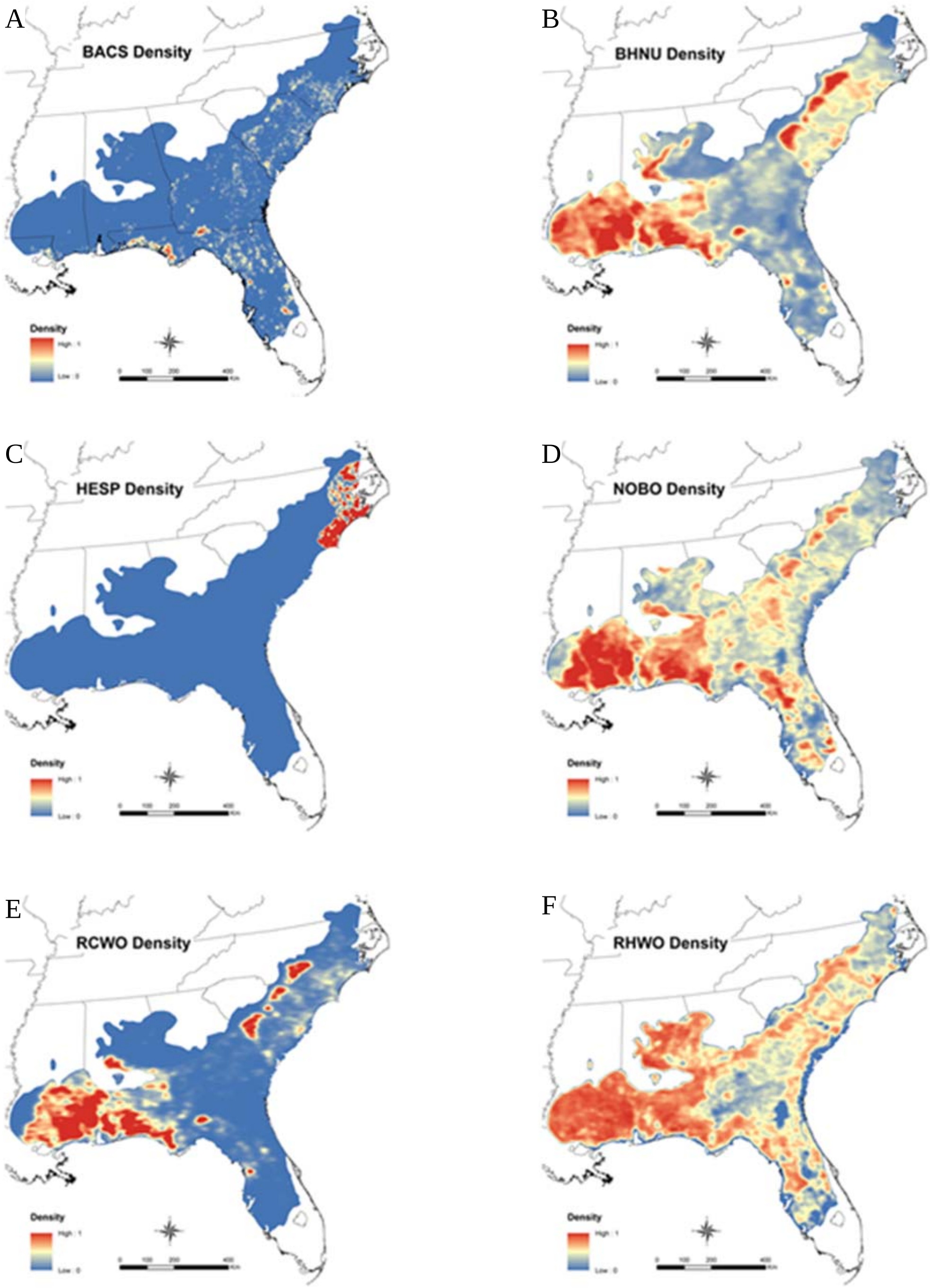


Figure 5. Density of potential habitat mapped by SEGAP with the range of longleaf pine for focal birds inhabiting open pine systems within the range of longleaf pine. A – Bachman's sparrow, B –Brown-headed Nuthatch, C – Henslow's Sparrow, D – Northern Bobwhite, E – Red-cockaded Woodpecker, F – Red-headed Woodpecker.

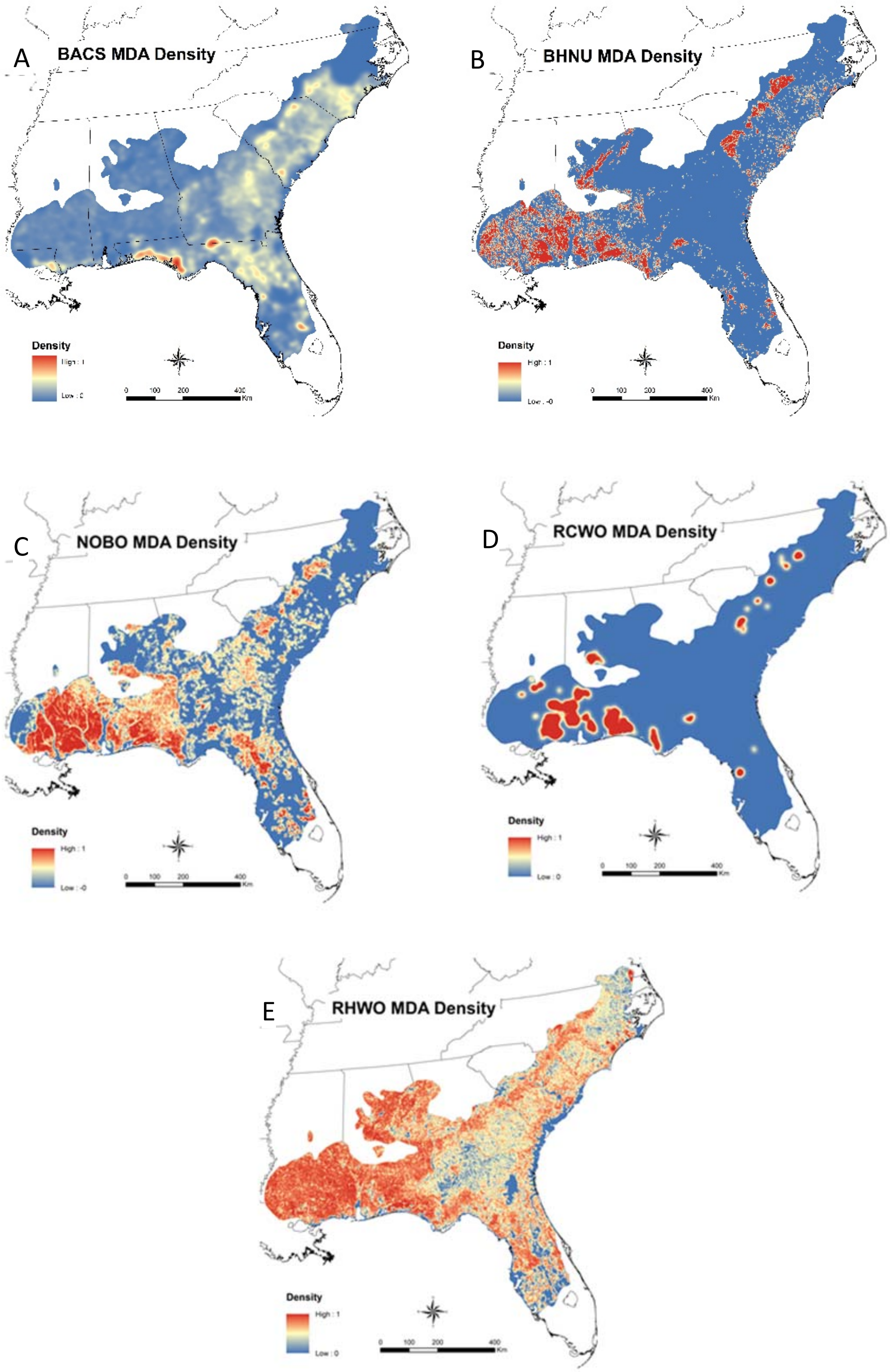


Figure 6. Density of putative source populations of focal birds with the range of longleaf pine. A – Bachman's sparrow, B –Brown-headed Nuthatch, C – Northern Bobwhite, D – Red-cockaded Woodpecker, E – Red-headed Woodpecker.

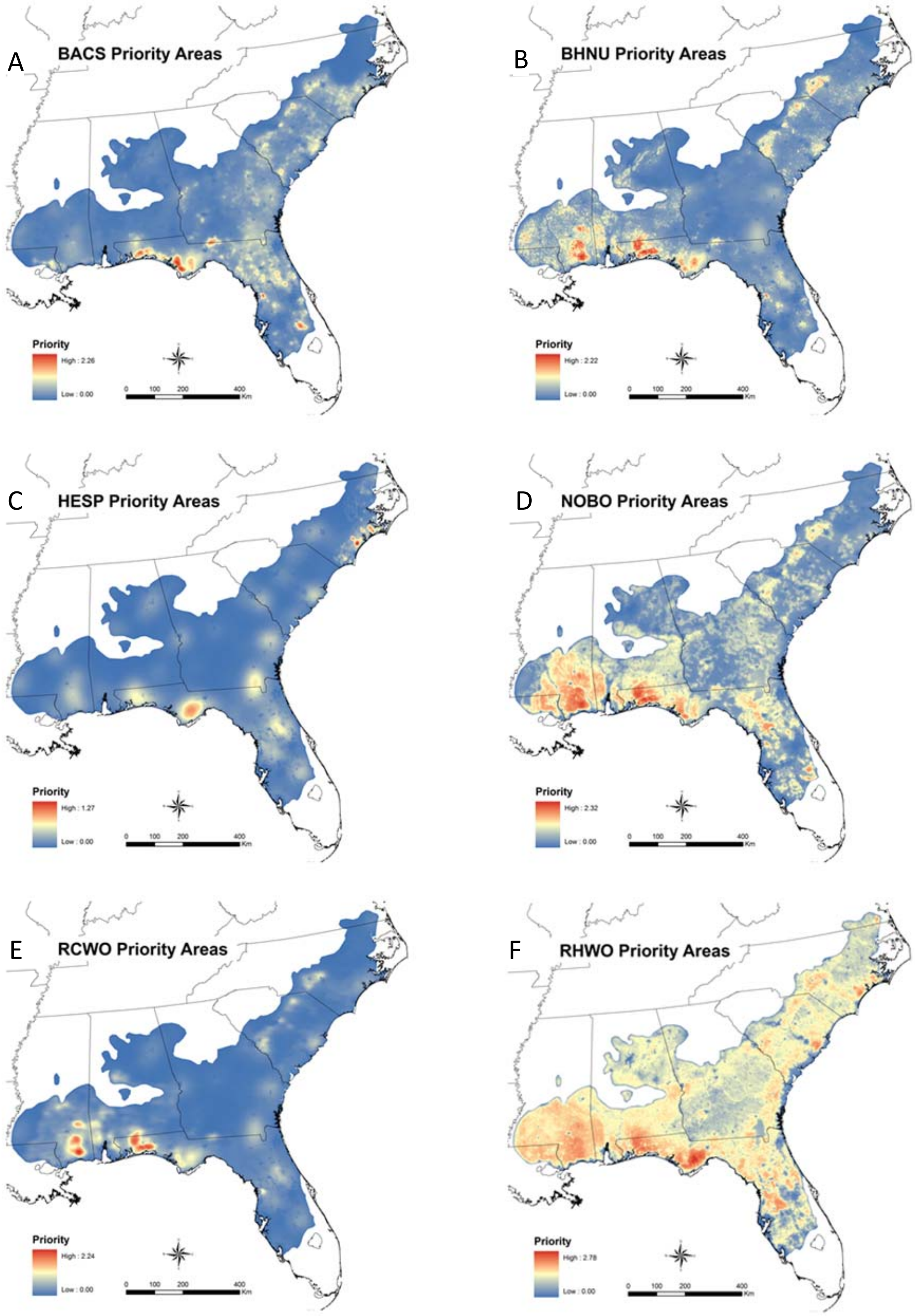


Figure 7. Map of conservation priorities for focal bird species within the range of longleaf pine. A – Bachman's sparrow, B –Brown-headed Nuthatch, C – Henslow's Sparrow, D – Northern Bobwhite, E – Red-cockaded Woodpecker, F – Red-headed Woodpecker.

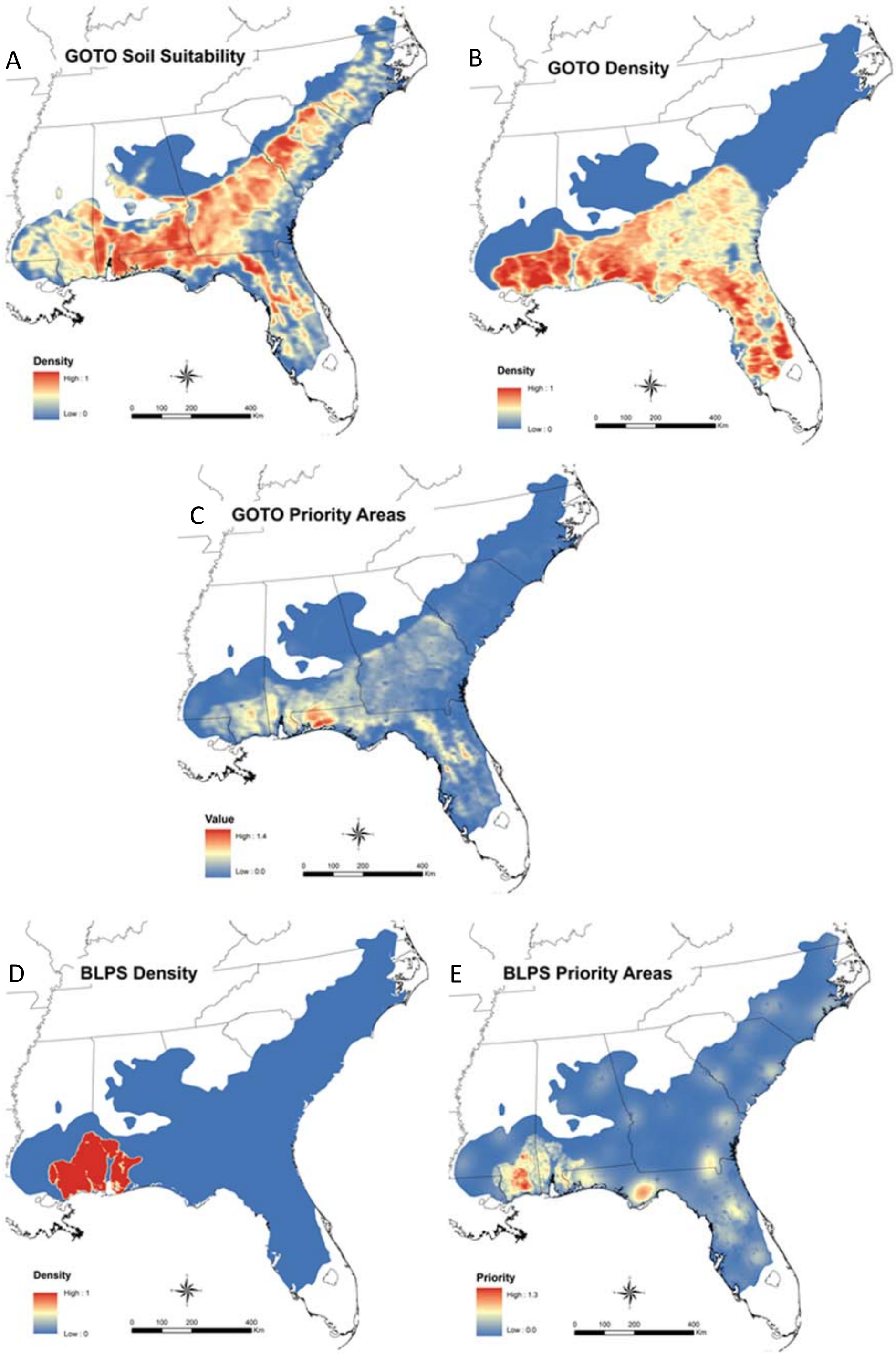
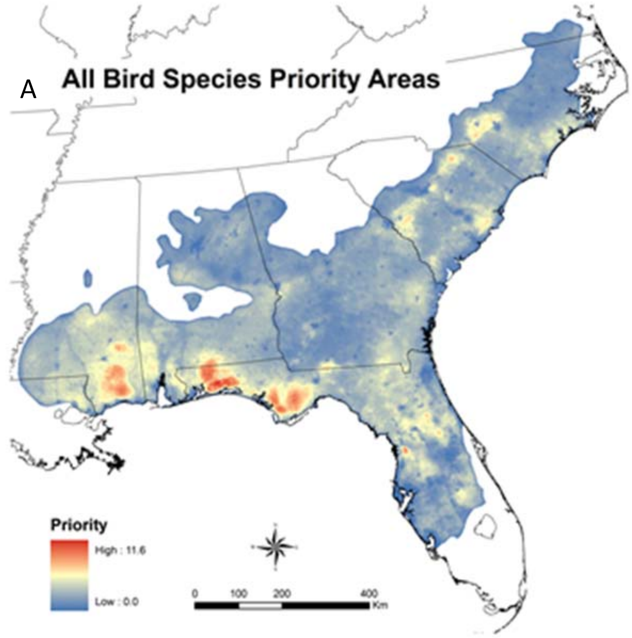


Figure 8. Maps of (A) soil priorities, (B) density of potential habitat, and (C) priority areas for gopher tortoise (D) density of potential habitat and priority areas for black pine snake.



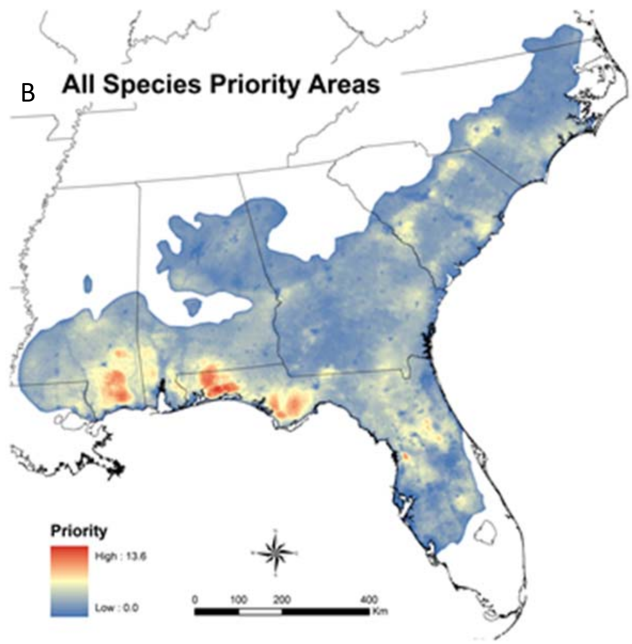


Figure 9. Map of priorities for all focal bird species (A) and focal bird and reptile priorities (B) within the range of longleaf pine.