Landscape-Scale Spatial Analysis of Longleaf Pine Ecosystem Resilience in North Carolina

Introduction

Longleaf pine forests are at risk. Today 4.3 million acres remain of the original extent that once spanned 92 million acres across the southeastern United States (Oswalt et al 2012). These remnant forests are threatened by exclusion of natural or prescribed fire regimes, fragmentation, unsustainable timber harvest, conversion to other land uses and vegetative types, and invasive species. Conservation actions to protect, restore, and manage longleaf pine forests are essential to halt the decline of these forests. The Nature Conservancy (TNC) is working across nine states—in partnership with many agencies and organizations—to expand longleaf pine forests. The North Carolina Chapter of TNC initiated this landscape-scale GIS-based analysis because of a desire to focus our conservation actions in the places where longleaf pine forests are most likely to persist in the long-term, adapt to changes, and continue to support biodiversity.

The conservation target for TNC's Longleaf Pine Whole System Project in North Carolina, and focus of this analysis, is the longleaf pine ecosystem. Because this is a coarse-filter target at a large scale, it encompasses a variety of habitats and species that are associated with longleaf pine. High quality longleaf pine systems are generally characterized by a canopy of widely-spaced longleaf pines with an herbaceous ground layer; but this simplified description masks the incredible biological diversity within this system and the significant variation between longleaf forests in different regions (Oswalt et al 2012). The ultimate goal for TNC is to conserve a "resilient" longleaf pine ecosystem. A resilient ecosystem is more likely to maintain its composition, structure, and functions, even in the face of disturbance or change. A longleaf pine ecosystem is more likely to be resilient if it has large connected blocks of intact forest, the presence of characteristic natural communities and species, and a periodic fire regime. For TNC, conservation of a resilient longleaf pine ecosystem means focusing conservation efforts in places where a longleaf pine ecosystem is likely to persist in the long term and implementing strategies aimed at increasing its resiliency—such as protecting and connecting high quality forest, restoring longleaf and native groundcover species in degraded habitats, and managing lands with prescribed fire.

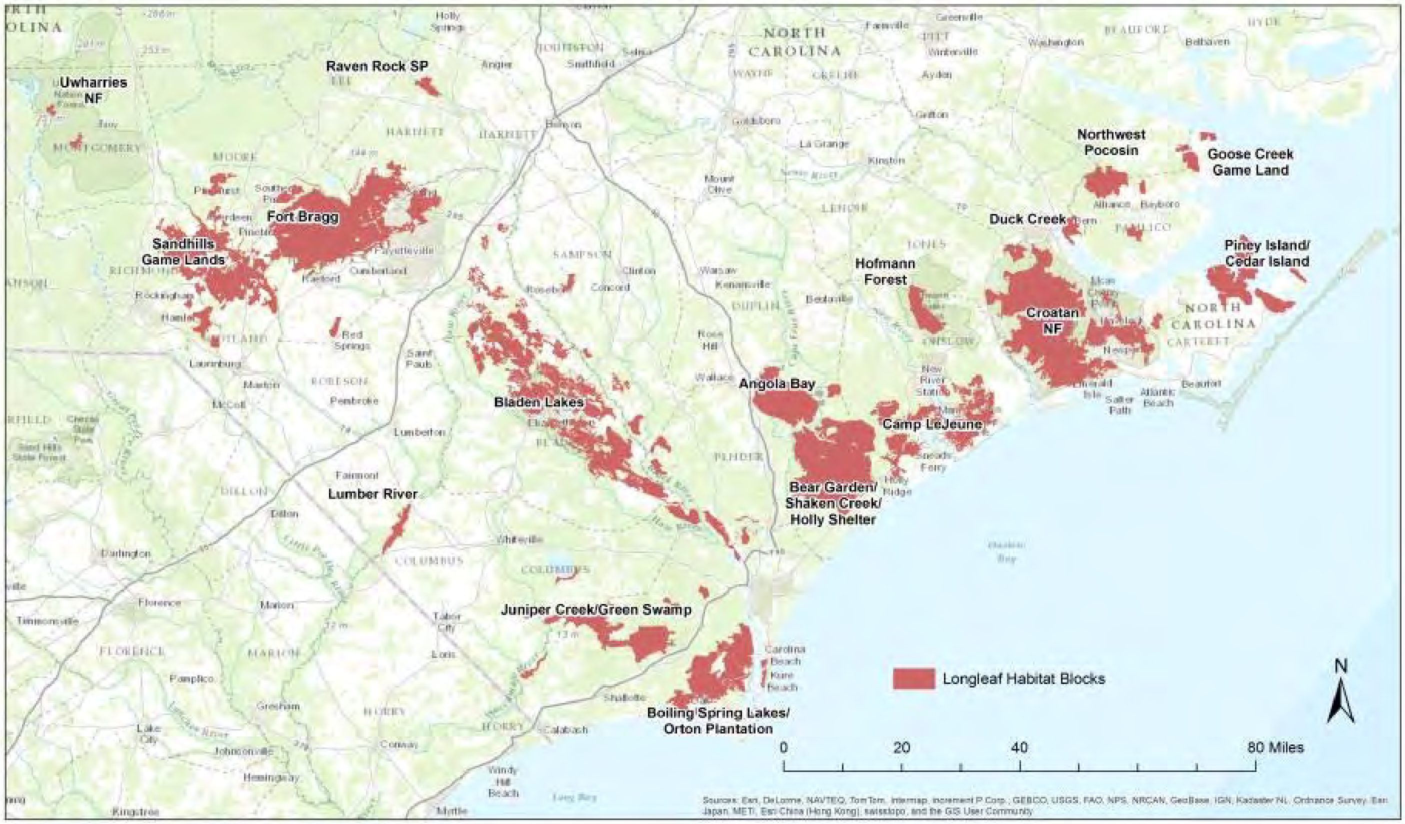
This spatial analysis was developed to guide TNC's conservation planning and activities across the range of longleaf pine forests in North Carolina. The specific objectives of this assessment were to:

1) Map the current extent of longleaf pine habitats in North Carolina based on available data
2) Establish a definition of a resilient longleaf pine ecosystem and use this definition to evaluate the potential ecological resilience of the existing habitat
3) Identify the optimal location of corridors that could connect longleaf pine habitat for the purposes of enhancing ecosystem resilience
4) Produce a map that would serve to identify areas in which to focus land conservation efforts for the purpose of achieving a more resilient longleaf pine ecosystem

Mapping the Extent of Longleaf Pine Habitats in North Carolina

The first step in this spatial analysis was to map the current extent of longleaf pine habitats in North Carolina. Knowing the location, size, and landscape context of our conservation target was fundamental to our planning effort, so we sought to create a landscape-scale map based on readily-available data. We chose to use data from the North Carolina Natural Heritage Program, part of the NC Department of Natural and Cultural Resources. The Natural Heritage Program has developed the state's most comprehensive database of natural resource information by combining on-the-ground surveys with advanced GPS and GIS technology. From their data sets, we extracted and mapped all longleaf pine-associated species, natural communities, and habitats (see Appendix A). These data were supplemented with other species distribution data. Our methodology does not map the location of all forests containing longleaf pine trees, but it does identify the locations known to support characteristic species and natural communities. Longleaf Habitat Blocks were then defined by grouping contiguous habitat. Any habitat separated by 2 kilometers or a fragmenting feature, such as major rivers and roads, constituted a separate "habitat block". These Longleaf Habitat Blocks formed the unit of analysis for the subsequent steps of our spatial analysis. Many of these habitat blocks correspond with lands that are owned or managed for conservation, but not all habitat blocks are protected. This map shows existing longleaf pine habitat regardless of conservation ownership or management status.

Figure 1: Map of Longleaf Pine Habitat Blocks



Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Evaluating the Ecological Resilience of Longleaf Pine Habitat Blocks

The next step was to evaluate the ecological resilience of the Longleaf Pine Habitat Blocks. Ecological resilience is defined as the ability of the ecosystem to recover from large-scale disturbance. In the face of catastrophic events like hurricanes, ongoing pressures such as human land use, and long-term shifts such as climate change, a resilient ecosystem is more likely to retain biological diversity and similar natural functions, structures, and processes. In contrast, a more vulnerable ecosystem lacks the capacity to withstand disturbance and is more likely to shift into an alternate or degraded state that often results in a loss of diversity and natural functions. Measuring resilience is difficult, but we believe that a healthy ecosystem possessing key ecological attributes is more likely to be resilient and an ecosystem lacking in the same attributes is more likely to be vulnerable in the long term. We identified several key ecological attributes of a longleaf pine ecosystem (Table 1), based on staff expertise and consultation of literature (Anderson 2008), that should increase its overall resiliency.

Table 1: Key Ecological Attributes of a Resilient Longleaf Pine Ecosystem

Size	Habitat blocks are large enough to support: • an appropriate prescribed fire regime • viable populations & gene flow of area-sensitive species • properly functioning hydrology & other natural processes • ability to recover from disturbance (i.e. catastrophic fires, hurricanes, invasive species, pathogens, etc.)
Landscape Context	• Habitat blocks are connected by natural areas that can allow for species movement and/or range shifts in response to environmental change
Condition	• Characteristic species and natural communities are present and viable • The appropriate forest structure and age classes are present

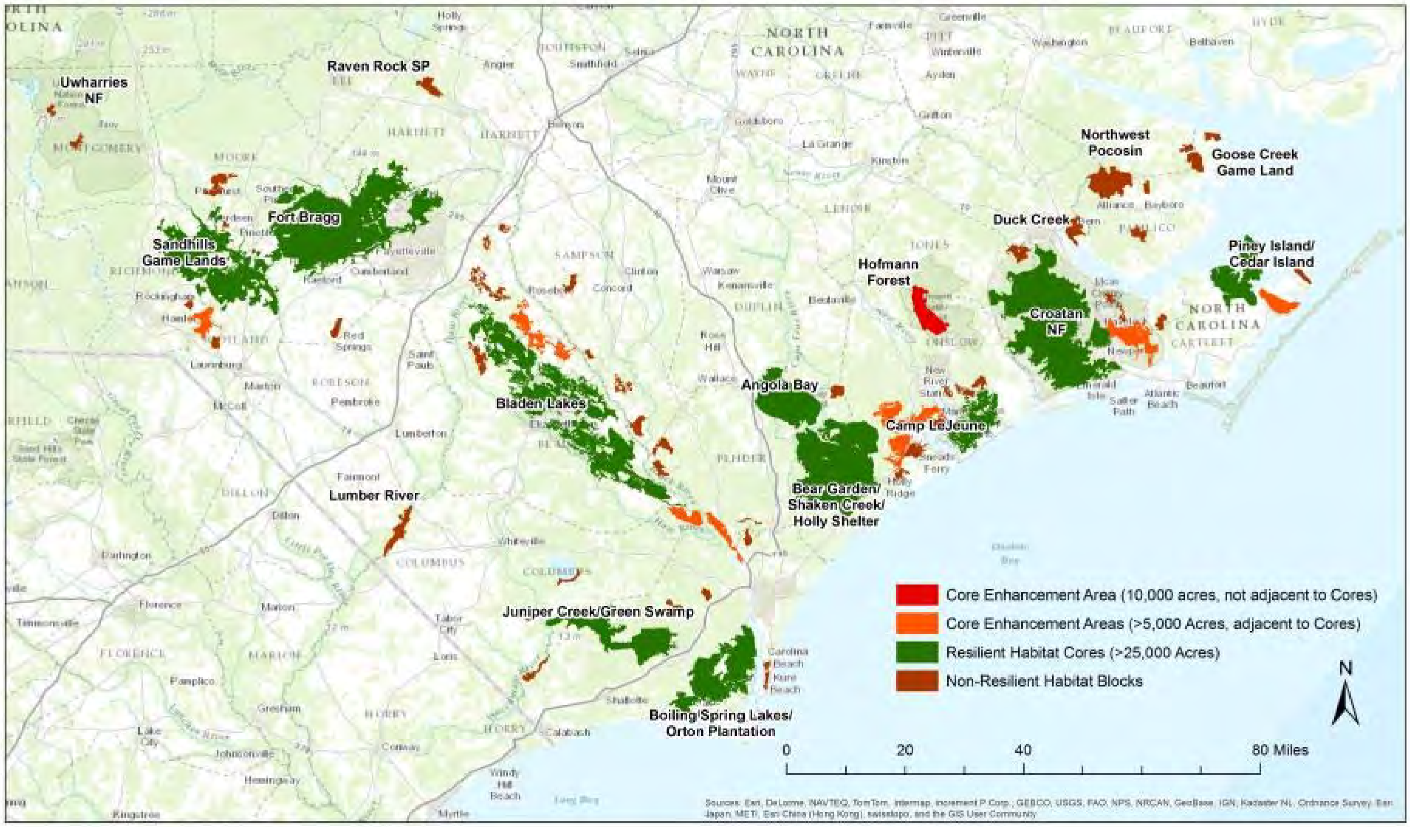
Given that the Habitat Blocks we mapped were defined by the known distribution of natural communities and species associated with longleaf pine, we decided to evaluate resilience based on the size and connectivity of Habitat Blocks. We acknowledge that the condition of these Habitat Blocks—forest composition, structure, and age in particular—is also critical to their ecological resilience, but assessing habitat condition was beyond the scope of this spatial analysis. Therefore, TNC also conducted a separate assessment of longleaf condition classes through on-the-ground surveys of TNC preserves and select partner lands.

For this analysis, we assumed that larger, more connected Longleaf Habitat Blocks were more likely to be resilient; and smaller, more isolated blocks were more likely to be vulnerable. We also assume that if a Habitat Block is isolated, it would need to be larger to sustain biodiversity and natural processes. Based on a literature review and expert opinion (see Appendix B), we established criteria to broadly categorize the Longleaf Habitat Blocks according to their potential degree of resilience. The categories of ecological resilience we defined are shown in Table 2.

Table 2: Resilience Categories of Longleaf Pine Habitat Blocks

Category	Definition	Criteria
Resilient Habitat Cores	Longleaf habitat blocks that are likely large enough to support viable populations, natural processes, and disturbance regimes	Habitat Blocks greater than 25,000 acres
Core Enhancement Areas	Longleaf habitat blocks with the potential to become more resilient with conservation actions to increase size, connectivity, or condition. Blocks that are more isolated need to be larger.	Habitat Blocks less than 25,000 acres and (i) greater than 10,000 acres if they are isolated (more than 2km from another habitat block) and (ii) greater than 5,000 acres if they are adjacent to Cores (less than 2 km from another habitat block)
Non-Resilient Habitat	Longleaf habitat blocks that are probably too small and/or isolated to be resilient in the long term	(i) Habitat Blocks less than 5,000 acres and (ii) isolated Habitat blocks less than 10,000 acres

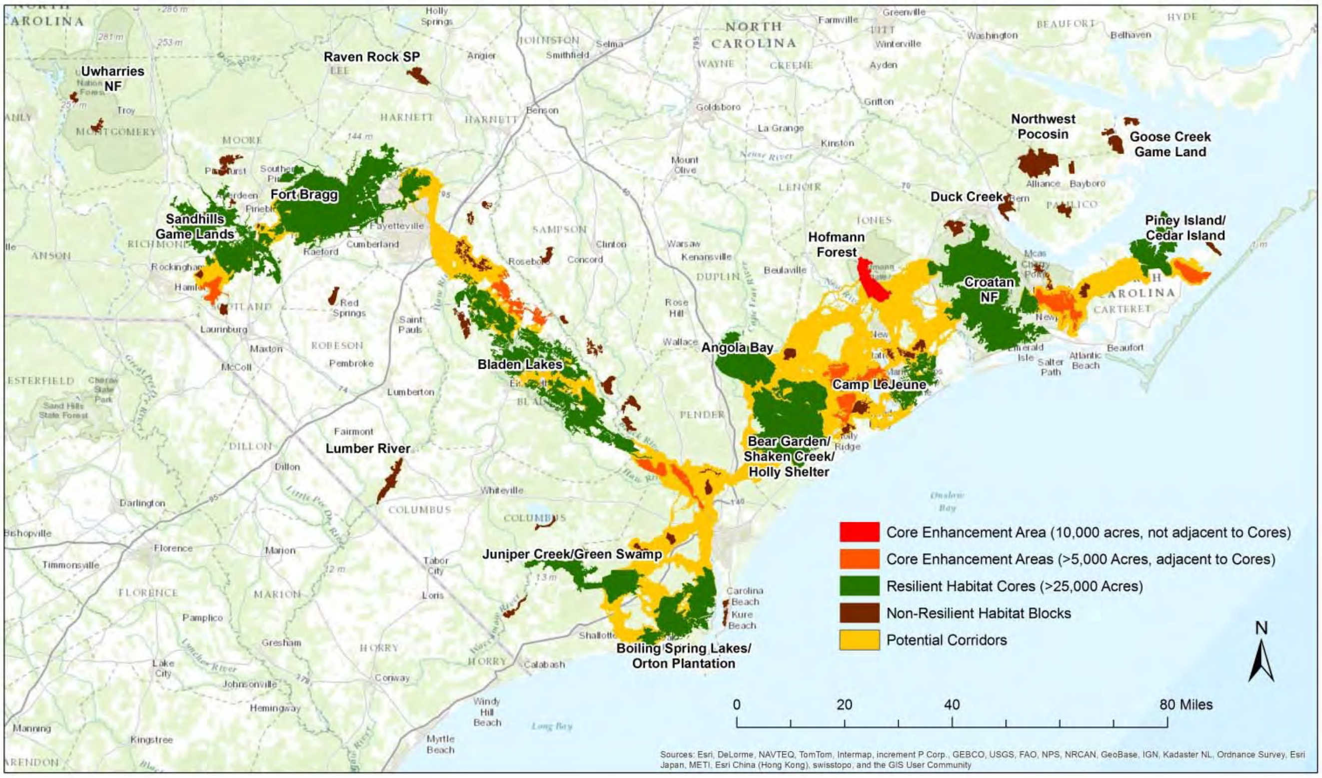
Figure 2: Map of Longleaf Pine Habitat Blocks Categorized by Resilience



Identifying Potential Corridors to Increase Resilience

The long-term resilience of the longleaf pine ecosystems in North Carolina will be enhanced if the existing Habitat Blocks are connected in a way that allows for the flow of species and ecological processes between them. Species and processes are more likely to move across natural areas, even non-longleaf habitat, whereas they may be impeded by developed and highly altered land uses. We wanted to identify corridors that connect Resilient Habitat Cores to each other. We also identified corridors between Core Enhancement Areas and their nearest Resilient Habitat Core, because joining those smaller habitat blocks to larger habitat would presumably increase overall resilience. These corridors are not based on the movement patterns or habitat requirements of specific species, but are based on the shortest linkages between adjacent Habitat Blocks through high quality natural habitat, avoiding development and large bodies of open water. Potential corridors were modeled using LinkageMapper (see Appendix C).

Figure 3: Map of Corridors Between Longleaf Pine Habitat Blocks



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Using the Resilience Analysis to Set Conservation Priorities and Goals

The map resulting from this analysis will be integrated into a conservation plan for TNC's NC Longleaf Whole System Project. Protecting and restoring Resilient Habitat Cores is the highest priority. Some Resilient Habitat Cores will be a higher priority than others, based on TNC's resources, capabilities, and niche amongst partner organization and agencies also working in this landscape. For each Resilient Habitat Core and its adjacent Core Enhancement Areas, we are overlaying data on the ownership, management status, and forest condition to map conservation strategies such as land acquisition, habitat restoration, collaborative agreements with other key landowners, and land use planning. Ensuring that corridors of high quality natural habitat link the cores will be a second tier priority. Once all the conservation strategies are spatially explicit, we will have the ability to quantify goals for each strategy. With quantifiable goals, we will have the basis for tracking and measuring progress over time. We will also use these goals to estimate the human and financial resources necessary to implementing our strategies over time.

Recommendations for Further Analysis

This analysis met the objectives of mapping the current extent of Longleaf Pine Habitats across North Carolina, evaluating the ecological resilience of those habitats, and identifying places on the landscape where conservation action could increase the resilience of this ecosystem. There is the potential for this analysis to undergo further iterations as additional or new data becomes available. Further analysis is valuable if it can help refine our priorities, strategies, or goals.

Here are some examples of additional data that may be incorporated in the future:

- Remotely sensed data on forest condition – TNC conducted on-the-ground surveys to assess the condition of longleaf pine forests on TNC preserves and select partner lands. While these surveys provided valuable data, the results are limited in geographic scope and it would be beneficial to have landscape-scale spatial data on habitat condition.
- Connectivity with longleaf pine habitat in adjacent states – The scope of this analysis was limited to the state of North Carolina. The longleaf pine ecosystem extends into adjacent states, South Carolina in particular. If we can obtain comparable data to map Longleaf Pine Habitat Blocks in South Carolina, we could then delineate corridors to core areas across the state line.
- Projections of urban growth and sea level rise – This analysis is based on the landscape at a specific point in time, but human land use changes through time. In the future, some areas may be under greater threat than others from pressures such as development or sea level rise. Overlaying this analysis with models predicting future conditions may help prioritize or sequence conservation actions in certain places.
- Other spatial planning efforts – Our map of core longleaf habitat and connectors could be compared with other plans for this landscape. TNC's Eastern Division is currently conducting a spatial analysis of the entire Eastern US to identify a connected network of resilient sites. While not specific to longleaf pine, comparing these analyses could provide insights on how longleaf pine conservation fits into the overall landscape context.

Acknowledgments

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List of Appendices

A. GIS data and methods for mapping longleaf pine habitat blocks
B. Logic and evidence for resilience categories
C. GIS data and methods for modeling corridors

Appendix A: GIS data and methods for mapping longleaf pine habitat blocks

Step 1: Mapping longleaf pine-associated habitat

Data to map longleaf pine habitats came from the North Carolina Natural Heritage Program (NHP) and can be found here: http://www.ncnhp.org/. We used two datasets from the NHP to delineate longleaf-associated habitat that is known to currently exist on the ground:

1) *Natural Heritage Natural Areas (NHNA)*: This shapefile identifies terrestrial and aquatic sites that are of special biodiversity significance. A natural area's significance may be due to the presence of rare species, exemplary natural communities, or important animal assemblages. For the purposes of this analysis, we selected and used only NHNA's that are associated with Longleaf Pine (See Table 3). The NHNA dataset is continuously updated; we used a version from July 2015. See the NHP website for more information.

Table 3: Selected Longleaf Pine-associated Natural Heritage Natural Areas

Low pocosin
High pocosin
Pond pine woodland
Streamhead pocosin
Streamhead atlantic white cedar forest
Small depression pocosin
Wet pine flatwoods
Pine savanna
Sandhill seep
Vernal pool
Small depression pond
Piedmont longleaf pine forest
Coastal fringe sandhill
Mesic pine flatwoods
Pine/scrub oak sandhill
Xeric sandhill scrub

2) *Landscape/Habitat Indicator Guilds (LHI Guild)*: The NHP uses an indicator species approach to identify and prioritize blocks of habitat for conservation based on their degree of landscape integrity. The species used are indicators of landscape integrity for a particular type of habitat or, conversely, are sensitive to the effects of fragmentation of that type of habitat. _The group of indicator species associated with a given habitat is termed a Landscape/Habitat Indicator Guild (LHI Guild). For the purposes of this analysis, we selected and used only LHI Guilds that are associated with Longleaf Pine (See Table 4). See Hall (2010) for more information.

Table 4: Selected Longleaf Pine-associated Landscape/Habitat Indicator Guilds

Xeric-Mesic Longleaf Pine and Mixed Oak Woodlands
Wet-Xeric Longleaf Pine Woodlands/Ephemeral Pools
Sandhill Streamhead Mires
Atlantic White Cedar Forest
Wet Acidic Shrublands
Herbaceous Peatlands and Pitcher Plant Meadows
Savannas and Wet Sandy Herbaceous Swales
Wet-Mesic Pine Woodlands
Wet-Xeric Longleaf-Wiregrass Woodlands
Xeric-Mesic Maritime Mixed Herbaceous Grasslands
Sandhill Seeps and Wet Sandy Herbaceous Swales
Sandhill Streamhead Swamps and Pocosins
Forest Canebrakes

Several other sources of data were explored and ultimately not included in our analysis. There was no existing dataset mapping existing longleaf pine based on remote sensing and/or land cover classifications that accurately reflected the location of longleaf pine-associated habitats on the ground.

Step 2: Grouping Longleaf Pine Habitat into Blocks

To then delineate discrete habitat blocks, we grouped any contiguous longleaf habitat. Habitat was not considered contiguous if it was separated by a distance greater than 2 kilometers or a fragmenting feature. Fragmenting features were major roads and major rivers. Smaller roads and streams were not included as fragmenting features. The datasets for fragmenting features were:

3) *NC Center for Geographic Information and Analysis (CGIA) Major Roads*: US highways and interstates were used as fragmenting features. Roads that affected this analysis were US 1, 15, 17, 70, 421, and 701.

4) *CGIA Major Hydrography*: Major Rivers were used as fragmenting features. Waters that affected the analysis were Black River, South River, and Northeast Cape Fear River.

Step 3: Cleaning up the Data

The resulting Longleaf Habitat Blocks were reviewed and validated by TNC staff with on-the-ground expertise. They visually inspected the GIS layer of Longleaf Habitat Blocks in combination with aerial photos, the Sandhills Conservation Partnership's Reserve Design Data, and species point data such as Natural Heritage Element Occurrences and Wildlife Resources Commission survey records (for Bachman's sparrow, red-cockaded woodpecker, gopher frog, pine snake, pine barrens tree frog, and southern hognose snake). Areas adjacent to or surrounded by a Habitat Block were added to that Habitat Block if the area contained a concentration of longleaf-specialist species, was known to be managed for longleaf habitat, or had similar habitat based on aerial photographs. Areas were excluded from Habitat Blocks if aerial photography or on-the-ground knowledge clearly indicated that it was actually an agricultural field, dense pine plantation, developed, or other types of non-suitable habitat.

Appendix B: Logic and evidence for resilience categories

Ecological response to disturbance can be defined through two strategies: resistance and resilience. Resistance is defined as the ability of species to withstand or absorb change; populations may experience a small reduction in numbers, but the overall population remains viable (Pimm 1991). The other strategy in the face of disturbance is resilience, or the ability to rebound quickly after an environmental perturbation (Holling 1973). In the case of longleaf pine, trees are classically resistant, i.e., they tend to survive disturbance events such as fire, hurricane, or wind, and particularly when compared to other pine species such as loblolly or pond pine (Gresham et al. 1991). Meanwhile, the understory is classically resilient, in that it rebounds quickly from disturbance (Brockway & Lewis 1997).

The resistance and resilience of a landscape are dependent on the size, condition, and landscape context (Anderson 2008). We first determined the minimum size of a habitat block, depending on whether it is connected or isolated. No definition of a size of a resilient patch of longleaf pine forest is available in the literature, but the ecological principle is that bigger patches are more resilient, because larger areas hold more species (including species with larger home ranges), provide areas of refuge in the event of patchy disturbances, and can better resist the impacts of wind and storms (Lindenmayer & Franklin 2002). For example, in longleaf pine forests, larger stands experience less tree mortality due to hurricanes (Platt et al. 2002). Anderson (2008) uses two sets of criteria for determining the minimum size of a resilient forest patch: (1) the “minimum dynamic area” needed to buffer against severe disturbances, and (2) the area needed to supply habitat for multiple breeding pairs of vertebrate species.

The minimum dynamic area is defined by the relative proportion of undisturbed to disturbed forest, under natural conditions, which is estimated in eastern U.S. to be four times the severe disturbance patch size (Anderson 2008). In longleaf pine forests, disturbances and maximum sizes of patches include windthrows (<1 acres; Palik & Pederson 1996)), lightning strikes (<1 acre; Palik & Pederson 1996), and hurricanes (30 acres; Hook et al. 1991; Wang & Xu 2008). Based on these disturbances, minimum dynamic area is very small (<200 acres). Scale of fire is hard to quantify, as longleaf pine mortality is very low in response to low or moderate severity fire, and stand-replacement fire is not characteristic of the system (Palik & Pederson 1996); however, patches can be large under suppressed conditions (e.g., the Juniper Road Fire in 2011 was >30,000 acres). A better threshold for site size may be driven by logistics of fire management, in which case approximately 5,000 or more acres is ideal (Margit Bucher, personal communication).

To determine the size needed for matrix forest blocks to contain multiple populations and potentially function as a source area for breeding species, we multiplied the average female territory size by 25, using the guideline that at least 50 genetically-effective individuals are necessary to conserve genetic diversity within a meta-population over several generations (Lande 1988; Anderson 2008). Red-cockaded woodpeckers, which are extensively studied, have higher requirements; an isolated patch should ideally support at least 100 potential breeding groups (25,000 acres; U.S. Fish and Wildlife Service 2003). Our approach is designed to be protective of all longleaf pine-associated species, not just one endangered bird species, but red-cockaded woodpeckers are the most well-researched species in the system, and a proven umbrella species for the community (Breckheimer et al. 2014). To further examine this claim, Table 5 presents the home range and associated patch size for a connected habitat block for several longleaf pine species.

Table 5: Longleaf pine-associated species, average home range size, necessary patch size for 25 females, and source of data.

Species	Home range (ac)	Patch size (ac)	Source
Red-cockaded woodpeckers	200 per Potential Breeding Group	6,250 (connected) 25,000 (isolated)	U.S. Fish and Wildlife Service 2003
Gopher frog	NA	2,000 - 9,000	Humphries & Sisson 2012
Bachman's sparrow	6	150 - 1,300	Haggerty 1998; Taillie et al. 2015
Northern pine snake	200	5,000	Woodward & Haddad, unpublished telemetry data
Saint Francis Satyr butterfly	NA	Entire known population occupies <25 acres	Kuefler et al. 2008

NA=data not available

Summary of disturbance and habitat analyses: Given that minimum dynamic area based on disturbance was very small (<200 acres), we identified 5,000 acres as a minimum area needed to accommodate prescribed fire. We then defined habitat blocks as 25,000 acres, to be protective of RCW populations, and connected core enhancement areas as 5,000, to be protective of most species (Table 5). We assigned the isolated core enhancement areas a threshold of 10,000 acres based on the fact that all species other than RCW would use patches this size.

Note: TNC's Eastern Division Conservation Science team has developed a methodology for identifying resilient sites for terrestrial conservation (Anderson et al 2014). Their approach is based on the concept that access to micro-climates increases species' ability to adapt to a changing climate. The terrestrial resilience analysis of the Southeastern US identifies places that have high landscape diversity (geophysical diversity creates micro-climates) and local connectedness (permeable natural land cover allows for movement). This project team explored incorporating the terrestrial resilience dataset into the mapping and evaluation of longleaf habitat, but ultimately ended up excluding it. As the geography of the longleaf range is generally flat, sandy soils, the Landscape Diversity component of the terrestrial resilience analysis tends to highlight river basins and areas along the Ecoregional boundary. The Local Connectedness component of the terrestrial resilience analysis does show areas of natural habitat, but is not specific to longleaf-associated habitat. It was felt that the presence and persistence of characteristic species and natural communities was critical to prioritizing longleaf sites for conservation so we chose to base our analysis on the known location of these species and communities. However, despite the difference in approaches, the priority sites that result from these two different analyses do have significant overlap. Approximately 85% of the area within Resilient Longleaf Habitat Cores we mapped is identified as above average resilience in the Terrestrial Resilience Analysis.

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Appendix C: GIS data and methods for modeling corridors

We used Linkage Mapper to identify and delineate corridors between the resilient habitat cores and core enhancement blocks. After creating the corridors, we used the Pinchpoint Mapper tool within Linkage Mapper to visualize and identify 'pinch points' or areas within the corridors where species movement may be hindered due to the lack of natural habitat.

Habitat Blocks/Focal Areas

Creating corridors requires focal areas or blocks to connect and an underlying resistance raster to calculate the least cost path between blocks. Our resilient habitat cores and core enhancement blocks served as our blocks.

Resistance Raster

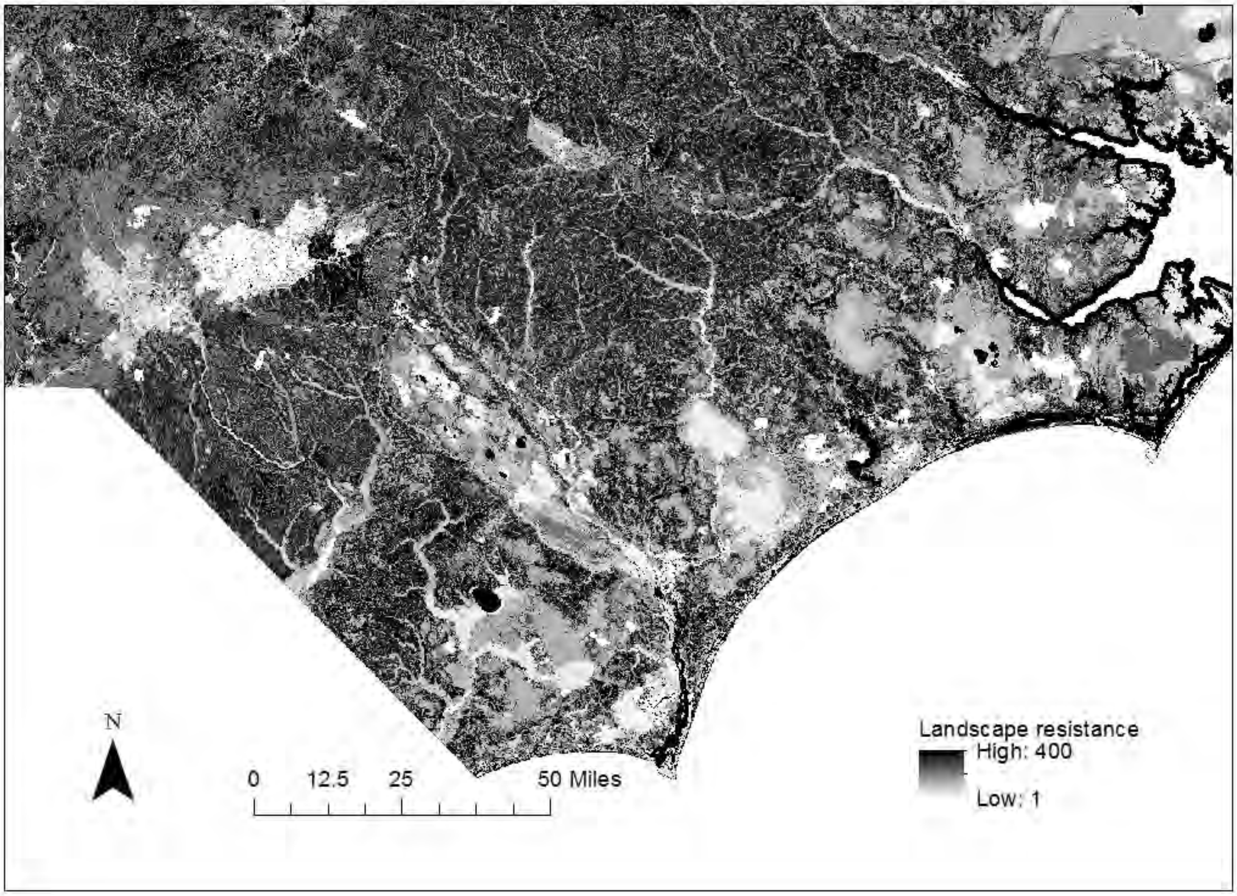
The resistance raster was a compilation of the following layers for North Carolina: 1) soil suitability for longleaf/loblolly pine, 2) biodiversity/wildlife habitat assessment, 3) USGS landcover dataset, and 4) the non-resilient longleaf habitat blocks from our earlier work. The first step in creating a resistance raster involved selecting relative resistance values for all classes within each layer (Table 6).

Table 6: Data Layers and Values for Resistance Raster

Data Layer	Class	Value
Longleaf Pine Suitable Soils	Longleaf site index greater than or within 20 of loblolly site index. Less capable crop soils.	10
	Longleaf site index greater than or within 20 of loblolly site index. More capable crop soils.	75
	Loblolly site index more than 20 greater than longleaf site index. Less capable crop soils.	25
	Loblolly site index more than 20 greater than longleaf site index. More capable crop soils.	100
Biodiversity/Wildlife Habitat Assessment	0	100
	1	90
	2	80
	3	70
	4	60
	5	50
	6	40
	7	30
	8	20
	9	10
	10	0
Biodiversity/Wildlife Habitat Assessment	Impervious surfaces (-1)	400
USGS Landcover	Open water	400
Non-resilient habitat blocks	Longleaf block 3 areas	1

For the soil layer, we assigned relatively high resistance values for capable crop soils, because a large percentage of this has already been converted to agricultural land, and a significant investment of time and money would be needed for restoration. Because our focus was on longleaf habitats, we also provided higher resistance values for sites with loblolly than longleaf soils. The value classes in the biodiversity/wildlife assessment layer ranged from -1 to 10, with high conservation habitat having high values. For this layer, we assigned resistance values in increments of 10 from 0 to 100, with cells of maximum conservation value (10) receiving a score of 0 and those of little or no conservation value (0) receiving a score of 100. Cells with values of -1 (impervious surfaces) were removed from this layer, but were used in a later step. The resistance values for both the soil and biodiversity/wildlife layers were then summed, resulting in a layer which had values that ranged from 10 (least resistant) to 200 (most resistant). The previously removed impervious surface cells were then overlaid on this new raster, and overlapping areas were given a value of 400. Regions of open water were extracted from the USGS landcover dataset and overlaid. Regions of overlap were given a resistance value of 400, because many longleaf associated species are unable to cross large expanses of open water. Then the non-resilient blocks were overlaid and cells that fell within these blocks were given a resistance of 1, because we elected to have low resistances for already existing longleaf habitat. Overall, this yielded a resistance raster with values that ranged from 1 to 400 (Figure 4).

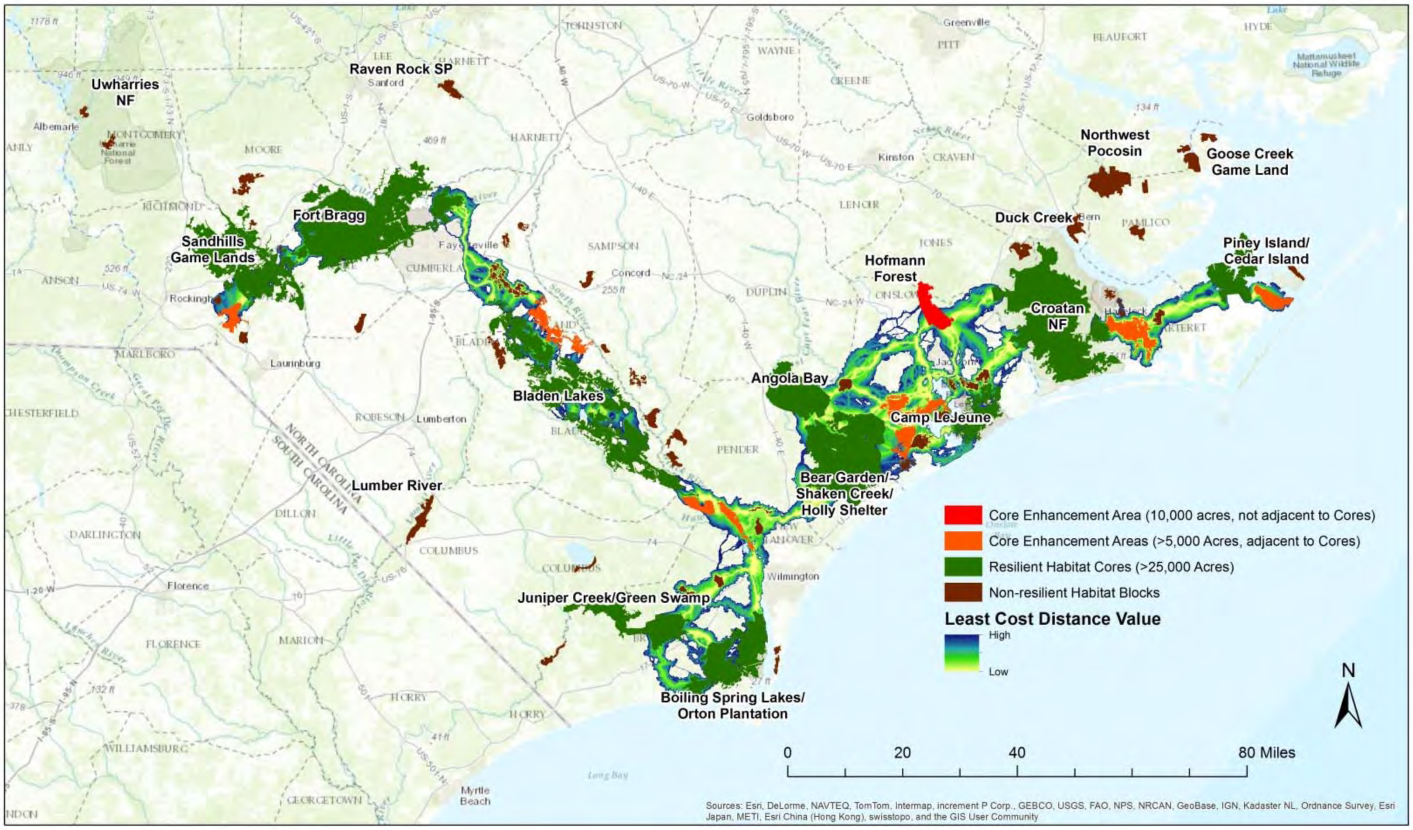
Figure 4: Resistance Map for Corridors between Longleaf Habitat Blocks



Linkage Mapper Analysis

The longleaf resistance layer and blocks were then used in Linkage Mapper to create corridors (Figure 5). Within the program, we elected to identify network adjacency by both cost-weighted and Euclidean distances and drop any corridors that intersected core areas. Finally, we removed any corridors that were greater than 100km in length or passed over more than 1km of open water.

Figure 5: Least Cost Difference Map for Corridors between Longleaf Habitat Blocks



Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community