Longleaf Pine Sustainability Analysis
Version 1
Technical Report

Final Report to The Longleaf Alliance

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Florida Natural Areas Inventory
Florida Resources and Environmental Assessment Center
Institute of Science and Public Affairs
Florida State University

Center for Landscape Conservation Planning
College of Design, Construction, and Planning
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ABSTRACT

The Longleaf Sustainability Analysis (LSA) is a longleaf ecosystem-centric spatial analysis designed to facilitate the strategic, transparent, and evidence-based identification of the “right work” in the “right places” across the historic range of longleaf pine, a need identified in the 2009 Range-Wide Conservation Plan for Longleaf Pine. The LSA combines map data about extant longleaf, suitable sites for restoration, landscape connectivity and other factors related to sustainability to prioritize areas on the landscape for implementation of restoration and conservation actions.

The LSA contains 3 categories of analysis that interact to prioritize places for both conservation and restoration of longleaf pine: Extant Longleaf Significance, Longleaf Pine Suitability, and Sustainability. Each of the analysis categories involved compilation and/or development of component data layers, including a new Landscape Connectivity analysis. These categories were combined to create two primary prioritization products: 1) Priority Areas for Conservation and Management, a map layer of priority classes for extant longleaf pine; and 2) Priority Areas for Restoration, a map layer of prioritized areas for establishment of new longleaf.

The LSA was developed in a relatively short timeframe, Nov 2022 – July 2023. Since it was designed and conducted at range-wide scale, the results may not align with local knowledge or priorities. Users are encouraged to review these datasets and provide feedback to inform a next version of the LSA. We expect this work to evolve with future iterations as additional data and funding become available.

ACKNOWLEDGMENTS

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LIST OF ACRONYMS

ALRI	America's Longleaf Restoration Initiative
AUC	Area Under the receiver operating Curve
CVS	Carolina Vegetation Survey
ELS	Extant Longleaf Significance
EVT	Existing Vegetation Type (LANDFIRE data)
FNAI	Florida Natural Areas Inventory
FUTURES	FUTure Urban-Regional Environment Simulation
LEO	Southeast Longleaf Pine Ecosystem Occurrences Geodatabase
LIT	Local Implementation Team; Local Implementation Team Area
LLP	Longleaf Pine
LPC	Longleaf Partnership Council
LSA	Longleaf Sustainability Analysis
LUI	Land Use Intensity Index
MoBI	Map of Biodiversity Importance (by NatureServe)
NLCD	National Land Cover Database
NRCS	Natural Resources Conservation Service
PAs	Protected Areas
PRISM	Parameter-elevation Regressions on Independent Slopes Model
PSI	Patch Size Index
SGAs	Significant Geographic Areas
TNC	The Nature Conservancy
UF-CLCP	University of Florida Center for Landscape Conservation Planning
USDA	United States Department of Agriculture

INTRODUCTION

Longleaf pine (LLP) forests, woodlands, and savannas once dominated the uplands of the southeastern coastal plain, covering approximately 92 million acres, but only a fraction now remains (Oswalt et al. 2012; Frost 2007). In 2008 longleaf was estimated to occupy only 3.4 million acres of its former range (ALRI 2009). Restoration of these ecosystems has received much attention in the last 20 years, especially since formation of the America's Longleaf Restoration Initiative (ALRI) in 2007 and subsequent 2009 Range-Wide Conservation Plan, which established a goal of increasing longleaf to 8 million acres by 2025. The latest estimate of 5.2 million acres indicates progress toward that goal but with more work to do (ALRI 2023).

The 2009 Conservation Plan emphasizes that, given limited resources, conservation and restoration efforts should be prioritized in areas with extant longleaf ecosystems of sufficient size, integrity, protected status, and connectivity potential to sustain functional landscapes and populations of target species into the future. The identification of 16 Significant Geographic Areas (SGAs) and the local prioritization efforts within them have served as the primary planning tools for ALRI since 2009. But the Plan also recognized that comprehensive inventories and assessments were needed for a strategic, science-based approach to conservation. With the recent development of the Southeast Longleaf Pine Ecosystem Occurrences Geodatabase (LEO GDB), the Southeast Fire Map, and other tools we now have sufficient information about the spatial extent, arrangement, and condition of extant longleaf pine to fulfill the Plan objective of a long-term sustainability assessment.

In response to this objective, we developed the Longleaf Sustainability Analysis (LSA), a longleaf ecosystem-centric spatial analysis designed to facilitate the strategic, transparent, and evidence-based identification of the "right work" in the "right places" across the historic range of longleaf pine. The LSA combines map data about extant longleaf, suitable sites for restoration, landscape connectivity, and other factors related to sustainability to prioritize areas on the landscape for implementation of restoration and conservation actions. The resulting priority maps are intended to support the objectives of ALRI's Range-Wide Conservation Plan 2.0 (ALRI 2023) and other conservation work for the next 15 years.

The LSA contains 3 categories of analysis that interact to prioritize places for both conservation and restoration of longleaf pine (Fig. 1):

1) Extant Longleaf Significance: A map layer of longleaf pine sites with 'significance' values based on factors related to ecological condition, wildlife value, and landscape context.
2) Longleaf Pine Suitability: A range-wide map layer of suitability values based on longleaf observation data and a combination of environmental variables including substrate, hydrology, fire regime, land cover, and climate.
3) Sustainability: A sustainability map layer that weights and combines factors for landscape integrity, connectivity, ability to burn, and climate change resilience.

Each of the analysis categories involves compilation and/or development of component data layers as described in the methods section of this report. The above analyses are combined to create 2 primary prioritization products for the LSA (Fig. 1):

1) Priority Areas for Conservation and Management: A map layer of priority classes for extant longleaf pine ecosystems derived from the overlap of extant longleaf significance and sustainability.
2) Priority Areas for Restoration: A map layer of prioritized potentially restorable longleaf ecosystems derived from the overlap of longleaf suitability and sustainability.

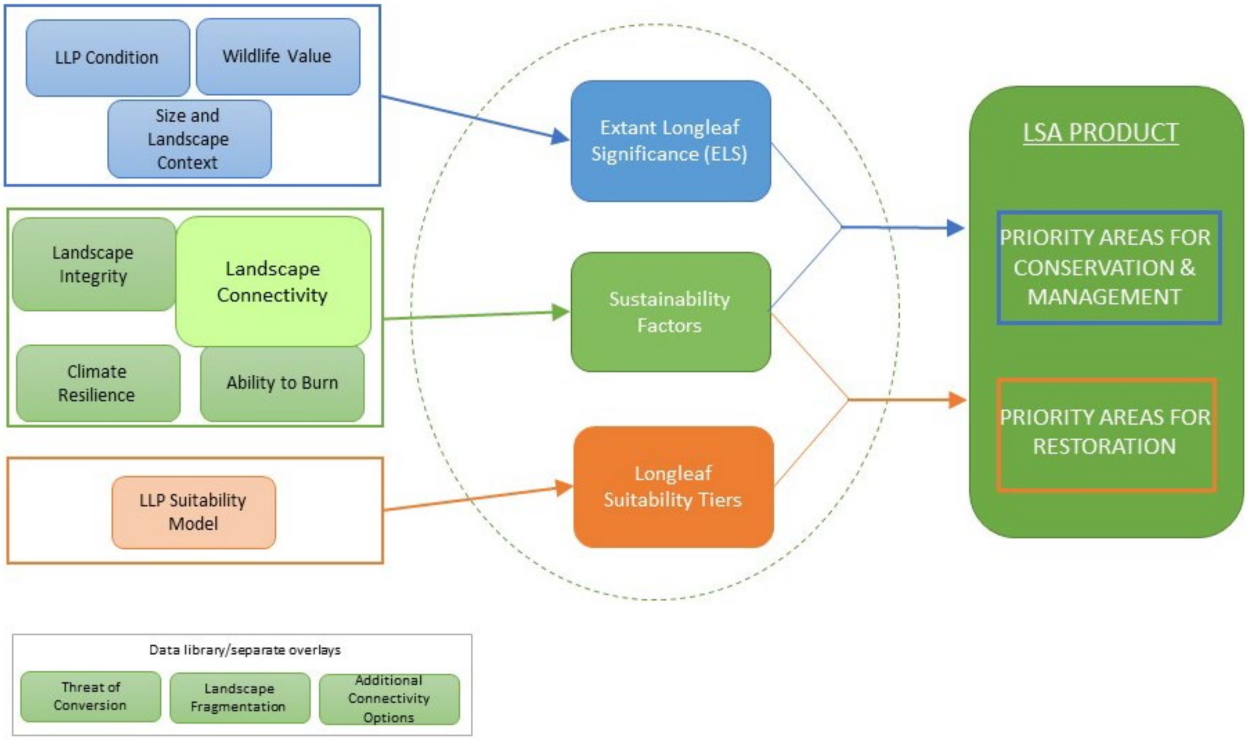

Figure 1. Overview of Input Layers & Analyses for the Longleaf Sustainability Analysis. The larger light green box for Landscape Connectivity reflects the relatively higher weight assigned to this factor.

Lead Partner Roles

The Florida Natural Areas Inventory (FNAI) and The University of Florida Center for Landscape Conservation Planning (UF-CLCP) developed the LSA with funding from The Longleaf Alliance through the USDA-NRCS via the U.S. Endowment for Forestry and Communities. FNAI provided overall project management. UF-CLCP developed the landscape connectivity, landscape integrity, and fragmentation layers and collaborated with FNAI on project design and decisions, while FNAI developed the remaining LSA spatial data. This work benefitted from the expertise of the LSA Working Group, a group of 10 longleaf pine professionals from across the southeastern U.S. that were convened for regular review and technical oversight of the LSA. Key decisions related to project design and deliverables were guided by the LSA Project Management Team.

METHODS

Work on the LSA occurred from November 2022 – July 2023. We consider the analyses described here as Version 1, with recommendations for a next iteration described in the Summary and Next Steps section of this report.

At the project outset we identified and reviewed the best available data inputs to inform the LSA. We prepared a summary describing potentially relevant data sources, including strengths and weaknesses, and detailed recommendations for use. This summary was revised based on input from the LSA Working Group and on awareness of new or relevant data over the course of the project.

The LSA involves numerous data inputs and sub-analyses. We developed an overview schematic of the LSA methods to help clarify and communicate project workflows as well as evolving project design among the project team and with the LSA Working Group (Fig. 1). The methods described below follow the schematic and the categories described in the introduction.

Extant Longleaf Significance

The Extant Longleaf Pine Significance (ELS) layer is intended to rank known longleaf sites for resource importance and viability. To accomplish this, we used a weighted sum analysis to combine factors related to longleaf pine (LLP) stand condition, wildlife value, and landscape context. The highest ranked sites are those where conservation is critical to maintain functional longleaf ecosystems range-wide. The ELS ranking also provides a foundation for evaluating sustainability and connectivity of existing and restorable longleaf sites to further inform restoration and management priorities. The factors and weighted sum method are described below.

Extant Longleaf

Longleaf occurrence polygons from the LEO GDB served as the base dataset for the ELS analysis. LEO polygons typically correspond to stands with relatively uniform condition within a stand. We used an interim version of the LEO GDB (LEO v2.0 for LSA) that contains data from several sources that were not available in the latest published version of LEO (SE LEO GDB 2022). Extant longleaf for the LSA included stands with confirmed LLP occurrences as well as those with very high likelihood of LLP occurrence.

Significance Factors

Longleaf Stand Condition

We selected 3 factors related to stand condition that could be measured consistently across most stands: LLP dominance, LLP stand type, and fire history. The first two are populated for most stands in the LEO GDB. Fire history was derived from the range-wide SE Fire Map (2022), with supplemental data from the LEO GDB. In addition to availability, selection of these attributes is supported by a 2021 survey in which LEO users identified the two most important condition attributes as LLP dominance and LLP stand type followed by 3 attributes of similar importance: stand age, native pyrogenic cover, and fire evidence. Stand age and pyrogenic cover are currently not available across all stands in the LEO GDB. We assume that fire evidence/history may be a reasonable proxy for native pyrogenic cover.

LLP Dominance

Dominance values in the LEO GDB are Dominant, Codominant, Occasional-rare, and Present – No Condition Data and were scored on a 5-point scale (Table 1). Both LLP dominant and codominant stands naturally occur and can represent equally desirable conditions; however, codominance is also assumed to occur in altered or planted stands where dominance would be the natural condition, so it scores slightly lower in our system. Occasional-rare is assumed to represent a condition that requires significant management to improve and warrants a low score. Stands with presence-only data are assumed to likely be dominant or codominant because these are most often submitted as 'longleaf stands', indicating occurrence at a higher level than 'occasional'. To account for this, we assumed scoring at least equivalent with codominant.

Table 1. Criteria for scoring longleaf pine dominance as a factor of Extant Longleaf Significance.

Dominance Value	Score
Dominant	5
Codominant	4
Present – No condition data	4
Occasional-Rare	1

LLP Stand Type

LLP Stand Type values in the LEO GDB are Natural, Planted or No Data and were scored on a 5-point scale (Table 2). Although a large spectrum of conditions can exist across both natural and planted stands, we assume that natural stands are more likely to retain components of a functional ecosystem, which is reflected in the higher score. Where stand type is unknown (21% of stands) we assigned the middle value of 3 to account for uncertainty.

Table 2. Criteria for scoring longleaf pine stand type as a factor of Extant Longleaf Significance.

LLP Stand Type Value	Score
Natural	5
Planted	1
Unknown	3

Fire History

We explored the use of several fire history datasets including SE Fire Map v1.0, LANDFIRE Public Events, and USGS Wildland Fire Combined Datasets 1800s-Present (Welty and Jeffries 2021). The LANDFIRE and USGS datasets tended to be larger fires on mostly public lands, and more burn unit based. The SE Fire Map has the most comprehensive fire history data and substantially better coverage of private lands. We selected SE Fire Map as the primary data source and developed scoring criteria based on metrics from that source. We considered additionally using the USGS dataset, but the available summary metrics did not fit our proposed scoring criteria and we were unable to analyze the raw data in the project time frame.

One challenge with using the SE Fire Map in our analysis is that it represents actual detectable burns at the pixel level, with resulting heterogeneity and patchiness, making it difficult to assign a precise fire history score at the stand level. We calculated the mean and maximum fire frequency (number of burns from 1994-2021) for each LEO stand and compared those to field verified values for 'Fire Evidence' (Table 3). The maximum fire frequency more consistently aligned with observed field values so we assigned that as the SE Fire Map fire frequency value for each stand. Our scoring system also uses the 'Time since Previous Fire' metric from SE Fire Map.

Known limitations of the SE Fire Map include the potential to underestimate low severity burns (e.g., cool season or burns under canopies). To address this, we additionally used the LEO field-verified Rapid Assessment attribute for 'Fire Evidence'.

Fire History score decisions were based on the following data inputs and respective methods:

- We used SE Fire Map v.1 for 2 time periods: 1) 'Last 10 yrs' (2013-2022); 2) 'Last 23 yrs' (2000-2022). We calculated Zonal Statistics for fire frequency and time since previous fire within each LEO polygon then used the maximum value for fire frequency and minimum value for time since previous fire. We assigned scores based on expert opinion of appropriate average fire return intervals in longleaf ecosystems (Table 3; Table 4).
- We also used the LEO Rapid Assessment attribute for 'Fire Evidence' (2019-2021 in LEO GDB v1.2). We assigned scores based on expert knowledge of the LEO Rapid Assessment protocol (Table 5). LEO Fire Scores of 5 or 3 override SE Fire scores (otherwise LEO Fire Evidence was not used).

Table 3. Average fire return interval over 23 years (2000-2022), used as a reference for assigning SE Fire Map fire history scores.

Number of burns	Average fire return interval in number of years, i.e., fire every X years
6	3.8
5	4.6
4	5.75
3	7.7
2	11.5

Table 4. Criteria for scoring stands based on 10-year fire frequency (no. of burns from 2013-2022), 23-year fire frequency (no. of burns from 2000-2022), and time since previous fire from SE Fire Map.

Fire Frequency and Time since Previous Fire	SE Fire Map Score
>=3 burns in last 10 yrs. OR >=6 burns in last 23 yrs.	5
2 burns in last 10 yrs. OR 3-5 burns in last 23 yrs. AND last burn 1-2 yrs.	4
1 burn in last 10 yrs. AND 3-4 burns in last 23 yrs. OR 5 burns in last 23 yrs.	3
1-4 burns in last 23 yrs. AND last burn >10 yrs.	2
0 burns	1

Table 5. Criteria for scoring stands based on fire frequency and recency from LEO Rapid Assessment (RA). LEO Fire Scores of 5 or 3 override SE Fire Map scores; LEO values of ‘Not evident’ were not used.

Fire Evidence from LEO RA	LEO Fire score
LEO frequent	5
LEO Recent not frequent	3
LEO infrequent	3
Not evident	n/a

Size and Landscape Context

LLP Patch size

We defined a patch as a cluster of longleaf pine stands occurring within 60m of each other, a distance that allows stands separated by secondary roads to be part of the same patch. Patches were assumed to be functional landscape units for many birds and ecosystem processes, and close enough to facilitate intra-patch management.

Patches were scored on a 5-point scale based on patch acreage in 5 approximately equal classes (i.e., ca. 20% of patches fall into each class); the percentage varied ±5% because acreage threshold values were rounded to nearest hundreds (or thousands if >10,000; Table 6).

Table 6. Criteria for scoring LLP patch size as a factor of Extant Longleaf Significance.

Patch Acreage Class	Score
>10000	5
2001-10000	4
501-2000	3
101-500	2
<=100	1

Land Use Intensity Index

The land use context in which longleaf occurs can affect ecological processes, ability to manage and other factors that contribute to functional integrity and sustainability. We evaluated longleaf patches based on the intensity of neighboring land uses, using a multi-scale Land Use Intensity Index (LUI) developed by UF-CLCP as a component of the Landscape Integrity Index (see Methods - Sustainability – Landscape Integrity section for description).

We ran zonal statistics to calculate the mean LUI value for each LLP patch. Mean values ranged from 1 – 10 and were derived from the original LUI 10-point scale, with 10 being most intense (note that this differs from the scale used in the Landscape Integrity analysis, where the values are inverted). We assigned an LUI score of 1 - 5 by collapsing mean LUI values from 10 into 5 classes. Note that scores on the resulting 5-point scale are inversely proportional to scores on the initial 10-point LUI scale (Table 7).

Table 7. Criteria for scoring Land Use Intensity as a factor of Extant Longleaf Significance.

Mean LUI for Patch	Score
<3	5
3-4.9	4
5-6.9	3
7-8.9	2
>=9	1

Proximity to Protected Areas

We assumed that patch adjacency to protected areas (PAs) is beneficial for ecological integrity and management coordination. Although connectivity between longleaf patches may be an ancillary benefit, this measure focuses on the association of patches within and adjacent to lands with protected status. Benefits would be highest for patches that are directly adjacent and drop off rapidly beyond that. We assigned scores to patches based on 2 buffer distances from protected areas.

We developed a hybrid ‘best available’ PAs dataset from multiple sources (TNC Public Secured Areas 2018 - Eastern Division [TNC 2018]; National Conservation Easement Database 2022 [NCED 2022]; USGS PAD 3.0 Vector Analysis dataset [USGS-GAP 2022]; Florida Conservation Lands [FNAI 2023a]) and buffered these areas by 60m and 100m. We assigned scores to longleaf patches on a 5-point scale based on the intersection with PAs and PA buffers; a patch received credit if any part intersected (Table 8). Note that patches within 10m of a PA were considered adjacent to account for mapping differences between sources. Scores are hierarchical and mutually exclusive.

Table 8. Criteria for scoring Proximity to Protected Areas as a factor of Extant Longleaf Significance.

Patch Distance to PA	Score
Adjacent to PA	5
Intersects 60m buffer of PA	4
Intersects 100m buffer of PA	3
Outside 100m buffer	1

Wildlife Value

The Wildlife Value layer is built of two components: a broad biodiversity rarity-weighted richness model, and a set of focal species associated with longleaf habitats. The former is intended to provide a general perspective on wildlife value, while the focal species are important representatives of longleaf habitat and conservation priorities in particular.

General Biodiversity Priorities

As a representation of general biodiversity value, we chose to use the NatureServe Map of Biodiversity Importance, or MoBI (Hamilton et al. 2022). This model is an overlay of individual species habitat models for 2,216 rare or at-risk species in the contiguous U.S. NatureServe produced a variety of overlays of these species for different purposes; we chose to use the Range-wide Weighted Rarity MoBI overlay as most relevant for the LSA because it prioritizes rarity and conservation need in a broad sense without respect to current protection on conservation lands. We classed this model into 5 tiers using ESRI's natural breaks (Jenks) classification.

Longleaf Focal Species

There is a large variety of species associated with longleaf pine habitats. They range from rare and endangered species to common. They also range from strictly reliant on longleaf habitats to generalists that incorporate longleaf into a larger distribution. To refine the potential list into a manageable number of species, we started with a set of objective criteria: NatureServe Global Ranks G1-G3 (rank explanations provided in Rank_and_Status_Explanation) with distributions covering multiple states within the extent of longleaf in the southeast. G1 species are considered critically imperiled, G2 are imperiled, and G3 are vulnerable. We did not include any single-state endemic species; most focal species covered several states. The one exception to these criteria was the inclusion of eastern pinesnake (*Pituophis melanoleucus*), a G4 species. We chose to include this species because it is characteristic and strongly associated with longleaf throughout most of the longleaf extent, and it is composed of three subspecies that individually are of conservation priority. One species that met the criteria but was omitted is the mimic glass lizard (*Ophisaurus mimicus*), a G3 species associated with longleaf habitats. This species is not well studied or surveyed, lending less confidence to its distribution modeling.

Thirteen species were selected for inclusion as longleaf focal species, including 6 reptiles, 3 amphibians, 2 birds, and 2 plants (Table 9.). The original species model source and LSA model customizations are described below for each species.

Table 9. Longleaf focal species for LSA Wildlife Value layer.

Scientific Name	Common Name	NatureServe Global Rank	Federal Listing Status
Ambystoma bishopi	reticulated flatwoods salamander	G2	E
Ambystoma cingulatum	frosted flatwoods salamander	G2	T
Crotalus adamanteus	eastern diamondback rattlesnake	G3	
Drymarchon couperi	eastern indigo snake	G3	T
Dryobates borealis	red-cockaded woodpecker	G3	E
Gopherus polyphemus	gopher tortoise	G3	PS:T[a]
Heterodon simus	southern hognose snake	G2	
Lithobates capito	gopher frog	G2	
Peucaea aestivalis	Bachman's sparrow	G3	
Pituophis melanoleucus	eastern pine snake	G4	
Pituophis ruthveni	Louisiana pinesnake	G1	T
Schwalbea americana	Chaffseed	G2	E
Spigelia gentianoides	gentian pinkroot	G2	E

[a]listed as threatened in a portion of its range

Reticulated flatwoods salamander (*Ambystoma bishopi*)

Distribution model source: NatureServe MoBI project (Hamilton et al. 2022)

Customization: None; this is the binary thresholded model as produced for the MoBI project.

Frosted flatwoods salamander (*Ambystoma cingulatum*)

Distribution model source: NatureServe 20221012. This model was recently completed by NatureServe for an ongoing project. It has received expert review and was assigned overall confidence of High by NatureServe.

Customization: Filtered full-spectrum model to binary threshold of 0.518.

Eastern diamondback rattlesnake (*Crotalus adamanteus*)

Distribution model source: Southeastern GAP project (North Carolina State University 2011)

Customization: none

Eastern indigo snake (*Drymarchon couperi*)

Distribution model source: Chandler et al. 2022.

Customization: Filtered full-spectrum model to binary threshold of 0.71. Limited model extent to east of the Chattahoochee/Apalachicola River system.

Red-cockaded woodpecker (*Dryobates borealis*)

Distribution model source: hybrid of FNAIHAB model (FNAI 2023b) in Florida; custom model with similar FNAIHAB methods for rest of range.

Customization: selected natural heritage occurrences for RCW, excluding those > 30,000 acres or with EO Rank of “X?” or “X” (extirpated), resulting in 8,350 records used. Used standard FNAIHAB primary and max buffering system (FNAI 2023b) with radius of 5,000 meters. Used buffers to select suitable habitat using LANDFIRE Existing Vegetation Type (LANDFIRE 2020a) as a source. Natural pineland classes were included as suitable habitat. Ruderal pine classes (plantation) were included if they intersected EOs (and clipped to primary buffers). Excluded single or double pixel patches >30m away from other suitable habitat.

Gopher tortoise (*Gopherus polyphemus*)

Distribution model source: hybrid of Crawford & Maerz 2018, plus FNAI 2022 model beyond Crawford's modeling extent.

Customization: Crawford's full spectrum model was filtered to a threshold of 50. Crawford's modeling extent did not cover the full range of gopher tortoise, so outside of that modeling extent, FNAI random forest model was used, thresholded at 0.511.

Southern hognose snake (*Heterodon simus*)

Distribution model source: Crawford & Maerz 2018

Customization: Crawford's full spectrum model was filtered to a threshold of 50.

Gopher frog (*Lithobates capito*)

Distribution model source: Crawford & Maerz 2018

Customization: Crawford's full spectrum model was filtered to a threshold of 50.

Bachman's sparrow (*Peucaea aestivalis*)

Distribution model source: hybrid of Southeastern GAP project (North Carolina State University 2011) and FNAI custom model for western portion of range.

Customization: GAP model was used as-is but did not extend into Louisiana and Texas where additional populations occur. We built a custom model for this region using FNAIHAB-style methods. We selected natural heritage occurrences for Bachman's sparrow in LA and TX, excluding those > 30,000 acres or with EO Rank of "X?" or "X" (extirpated), resulting in 87 records used. Used standard FNAIHAB primary and max buffering system (FNAI 2023b) with radius of 2,000 meters (same as seaside sparrows in FL). Used buffers to select suitable habitat using LANDFIRE Existing Vegetation Type (LANDFIRE 2020a) as a source. Open canopy pine and/or oak forest classes were included as suitable habitat. Excluded single pixel patches.

Eastern pine snake (*Pituophis melanoleucus*)

Distribution model source: hybrid of models for three subspecies: black pine snake (southeast GAP), northern pine snake (southeast GAP), and Florida pine snake (Crawford & Maerz 2018).

Customization: Crawford's full spectrum model was filtered to a threshold of 50. The three models were combined; any location identified in any of the three models was included in the final compilation.

Louisiana pinesnake (*Pituophis ruthveni*)

Distribution model source: NatureServe MoBI project (Hamilton et al. 2022).

Customization: MoBI full spectrum model was filtered to a threshold of 0.867.

Chaffseed (*Schwalbea americana*)

Distribution model source: NatureServe MoBI project (Hamilton et al. 2022).
Customization: None; this is the binary thresholded model as produced for the MoBI project.

Gentian pinkroot (*Spigelia gentianoides*)

Distribution model source: NatureServe MoBI project (Hamilton et al. 2022).
Customization: None; this is the binary thresholded model as produced for the MoBI project.

Wildlife Value Layer Compilation

Focal species were overlaid for a simple richness layer without weighting, and combined with MoBI tiers, with 5 as the highest (Table 10).

Table 10. Criteria for scoring Wildlife Value.

Description	Priority Value
5+ focal species	5
2-4 focal species OR MoBI Tier 1	4
1 focal species OR MoBI Tier 2	3
MoBI Tiers 3-5	2
No focal species or MoBI value identified	1

ELS Weighted Sum

The seven factors described above were combined as a weighted sum. We considered and tested various weighting schemes. The resulting priorities are influenced by all factors but with greater weight toward large, natural stands with high wildlife value (Table 11). These 3 factors—LLP Stand Type, Patch Size, and Wildlife Value -- provided reliable discrimination among patches and meaningful contribution to range-wide ‘significance’. The weighted sum was reclassified into 10 classes based on natural breaks (Jenks).

Table 11. Weighting scheme for weighted sum analysis of ELS factors.

Factor	Weights (% influence out of 100)
Fire Frequency	10
LLP Dominance	10
LLP Stand Type	20
Patch Size	20
Land Use Intensity	10
Proximity to Protected Areas	10
Wildlife Value	20

Longleaf Pine Suitability

FNAI developed a longleaf pine (LLP) suitability model using Maxent which creates a probability of suitability for longleaf restoration based on the relationship of known longleaf pine occurrences and a suite of environmental variables. The primary purpose is to identify areas suitable for LLP to help determine restoration priorities versus strictly predicting current occurrences of longleaf. This model was developed for a range-wide view of priorities and might differ if developed for a more local or regional extent.

Input Data

Longleaf Pine Observations

- Southeast Longleaf Pine Ecosystem Occurrences Geodatabase (SE LEO GDB 2022)
- Carolina Vegetation Survey (CVS) data (Peet & Roberts 2013)
- LANDFIRE Reference Database v. 2022 (LANDFIRE: LANDFIRE Reference Database 2022)

Environmental variables

Eleven environmental variables were included in the Maxent model (Table 12).

Table 12. Environmental variables included in the LSA longleaf pine suitability Maxent model.

Data Category	Data Type	Source
Climate	Annual mean temperature	PRISM (Daly et al. 2008)
	Annual precipitation	PRISM (Daly et al. 2008)
	Climatic water deficit	PRISM (Daly et al. 2008)
Fire regime	Recent fire frequency	SE Fire Map 2021
	Historical fire frequency	LANDFIRE 2020b
Substrate	Soil - Percent sand	Polaris (Chaney et al. 2016)
	Soil drainage	SSURGO (USDA–NRCS 2019)
	Soils and bedrock	Anderson et al. 2016a & 2016b
	Annual mean soil moisture	Vergopolan et al. 2021
Ecosystem characteristics	Existing vegetation type	LANDFIRE 2020a
	Historical vegetation type	LANDFIRE 2020b

Mapping Steps

Training Data (LLP Occurrences)

We filtered the occurrences to include only stands that were LLP dominant or codominant. LEO data were converted from polygons to points for consistency with CVS and LANDFIRE Reference data. Each LEO polygon, which represents a longleaf stand, was converted to one point located within the center of the polygon to use as the species observation data. The LEO, CVS, and LANDFIRE Reference data were merged and any points that intersected roads in the LANDFIRE Existing Vegetation Type (EVT) data were removed to reduce errors associated with EVT resolution. To address the potential for spatial bias and oversampling, we removed duplicate points and rarified the data by retaining only one occurrence per

800m. From these, we selected 1,000 random points to include as training and testing data in the model.

Environmental Variables

We chose 11 high resolution (30m) environmental variables related to climate, fire regime, substrate, and ecosystem characteristics based on their current and historical biological relevance to longleaf pine habitat suitability (Table 12). Several environmental variables underwent additional processing for use in the model. The PRISM variables were manipulated by Stephanie Auer (NatureServe), Kevin Butler (ESRI), Tim Howard (NY Natural Heritage Program), and Ellie Linden (NatureServe) to remove noise and biases, create a mean of each bioclimatic variable, fix erroneous pixels, and resample to 30m. The resulting PRISM datasets represent 30-year averages of 1981-2010. For the soil moisture dataset (i.e., SMAP-HydroBlocks), FNAI, with permission from Vergopolan et al. (2021), mosaicked raster tiles for each of 5 annual datasets, from 2015-2019, then combined these to generate a single raster with mean 5-year soil moisture values. We tested for correlations between all environmental variables and reduced collinearity by excluding the highly correlated variables ($r > 0.7$). Minimum temperature of the warmest quarter, minimum temperature of the coldest quarter, precipitation of the wettest quarter, precipitation of the driest quarter, slope, and elevation were considered but ultimately excluded.

Maxent Model

We used the open-source maximum entropy (Maxent) distribution model (Phillips et al. 2004, Phillips et al. 2021) in R to develop the model, and the R package ENMeval 2.0 to fine-tune the model. We used an area under the receiver operating curve (AUC) for model evaluation, which depicts performance as better than random when AUC is over 0.5 and perfect discrimination at 1.0. We also used the jackknife method to assess the importance of variables in the final model (Phillips et al. 2006). Finally, we removed the extant longleaf pine polygons (from the LEO dataset) from the output of this model to create a surface layer of restoration suitability.

Suitability Thresholds and Reclassification for Restoration Priorities

To identify restoration priorities, we defined thresholds for the model based on statistical values. The tier 1 threshold was determined using maxSSS in R. This value (0.457) represents the maximum of sensitivity plus specificity, which is the probability at which the sum of sensitivity (proportion of actual presences that are accurately predicted) and specificity (proportion of actual absences that are accurately predicted) is maximized. The tier 2 threshold (0.239) was determined using the 10th Percentile and Training Presence, which is the probability at which 90% of the input presence points are classified as suitable habitat. We used the tier 2 threshold as the cut off value for suitability. We reclassified the probability values into a 10-point scale (to standardize with LSA datasets), using natural breaks (Jenks).

Sustainability

Four map layers – Landscape Connectivity, Landscape Integrity, Climate Resilience, and Ability to Burn – were developed or acquired as input for a range-wide map layer of Sustainability priorities. These 4 factors and the equal weights process of combining them into a single Sustainability dataset are described below.

Landscape Connectivity for Longleaf

The connectivity of forests at the landscape scale has an effect on ecological processes such as species diversity, gene flow, seed dispersal, and animal migration and movement (Shanthala Devi et al. 2013). The logic and mathematics of electrical circuit theory can be used to address issues like the movement of genes, animals, or processes across various settings. The Circuitscape program tracks "current" flow between source patches and quantifies the geographical patterns of current, when places of higher resistance and impediment force current to divert to routes of lower resistance (Hall et al. 2021). Using various statistical modeling and optimization techniques, researchers can create resistance surfaces to identify the impact of various environmental conditions in limiting current flow. For the LSA, we are modeling flow across a resistance surface defined by habitat suitability for longleaf pine.

Input Data

- Longleaf suitability Maxent model
- Southeast Longleaf Pine Ecosystem Occurrences Geodatabase (SE LEO GDB 2022)

Mapping Steps

We used the longleaf suitability Maxent model produced by FNAI and the Omniscape algorithm within Circuitscape to produce fine-scale (90m) connectivity maps for longleaf pine across the Southeastern range states. For our research, we used the FNAI Maxent landscape suitability model with the longleaf extant patches (from SE LEO GDB) “burned in” as the highest suitability (least resistance). A negative exponential function that converts habitat suitability into resistance has been suggested in prior research on resistance surfaces for use in the building of corridors for the dispersal of mobile animals (Keeley et al. 2016; Mateo-Sánchez et al. 2015). Using the following equation, the negative exponential 4 scaling was used to generate a resistance surface from the longleaf suitability model:

$$c = 100 - 99\ x\ \left(\frac{1 - \exp(-4\ x\ h)}{1 - \exp(-4)}\right)$$

As used in the LSA, Omniscape depicts connectivity between each pixel in an "omnidirectional" application across the complete matrix of suitability values. Omniscape, a moving window form of Circuitscape, divides the landscape automatically into smaller subdivisions by iteratively computing current flow between all (or a regularly spaced subset of) the pixels of a circular moving window with a user-specified radius (Hall et al. 2021). Landscape features that function as impediments to movement, such as urban areas and other areas with low suitability for longleaf restoration, are given high resistances, and features favorable to movement, such as extant longleaf pine patches and areas highly suitable for longleaf restoration, are given low resistances. Within Omniscape we used a moving window radius of 100m, and a block size of 35 pixels.

Three maps are produced from Omniscape: 1) cumulative current flow 2) flow potential and 3) normalized flow, of which there are three subsets: a) normalized impeded flow, b) normalized intensified flow, and c) normalized channelized flow. We used the cumulative current flow, which is a sum of the current maps from all iterations of the moving window analysis, in the LSA to represent landscape connectivity for longleaf restoration. The cumulative current flow dataset was reclassified into a 10-point scale (to standardize with LSA datasets), using natural breaks (Jenks). The other outputs are described and available in the ‘additional datasets’ section.

Landscape Integrity

The UF-CLCP created the Landscape Integrity Index (LSI) based on previously developed methods for Critical Lands and Waters Project 4.0 (Oetting et al. 2016). It is made up of two interrelated landscape indices that evaluate ecological integrity in relation to land use intensity (LUI) and patch size index (PSI). Large areas of natural and seminatural land use are given the highest weight in the Landscape Integrity Index.

Input Data

- LANDFIRE Existing Vegetation Type (EVT) (LANDFIRE 2020a)
- USGS National Transportation Dataset- Primary and Secondary Roads (U.S. Geological Survey, National Geospatial Technical Operations Center 2022)

Mapping Steps

Using five primary land cover/land use categories—natural, semi-natural, improved pasture, agricultural/low-intensity development, and high-intensity development—the Land Use Intensity Index (LUI) analyzes LANDFIRE EVT intensity across the southeast. To rank land use intensity categories, a moving window (neighborhood) analysis was performed at three scales (10 acres, 100 acres, and 1000 acres). We selected the three levels of analysis because many species and ecological processes occur at different scales. The LUI ranks neighborhoods from least to most intense on a scale of 1 to 10 (1 being the least intense and 10 being the most intense). The final LUI is determined by summing the scores on all three scales, with the two bigger scales receiving equal weight and the lowest scale receiving half.

The Patch Size Index (PSI) measures natural and semi-natural land cover patches using main roadways and land use data. This study regarded all principal and subsidiary highways as the most likely to split habitat. Patches are continuous areas with suitable land cover. The PSI characterizes the ecological integrity of terrestrial (and wetland) ecosystems by not including open water when assigning patches or calculating patch area. Larger patches are assumed to have less disturbance potential and more ecological integrity than smaller patches, and vice versa. This technique ordered patches by area on a 10-point scale.

Adding the Land Use Intensity and Patch Size Indices, and dividing by two, yielded the non-weighted average. These landscape indices show that regions with a value of 10 have the highest ecological integrity, while regions with a value of 1 have the least. Urban regions with an index value of 1 have minimal ecological integrity, while those with 7–10 have more promise. Areas between 5 and 6 have modest ecological integrity.

Climate Resilience

To ensure the long-term viability of extant longleaf pine ecosystems as well as the persistence of restoration investments, the LSA must consider the impacts of a changing climate. Although longleaf pine ecosystems are relatively resilient compared to other pine forests, they may be impacted by climate change through increases in the intensity and frequency of extreme events such as hurricanes, droughts, and floods, changes in the historical fire regime, changes in precipitation patterns, changes in primary productivity, an earlier onset of spring, shifts in the ranges of species and ecosystems, changes in migration patterns, and local species extinctions. In prioritizing areas that are the most resilient to a changing climate, this analysis prioritizes areas that are most likely to adapt to and/or least likely to be significantly impacted by these changes.

We selected data developed from The Nature Conservancy's (TNC) Resilient and Connected Network Analysis – Resilient Terrestrial Sites (Anderson et al. 2016a, Anderson et al. 2016b), which measures resilience through landscape diversity. In this analysis, sites are scored based on the estimated capacity to maintain species diversity and ecological function as the climate changes. Prioritizing heterogenous areas is one of several approaches that have been developed to incorporate climate change into spatial conservation planning. This concept is based on studies that show that geographical and bioclimatical diversity supports biodiversity (Rosenzweig 1995, Anderson & Ferree 2010), which will support a variety of systems in the future as the climate changes. This is also known as prioritizing the "stage" on which biodiversity "plays." TNC's methods include identifying distinct environments based on surficial geology and bedrock and mapping areas that have a high diversity of microclimates and microhabitats based on topography, soils, elevation, and hydrology. The sites with the highest resilience are natural strongholds for biodiversity since they contain many different habitat niches that can continue to support biodiversity as the climate changes. For detailed methodology, see Anderson et al. 2016a and Anderson et al. 2016b.

Input Data

- TNC Resilient Terrestrial Landscapes (Anderson et al. 2016a, Anderson et al. 2016b). For LSA analysis purposes we received access to an internal version of this dataset that contains data under review for tribal lands. These areas are excluded in TNC's public version of these data, pending review, and will also be excluded in the LSA version provided to partners.

Mapping Steps

We classified the original 9 TNC resilience categories to a 10-point scale (to standardize with other LSA datasets; Table 13).

Table 13. Criteria for scoring TNC Resilience for use in the LSA Sustainability analysis.

TNC Resilience Category	Priority value for LSA
Most resilient	10
More resilient	9
Slightly more resilient	8

Average/median resilience	7
Slightly less resilient	6
Less resilient	5
Least resilient	4
Sea Level Rise	2
Developed	1

Ability to Burn

The ability to burn now and in the future is a critical factor for long-term sustainability of investments. Fire history is an indicator for recently burned sites but may be limited for predicting the ability to burn in the future, or to burn restoration sites. We used landscape factors, primarily distance from smoke sensitive areas (i.e., buffered wildland-urban interface), to estimate the ability to burn. We combined data from the National Land Cover Database (NLCD) and the Microsoft Building Footprints to represent development most accurately within the landscape. NLCD classifications are created using a decision-tree based algorithm on Landsat imagery from 2019. Microsoft Building Footprints are derived using deep learning object classification methods on aerial imagery with different capture dates; the majority of the data in the region is based on satellite imagery from 2019-2020 with the remainder averaging around 2012. Other landscape factors such as ecological integrity, fragmentation, and size will also influence ability to burn, and are captured within other LSA sustainability layers. We also simulated ability to burn in the future using similar methods with projected future development classes.

Input Data

- National Land Cover Database (NLCD) 2019 (Dewitz & USGS)
- Microsoft Building Footprints (Heris et al. 2020)
- FUTURES v 2.0 dataset for CONUS (Sanchez et al. 2020, Petrasova et al. 2023)

Mapping Steps – Current Ability to Burn

We followed the methods described by Grand and Kleiner (2016), with revisions as follows. For recent LULC, we extracted High, Medium, and Low-density Development classes from the 2019 NLCD and extracted Microsoft Building Footprints for the states within the longleaf pine range. We merged the datasets and created a polyline feature class of development. We ran the kernel density tool on the development polyline with a search radius of 1,600m, which is based on the expert opinion from Grand and Kleiner (2016) that smoke management concerns are minimal at this distance or greater. In this case the kernel density calculates the density of development in a 1,600m neighborhood around those development features. We also ran sensitivity tests with distances of 800 and 2,400m; because the differences in outputs were ambiguous and relatively small, we concluded that 1,600m was reasonable.

This output was subtracted from 1 which resulted in a continuous density surface layer of where highest values correspond related to the most undeveloped areas. This inverse of urban density is representative of a practitioner's ability to burn the landscape. Then, we classified the VALUE field into a ten-point scale (to standardize with other sustainability datasets), using natural breaks (Jenks).

Mapping Steps – Future Ability to Burn

For analyzing future ability to burn, we selected FUTURES simulated growth year of 2050 based on the 15-year time horizon of the ALRI Conservation Plan 2.0 and the increasing uncertainty of projections in subsequent decades (see Threat of Conversion section). We retained the original probability values of the FUTURES dataset, but thresholded the raster at 0.5 (50% probability) as this represents the area most likely to urbanize). We merged the thresholded FUTURES dataset with the 2019 NLCD and Microsoft Building Footprints and created a polyline of development for the year 2050. Then, we followed the remaining steps above to develop the future ability to burn density surface layer.

Mapping Steps – Final

The present and simulated future ability to burn datasets were combined by adding their values. This ensures that current threat values are equal or higher than future threat values in the resulting raster. We reclassified the VALUE field into a ten-point scale (to standardize with other LSA datasets), using natural breaks (Jenks).

Sustainability Overlay

We developed a sustainability surface layer with values from high to low sustainability using a weighted overlay of the factors listed below. These factors included products developed specifically for the LSA as well as existing data. Data factors and weights were determined based on the long-term sustainability of longleaf pine and data availability.

Input Data (see separate sections above for methods)

- Landscape Connectivity
- Landscape Integrity
- Climate Resilience (reclassified TNC Resilient Terrestrial Landscapes)
- Ability to Burn

Mapping Steps

We created an overall LLP Sustainability map layer using a weighted overlay with the weights determined from several factors such as importance to longleaf pine sustainability and data uncertainty (Table 14). Connectivity, which received the highest weight, was considered most essential for long-term functional longleaf systems, including the species that depend on them; in addition, the LSA connectivity analysis was the only input factor designed specifically for longleaf. Future-based datasets with inherent uncertainty -- climate resilience and future ability to burn -- received lower weights. We reclassified the resulting values into a ten-point scale (to standardize with other LSA datasets), using natural breaks (Jenks).

Table 14. Weights assigned to inputs of LSA Sustainability overlay analysis. Weights represent percentage contribution to the final overlay.

Sustainability Factor	Weight
Landscape Connectivity	50

Landscape Integrity	20
Climate Resilience	15
Ability to Burn	15

LSA Priorities

The major categories of analysis described above were combined to create 2 primary products – Priority Areas for Conservation and Management for extant longleaf and Priority Areas for Restoration for areas highly suitable for longleaf re-establishment. For each of these products, we created 2 presentation formats: 1) a map layer with values from 1 to 10, representing an averaging (equal weights) of longleaf habitat (extant or suitable) and sustainability factors; and 2) a map layer in which users can see the contribution of both the longleaf habitat and sustainability factors in a combination matrix. These presentation formats are referred to as 'Equal Weights Dataset' and 'Combine Dataset', respectively, and are described below for each primary product.

Priority Areas for Conservation and Management

We developed two different Conservation and Management map layers: an Equal Weights Dataset and a Combine Dataset, both of which use the ELS and Sustainability components described above as inputs. These priorities identify areas where focusing conservation, protection, and management of extant longleaf would contribute to connectivity and overall sustainability of longleaf pine systems.

Input Data

- Extant Longleaf Pine Significance (ELS; developed for LSA)
- Sustainability (developed for LSA)

Mapping Steps – Equal Weights Dataset

We combined the ELS and Sustainability components (which had each been reclassed into 10 priority classes) in an overlay of equal weights, resulting in a dataset that reflects the average value of the inputs. We used quantiles to reclassify the output into 10 classes where 10 is the highest priority. Since the overlay result was non-normally distributed, quantiles was a better fit for priority groupings than other statistical methods, e.g., natural breaks (Jenks).

Mapping Steps – Combine Dataset

We reclassified the full value ELS and Sustainability components into 3 classes each (e.g., High, Med, Low) using natural breaks (Jenks), then combined them using the Combine function in ArcPro. The resulting 9-class dataset retains attributes for both the ELS and Sustainability so users can understand the contribution of each component. We added a 'Legend' field to show these combinations in a single field. The highest priority areas are where the ELS and Sustainability were both ranked High. Note that the raster 'Value' field is not meaningful for prioritization and simply represents a unique combination of inputs.

Priority Areas for Restoration

We developed two different longleaf pine restoration priority map layers: an Equal Weights Dataset and a Combine Dataset, both of which use the LLP Suitability and Sustainability components described above as inputs. These priorities identify areas where re-establishing longleaf would contribute to connectivity and overall sustainability of longleaf pine systems.

Input Data

- Longleaf Pine Suitability (developed for LSA)
- Sustainability (developed for LSA)

Mapping Steps – Equal Weights Dataset

We combined the LLP Suitability and Sustainability components (which had each been reclassed into 10 priority classes) in an overlay of equal weights, resulting in a dataset that reflects the average value of the inputs. We used quantiles to reclassify the output into 10 classes where 10 is the highest priority. Since the overlay result was non-normally distributed, quantiles was a better fit for priority groupings than other statistical methods, e.g., natural breaks (Jenks).

Mapping Steps – Combine Dataset

We reclassified the full value LLP Suitability and Sustainability components into 3 classes each (e.g., High, Med, Low) using quantiles and natural breaks (Jenks), respectively, then combined them using the Combine function in ArcPro. The resulting 9-class dataset retains attributes for both Suitability and Sustainability so users can understand the contribution of each component. We added a 'Legend' field to show these combinations in a single field. The highest priority areas are where LLP Suitability and Sustainability were both ranked High. Note that the raster 'Value' field is not meaningful for prioritization and simply represents a unique combination of inputs.

Additional Datasets

In this section we describe datasets that were created for LSA but not integrated into priority products. These datasets provide additional information and may be used in GIS as stand-alone map layers or as separate overlays with other LSA datasets.

Threat of Conversion

The long-term ability to prevent land conversion of extant longleaf pine sites as well as the long-term persistence of restoration investments is a critical piece to landscape sustainability. We selected existing data developed from the FUTURES model (Sanchez et al. 2020, Petrasova et al. 2023). FUTure Urban-Regional Environment Simulation (FUTURES; Meentemeyer et al. 2013) is an open-source modeling framework for predicting urban development.

The researchers simulated urbanization for the continental United States based on developed land cover classes from the National Land Cover Database (NLCD 211) and historical population and other socio-economic data from the U.S. Census Bureau. They projected probability of urban growth under a Status

Quo scenario of growth for each decade, from 2020 to 2100. Open water bodies, riparian buffer zones, and protected areas were excluded from the analysis as they assumed that no new development would occur in these areas. They also assumed that development is more likely to occur around water bodies and flat areas and less likely to occur near wetlands, highly industrialized agriculture, and steep topography.

Threat of future conversion has varied implications for longleaf practitioners depending on site context, conservation or restoration strategies, and risk tolerance. Decisions about investing to prevent conversion versus avoiding potential investment loss are complex and make a one-size-fits-all approach impractical. Given this, the FUTURES model will be included as a separate map overlay on other LSA results rather than a component of the prioritization analyses.

Input Data

- FUTURES v 2.0 dataset for CONUS (Sanchez et al. 2020, Petrasova et al. 2023)
- Priority Areas for Conservation and Management (Equal Weights) (see separate section for methods)
- Priority Areas for Restoration (Equal Weights) (see separate section for methods)

Mapping Steps

We selected FUTURES simulated growth year of 2050 based on the 15-year time horizon of the ALRI Conservation Plan 2.0 and the increasing uncertainty of projections in subsequent decades. We retained original probability values, but thresholded the raster at 0.15 (15% probability) to minimize data artifacts from county-level data that appeared at lower values. The thresholded dataset was masked to the extent of the Priority Areas for Conservation and Management layer to produce the dataset ‘Conversion Threat within Conservation and Management Priority Areas’; it was also masked to the extent of the Priority Areas for Restoration to produce the dataset ‘Conversion Threat within Restoration Priority Areas’. The FUTURES dataset was not added as a prioritization input in the Longleaf Sustainability Analysis. Instead, it is included as a map overlay so that individual practitioners will be able to decide the best strategy to mitigate or address the threat of potential conversion.

Landscape Fragmentation

This dataset contains priority classes for the Fragmentation Index, which is based on methods developed for the first Florida State Wildlife Action Plan as part of a co-project between the Nature Conservancy and the UF Center for Landscape Conservation Planning. The Fragmentation Index is a neighborhood (also known as a shifting window) analysis of intact landcover to determine the level of habitat fragmentation.

Input Data

- LANDFIRE Existing Vegetation Type (EVT) (LANDFIRE 2020a)

Mapping Steps

The land cover classes in the LANDFIRE EVT were reclassified into intact and not intact classes, resulting in a reclassification where are cells are given a value of 1 or 0. All natural land cover types are given a value of 1, pine plantation (and other silviculture) and woodland and unimproved pastures are given a 1, improved pasture within the dry prairie region of south-central and southwest Florida area also given a 1, as well as various other land covers that represent areas lightly modified by human activity but similar to natural communities in structure and function. All other land uses are given a value of 0.

This reclassified raster layer is then analyzed using ESRI's ArcGIS Focal Statistics function with the Sum statistic at three different scales: 10 hectares, 100 hectares, and 1000 hectares. These three resulting layers are then all reclassified individually using natural breaks (Jenks) from summed scores ranging from 0 to the highest possible value (the maximum value varies depending on focal scale) to values of 1 to 9, where 1 represents the most fragmented areas and 9 represent the least fragmented/most intact areas. These three reclassified rasters are then combined by averaging (equal weighting) to create a final Fragmentation Index layer.

Additional Connectivity Outputs

There are four supplementary connectivity datasets: 1) flow potential, 2) normalized impeded flow, 3) normalized intensified flow, and 4) normalized channelized flow. Flow potential depicts current flow under "null" resistance conditions and shows what the current would look like if it were not constrained by barriers and resistance. Potential flow is computed with the terrain's resistance set to 1 (Landau et al. 2021). Normalized flow is derived by dividing the current flow by the potential flow. The normalized flow layers were classified and put into separate layers with a binary (0,1) classification: A) impeded (<-0.5 SD from mean) to represent impediments to current flow, B) intensified (1 to 2 SD from mean) are areas of restricted flow or bottlenecks, and C) channelized (>2.0 SD from mean) to depict the most severe bottlenecks on flow. See 'Connectivity' section for details on data inputs and mapping steps.

RESULTS

The results of the LSA are primarily a series of GIS map layers described and displayed as figures in this section. Full-page views of all maps are provided in the LSA User Guide (Appendix A). Note that on all maps LIT boundaries refer to the Local Implementation Team (LIT) areas where interagency teams work collaboratively on longleaf conservation and restoration. These are also referred to as Significant Geographic Areas for longleaf.

Extant Longleaf Significance

The Extant Longleaf Significance (ELS) prioritization is based on 7 factors related to longleaf condition, context, and wildlife value. Of these, only wildlife value was developed as a separate dataset for the LSA; therefore, we discuss the results of that in addition to the overall ELS map below.

Wildlife Value Map Layer

The Wildlife Value map layer was developed for the LSA but could also be useful as a stand-alone analysis for other longleaf conservation and management planning. The top two priority classes cover

19.4 million acres and represent the most suitable areas for longleaf focal species and biodiversity in general. These priority areas are well distributed across the range of longleaf, occurring in every state included in the range.

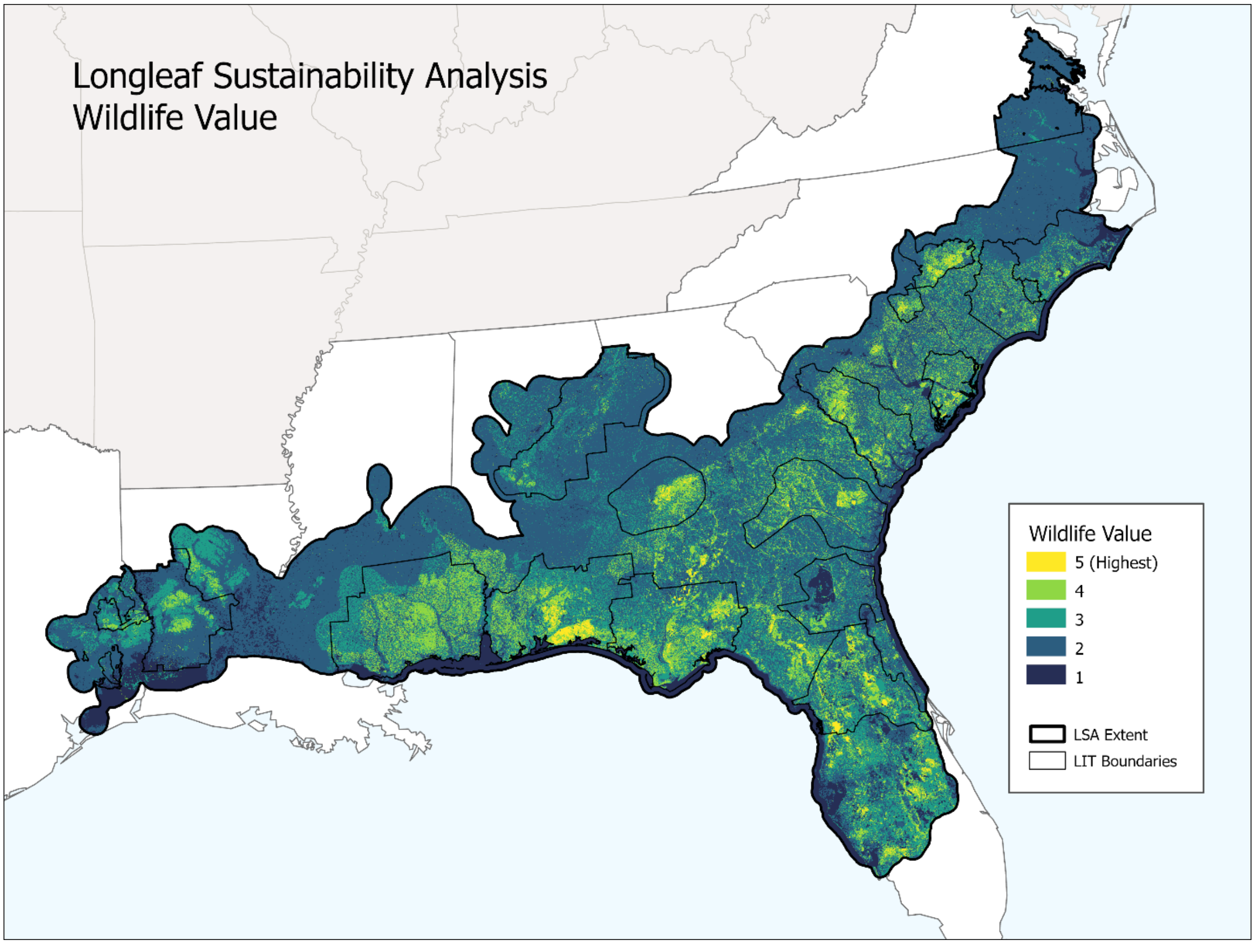

Figure 2. Wildlife value with priority classes based on the overlay of longleaf focal species and generalized biodiversity.

ELS Map Layer

Extant longleaf for the LSA comprises 5.6 million acres in 137,459 sites/stands and ca. 49,000 near-contiguous patches. The acreage total for the LSA is higher than that reported by the LEO project because we include some sites with a high likelihood of LLP occurrence, although their status remains officially 'unknown' in the LEO GDB. The highest priority sites for the ELS occur primarily on public lands with large expanses of intact longleaf and documented focal species occurrences (Fig. 3). Lower priorities tend to be on private lands where sites are smaller and often in a matrix of more intensive land uses. We use the term 'priorities', but the ELS along with the Conservation and Management products it informs, could also be thought of as a system to determine the conservation and management needs for extant longleaf. The ELS is intended to help address ALRI goals for maintaining existing longleaf ecosystems in good condition and improving those that do not have the full complement of species and ecosystem functions.

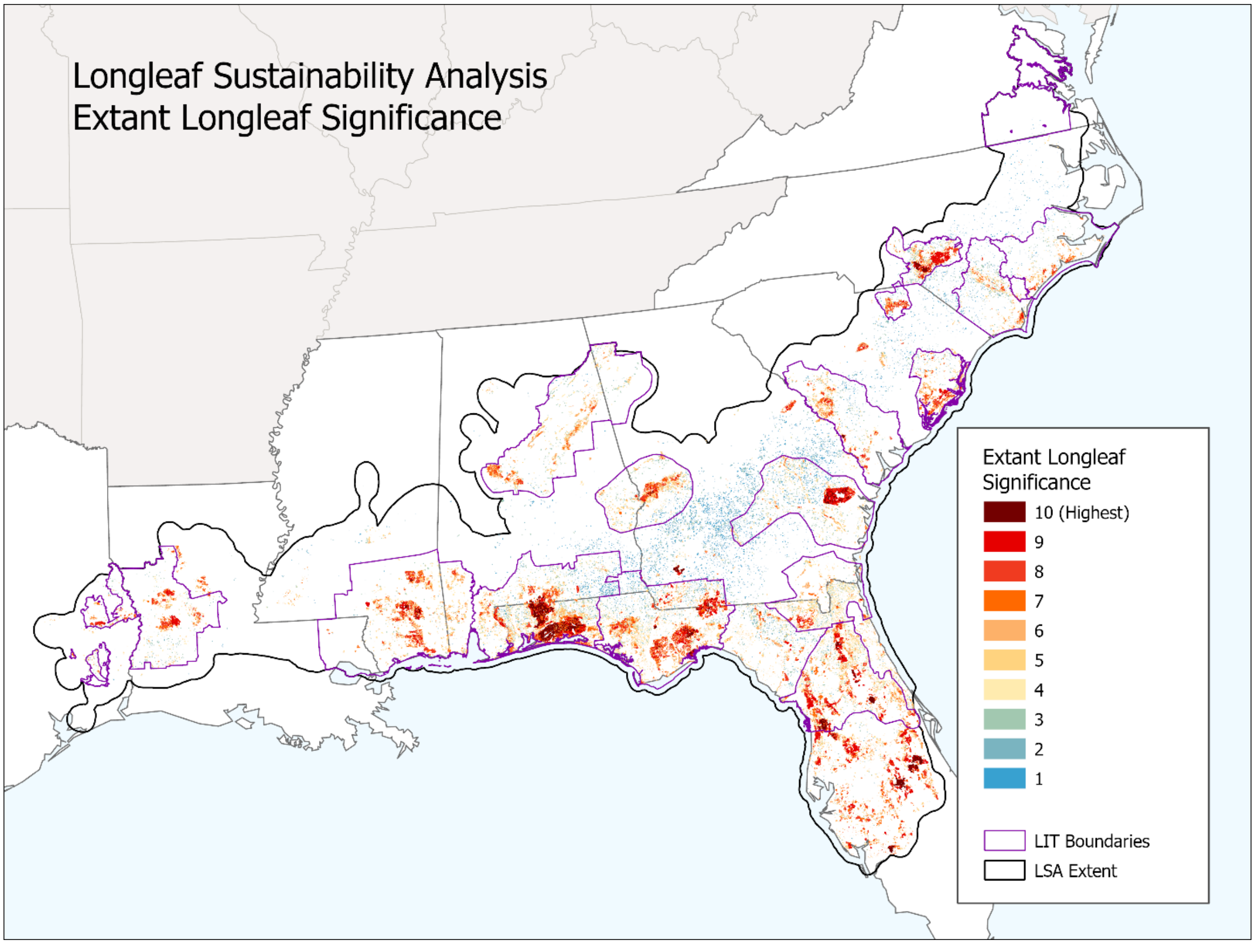

Figure 3. Extant Longleaf Significance based on overlay of 7 factors related to ecological condition, landscape context and wildlife value.

Longleaf Pine Suitability

Model evaluation

Details of model evaluation are in Appendix B. We chose a commonly reported measure, permutation importance, to represent the indicator of variable importance. The permutation importance (Table 15) shows that existing vegetation type, soil (percent sand), and annual precipitation are the most important environmental variables for this model. We evaluated model performance using the area under the receiver operating characteristic curve (AUC). The overall model performance is in the 'excellent' category (AUC > 0.8 for training and testing) at 0.836 (Hosmer et al. 2013). We further evaluated the results using independent data from LEO that were not used as training or testing points in the model. The AUC value of the independent data is 0.851 for LLP dominant and co-dominant stands, and 0.903 for the subset of those that are natural stands. The spatial result was also evaluated for ecological realism by FNAI staff and the LSA leadership team.

Table 15. Analysis of variable contributions to Maxent longleaf pine suitability model.

Variable	Permutation importance
Existing vegetation type (LANDFIRE)	30.4
Percent sand (Soils) (Polaris)	17.4
Annual precipitation (PRISM)	10.5
Soil drainage (SSURGO)	7.8
Current fire frequency (SE Fire Map)	7.7
Annual mean temperature (PRISM	7.3
Climatic water deficit (PRISM)	4.8
Soils and bedrock (Anderson et al. 2016)	4.1
Historical fire frequency (LANDFIRE)	3.6
Historical vegetation type (LANDFIRE)	3.5
Annual mean soil moisture (Vergopolan et al. 2021)	3

Model content

The Maxent LLP Suitability model prioritizes areas for longleaf restoration based on the probability of suitable habitat, i.e., higher suitability equals higher priority. The thresholded model (i.e., Tiers 1 & 2 and excluding extant longleaf) includes approximately 47.3 million acres, with 4.5 to 5 million acres in each of 10 priority classes (Fig. 4). Overlap of the thresholded model with LANDFIRE EVT categories shows that the highest proportion, 33%, is pine plantation, and the acreage is relatively even across priority classes (Table 16). This is expected because the model training data included longleaf plantations and we assume that many former longleaf sites are now planted with other pines. Within the top 3 priority classes, 27% overlaps with natural longleaf classes; some of this is likely extant longleaf pine that is not currently included in the LEO database and some is known to be erroneous classification within the EVT, or recent conversion of natural forest. In the middle and lower priority classes, land cover types shift away from natural longleaf classes to include more ruderal/successional forests and agriculture.

Another possible use of the suitability model is to extract areas by land cover type and use the probability values to prioritize within them, e.g., a restoration priority layer for agricultural lands. In a survey of LSA Working Group members we asked them to rank the land cover categories shown in Table 16 for their restoration potential. Although pine plantation had the highest average, the ranking varied widely, which demonstrates the importance of user perspective and potential need for alternative data views.

Table 16. Overlap of land cover categories derived from LANDFIRE EVT with LSA longleaf pine suitability priorities, where highest priority is 10. Column totals equal 100%.

Land Cover Category	Suitability Priorities 8 – 10	Suitability Priorities 5 – 7	Suitability Priorities 1 – 4
Natural longleaf pine classes	27%	11%	7%
Pine plantation	36%	35%	28%
Ruderal/successional forests	13%	17%	16%
Ruderal grasslands	8%	8%	8%
Agriculture	2%	11%	21%
Other	14%	18%	21%

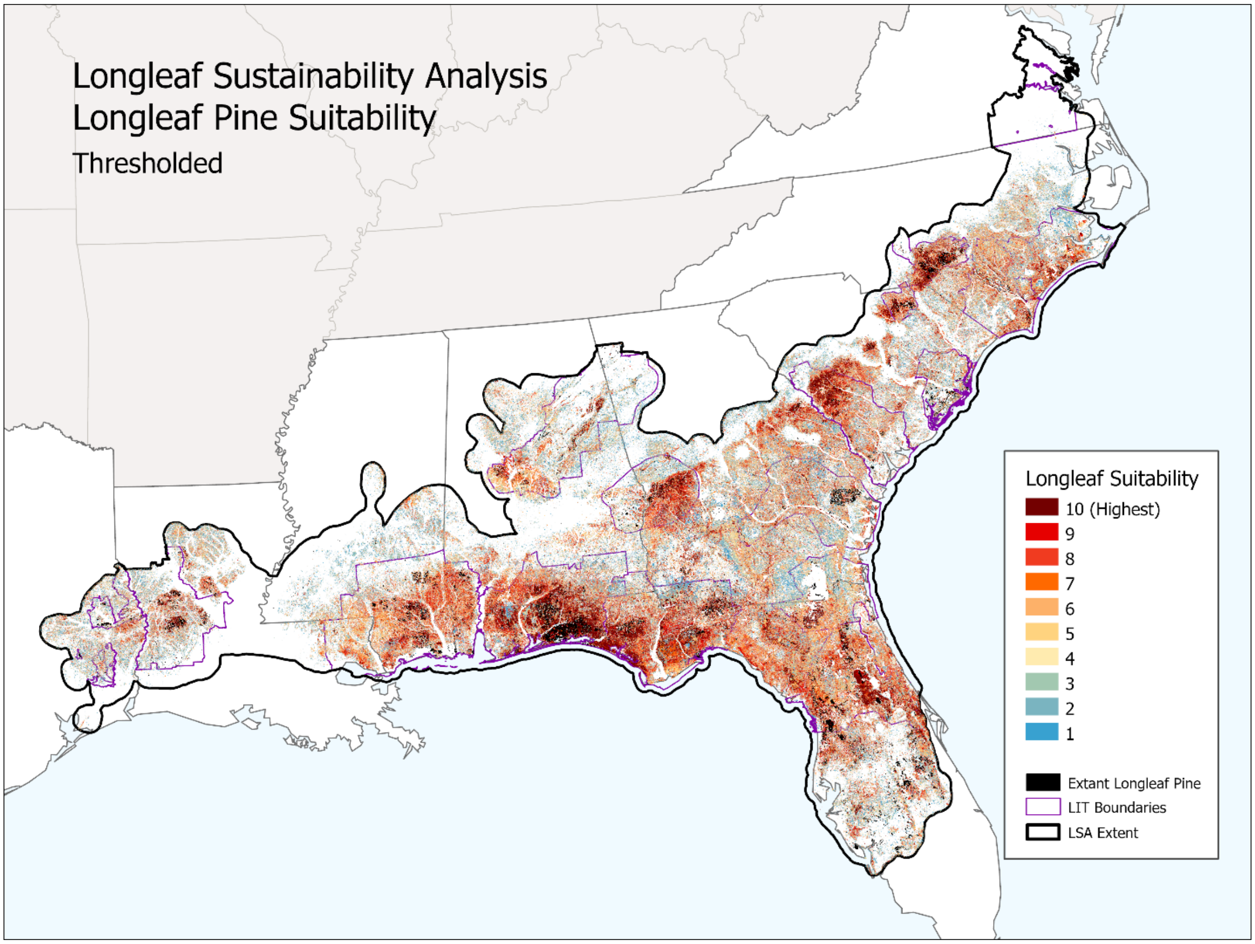

Figure 4. Longleaf Pine Suitability based on Maxent model; model thresholded at 10th Percentile and Training Presence (includes probability values above 0.239).

Sustainability

Component maps

The four component maps that contribute to LSA Sustainability highlight distinct aspects of longleaf sustainability (Fig. 5). The highest priorities for longleaf connectivity are largely in and near protected areas with extant longleaf, but also show potential connections adjacent to and between LITs, e.g., between Chattahoochee Fall Line Conservation Partnership (CFLCP) and Altamaha/Ft. Stewart Longleaf Restoration Partnership (FTSA) in Georgia, and Apalachicola Regional Stewardship Alliance (ARSA) and Okefenokee to Osceola (O2O) in Florida (see Fig. 5, Map A). The other 3 components prioritize landscape-level factors that are not driven by longleaf-specific inputs. The top priority classes for all these capture large intact natural landscapes, including both uplands and wetlands, but to varying degrees. All components devalue intensely developed areas. See Appendix A for full page maps.

Sustainability map

The LSA Sustainability map layer reflects the weighting of its 4 components (Fig. 6). The 50% contribution of connectivity to the overall prioritization is evident, i.e., connections in Fig. 5, map A, are still apparent here. In the sustainability map, lower priorities of the connectivity map are moderated by the other components, and some of the higher wetland priorities, e.g., Okefenokee swamp in the landscape integrity and climate resilience maps (Fig. 5, maps B and C) are moderated by the longleaf-centric connectivity component. This moderation is reflected in relatively high acreage within the middle priority classes. The overall Sustainability map achieves a balance of factors important for longleaf resilience, but users may also find component maps helpful for understanding sustainability tradeoffs for a given conservation or management action. This map (as well as its components) represents a value surface across the entire longleaf range; however, its ultimate use for the LSA is in combination with more discrete extant and suitable longleaf areas in the products described below.

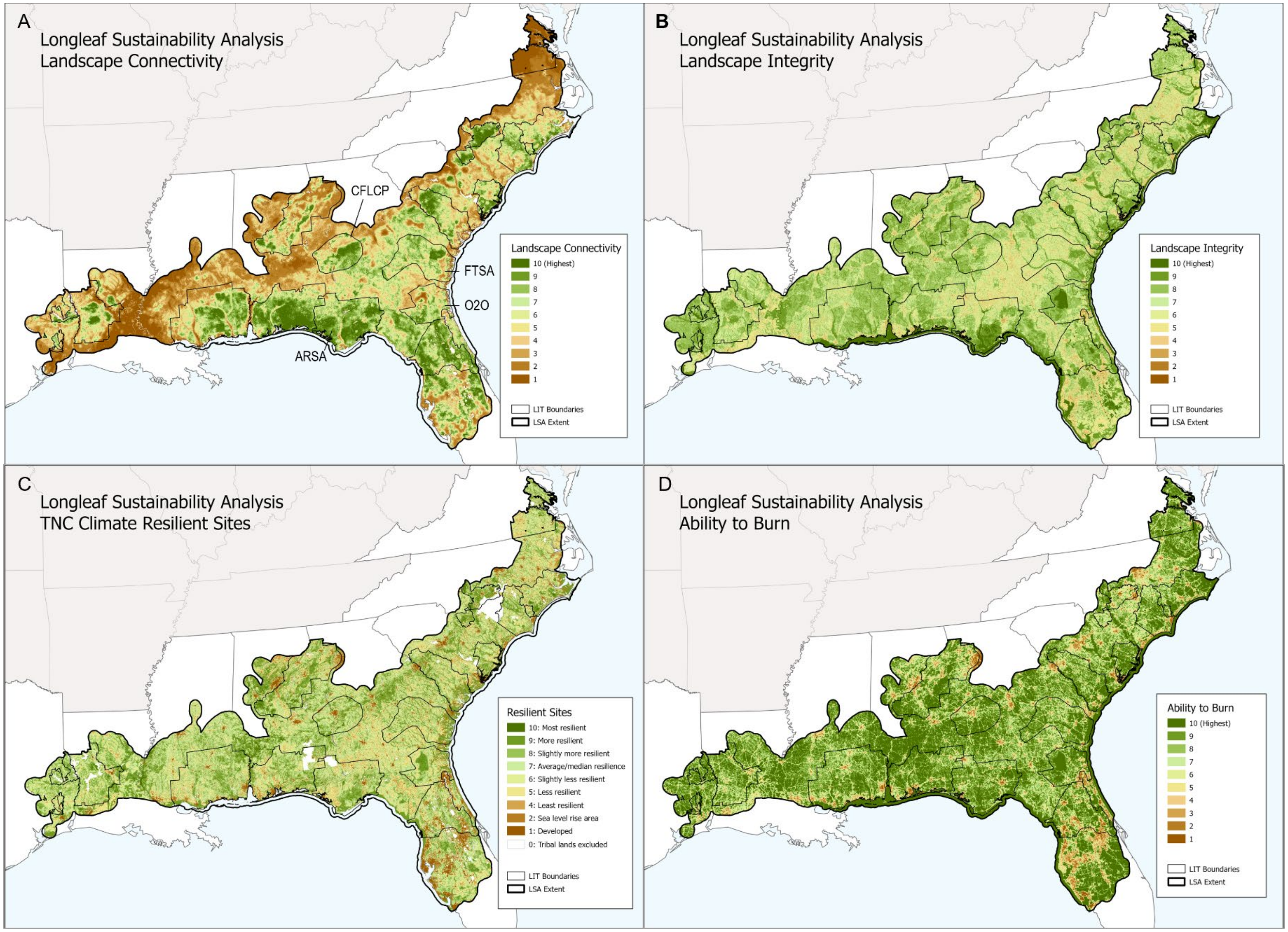

Figure 5. Map components used in the LSA Sustainability weighted overlay analysis: A) Longleaf Landscape Connectivity; B) Landscape Integrity; C) TNC Climate Resilient Sites; D) Ability to Burn.

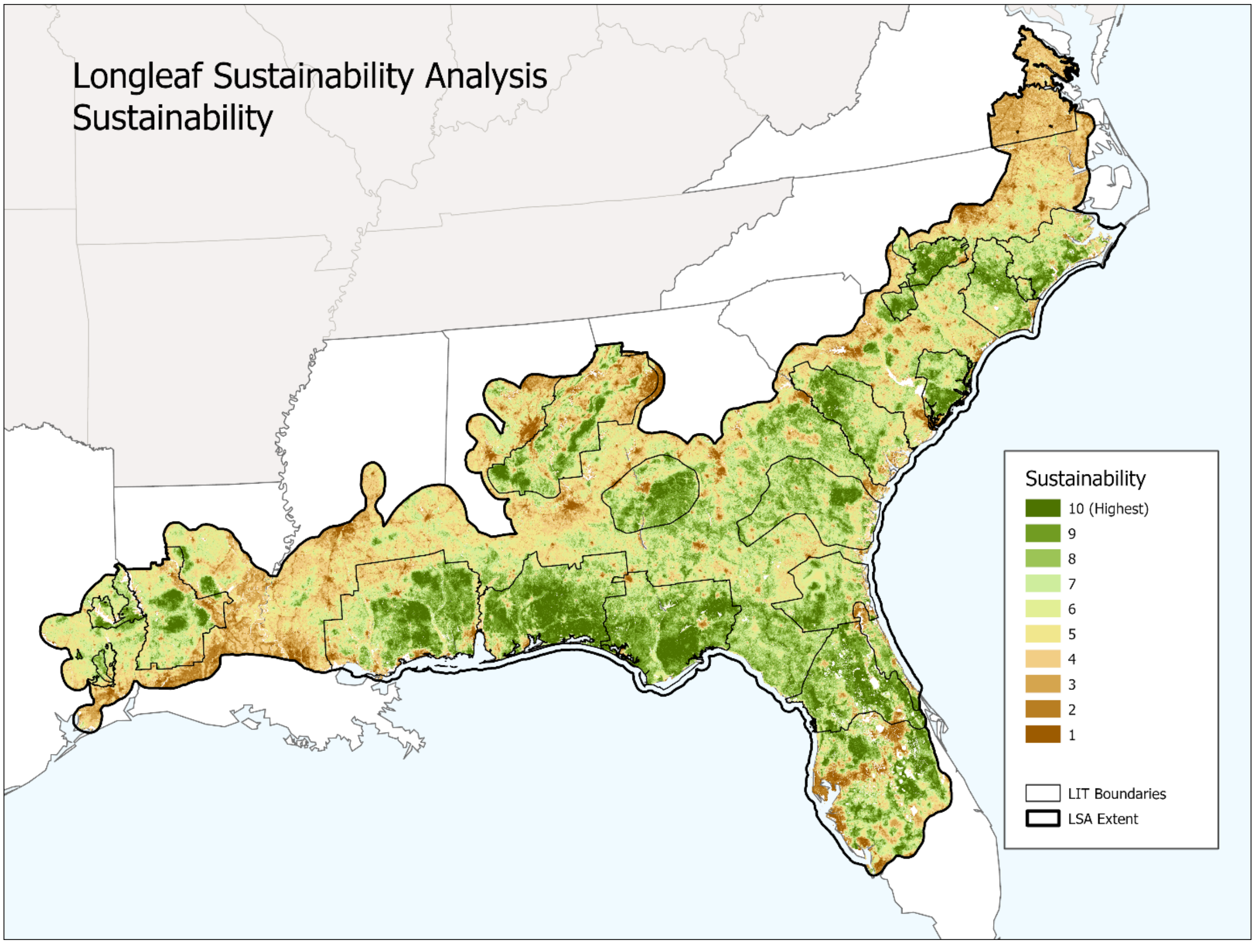

Figure 6. Sustainability priorities based on weighted overlay of landscape connectivity, landscape integrity, climate change resilience, and ability to burn.

LSA Priorities

These results represent the primary products of the LSA. We developed priority maps for both Conservation and Management of extant longleaf and Restoration of longleaf where it does not currently occur. Since so much is already known about significant areas of extant longleaf, the LSA likely has greater potential to inform restoration priorities.

Map Formats

For both products, the results are presented in two formats, Equal Weights and a Combination Matrix (referred to as ‘Combine’ in methods and figures). Although the formats are created with the same inputs, i.e., extant/suitable longleaf and suitability, they result in different maps and the choice of which format to use will depend on user perspective. The Equal Weights is best suited for use as a range-wide prioritization. It provides a full integration of the inputs and results in a more complete, seamless display of priority classes. The Combine is best suited when users want to understand the contribution of the input components and potentially have flexibility in interpreting priorities. Since the Combine method required binning of the original 10-class inputs into 3 classes, the input priorities were relatively coarse, which is reflected in the resulting map classes. The Combine map indicates the priority level of both the longleaf and sustainability input data. Although we chose a sort order for these classes, users may choose to value one combination over another.

Priority Areas for Conservation and Management

The Priority Areas for Conservation and Management are intended to help address ALRI goals for maintaining and improving extant longleaf by providing a range-wide view of ecological significance in conjunction with relevant sustainability factors.

Equal Weights Map Layer

The Equal Weights map, as expected, shows highest priorities within large intact longleaf tracts, primarily on protected areas (Fig. 7, Table 17). The map differs only subtly from the Extant Longleaf Significance map, which suggests a correlation between longleaf significance (as defined by the LSA) and sustainability.

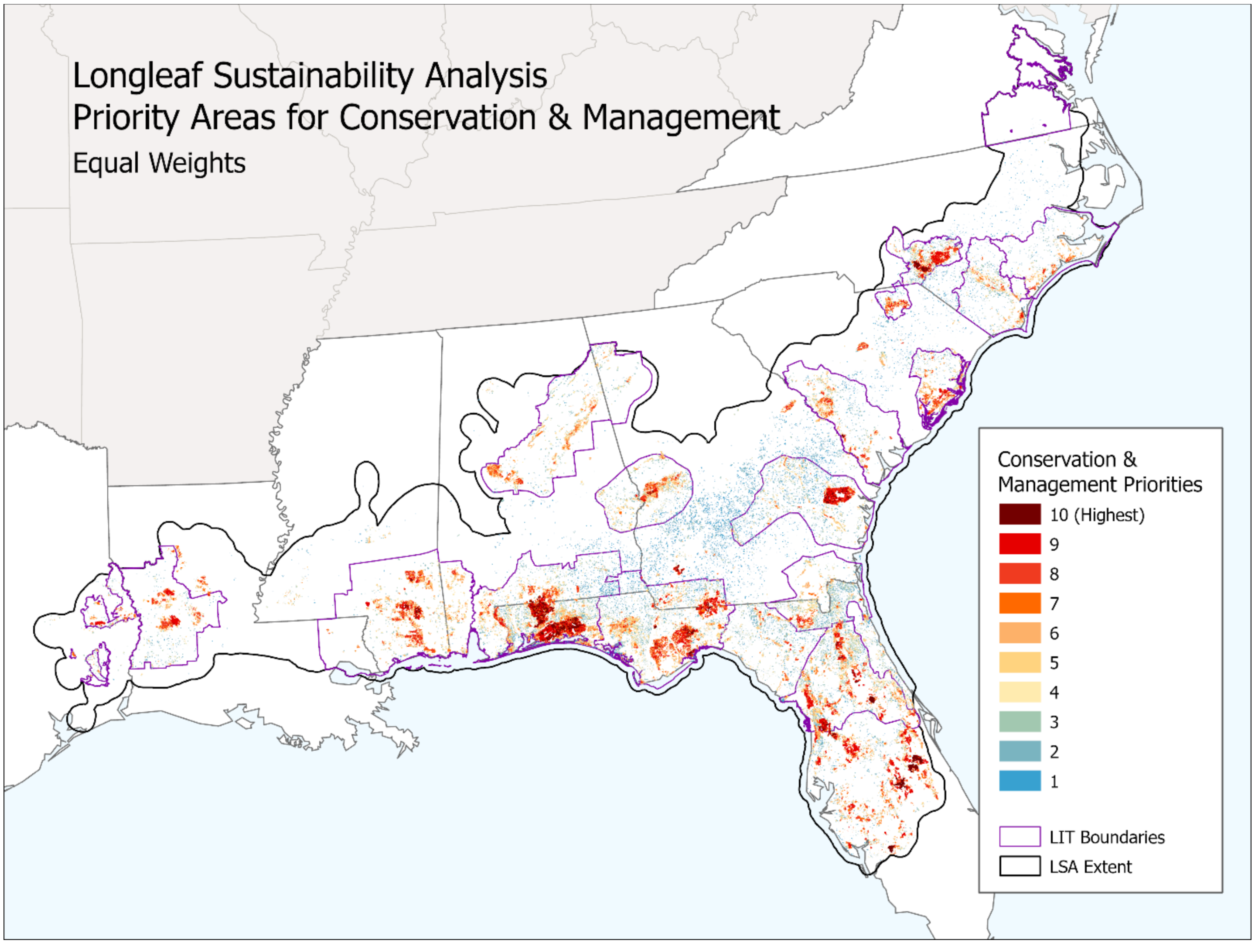

Figure 7. Priority Areas for Conservation and Management for extant longleaf pine (Equal Weights method).

Table 17. Proportion of area within each Conservation and Management priority class by owner type. Column totals equal 100%.

Owner Type	Priority Classes 8-10	Priority Classes 5-7	Priority Classes 1-4
Federal	50%	24%	3%
State	23%	15%	3%
Local	1%	1%	<1%
Private - Conservation Land	2%	1%	<1%
Private - Conservation Easement	4%	3%	1%
Private - Unprotected	20%	56%	92%

Combine Map Layer

The Combine Conservation and Management map, like the equal weights, shows high priority opportunities for maintaining significant longleaf tracts in and around protected areas (Fig. 8). This map differs from the equal weights, however, by also identifying areas of moderate significance that hold potential for sustainability if improved. For example, in the equal weights, small tracts in south-central Georgia display as relatively low overall priority but in the Combine show as a discrete class (ELS 1, Sustainability 3). These may be small, relatively young plantations that given sufficient time and appropriate management, along with restoration of other nearby sites, could become part of a connected, resilient landscape.

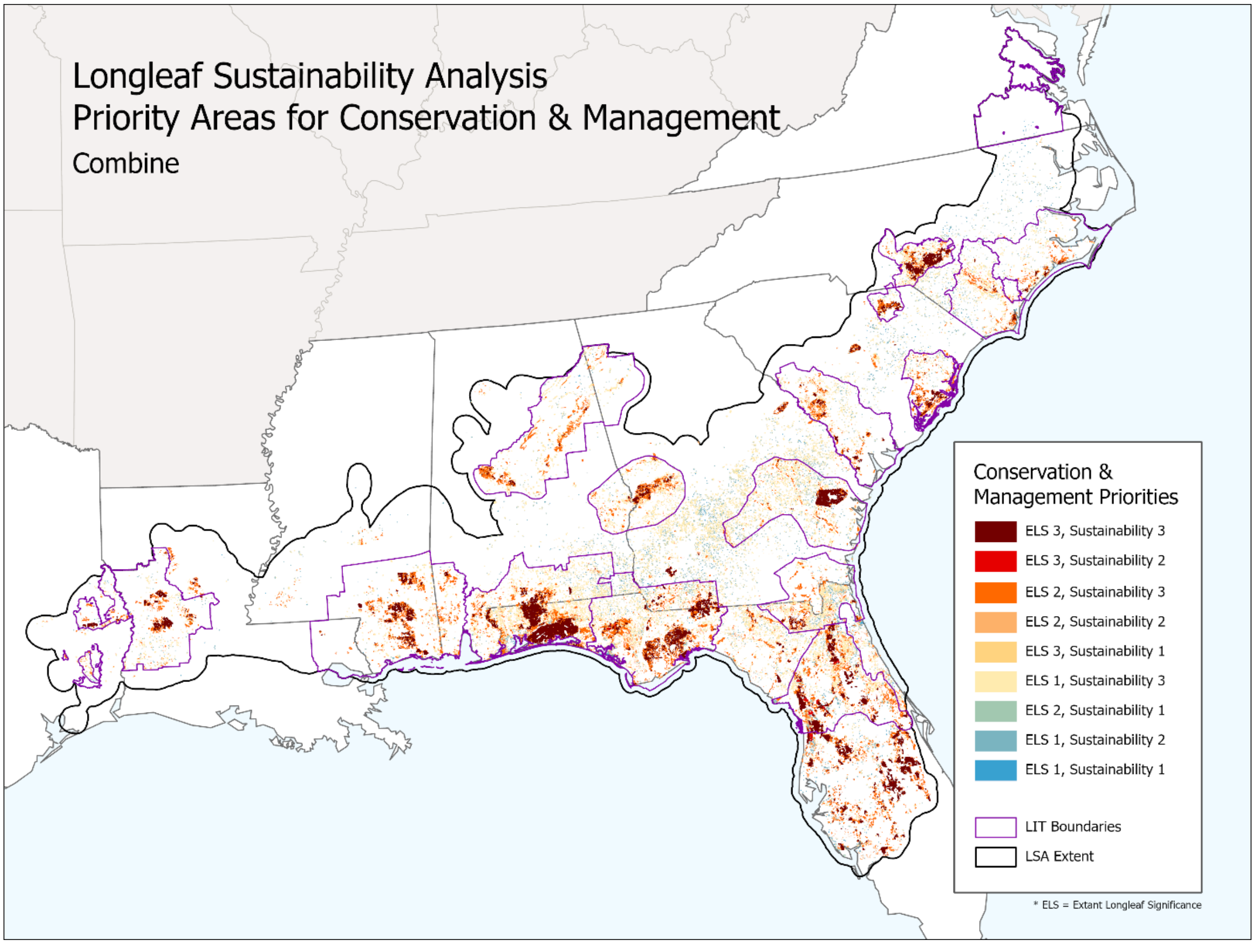

Figure 8. Conservation and Management combination matrix (Combine method) for extant longleaf.

Priority Areas for Restoration

The Priority Areas for Restoration are intended to help address ALRI goals for establishing new longleaf by providing a range-wide view of longleaf habitat suitability in conjunction with relevant sustainability factors. See 'Map Formats' section above for best uses of the map layers described below. Note that the restoration results are masked to the extent of the thresholded longleaf suitability input, i.e., empty space indicates suitability values were below the model threshold; however, there may still be high sustainability and uncertain suitability in these areas.

Note that longleaf habitat suitability and the resulting priority areas for restoration are known to be under-represented in Virginia because of data omissions and modeling limitations associated with edges of the longleaf range. The TNC Northern Range Priority Area is displayed on the map to better reflect conditions in the northern range until this is addressed in a future iteration of the LSA.

The Equal Weights map (Fig. 9) shows that the highest priorities (8-10) for sustainably restoring longleaf are mostly within LITs, and largely in the vicinity of extant longleaf. Opportunities also exist outside of LITs, for example around Ft. Gordon, GA and Ft. Jackson, SC. In addition, the potential private land connections seen in the Landscape Connectivity map (Fig. 5, Map A), for example in central Georgia, carry over as high restoration priorities here. Most of the area within all restoration priority classes is on private lands (Table 18).

Areas around some large aggregations of extant longleaf show only moderate priorities for restoration. For example, opportunities appear more limited adjacent to Ft. Stewart and Francis Marion National Forest, where much of the protected areas is already in longleaf but the surrounding landscape is either unsuitable or highly fragmented by development or agriculture.

Table 18. Proportion of area within restoration priority classes by owner type. Column totals equal 100%.

Owner Type	Priority Classes 8-10	Priority Classes 5-7	Priority Classes 1-4
Federal	13%	5%	3%
State	6%	4%	2%
Local	<1%	<1%	<1%
Private - Conservation Land	<1%	<1%	<1%
Private - Conservation Easement	3%	2%	1%
Private - Unprotected	77%	89%	93%

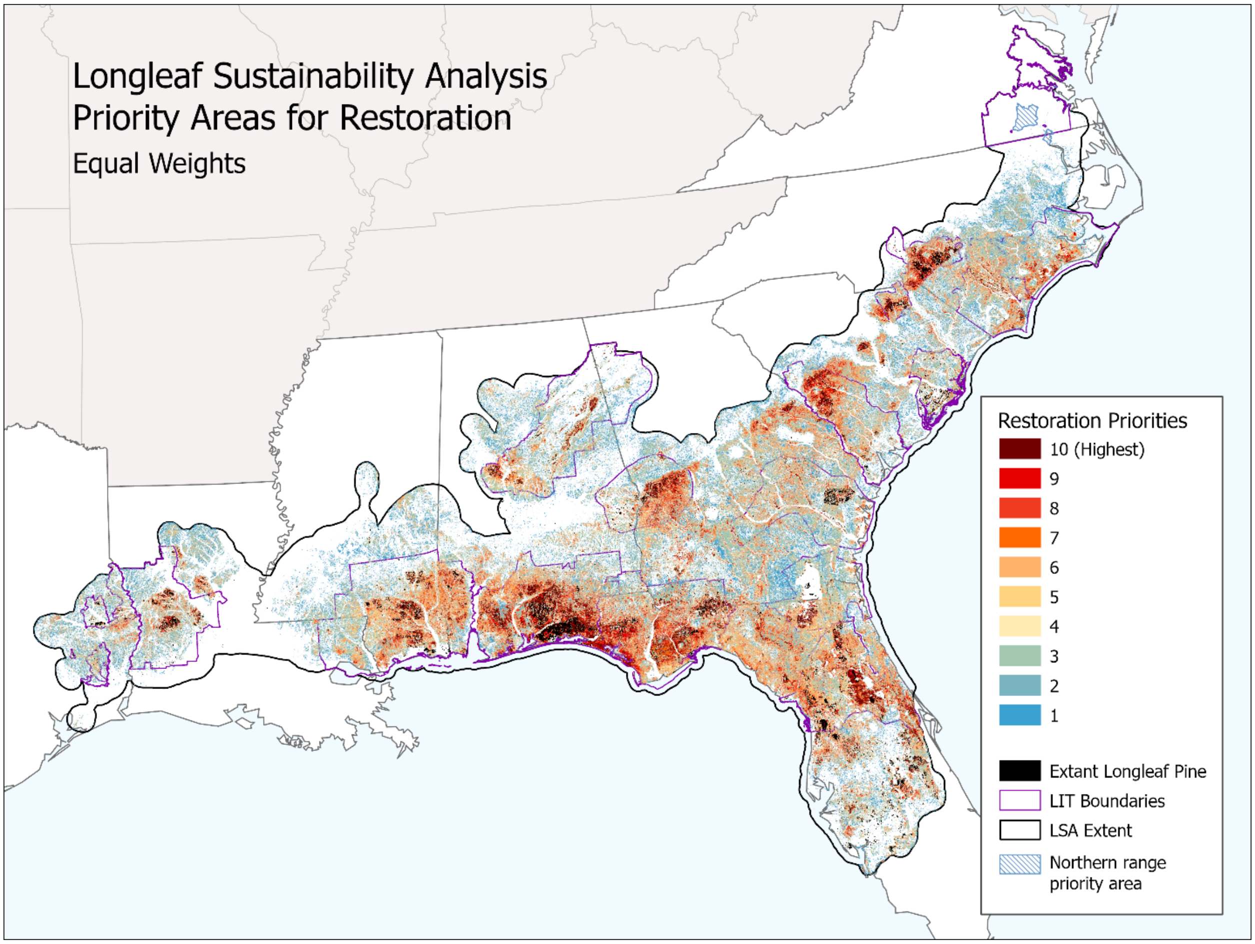

Figure 9. Priority Areas for Restoration (Equal Weights method) for longleaf pine based on habitat suitability and sustainability.

Combine Map Layer

The basic patterns described for the equal weights map are true for the Combine map (Fig. 10), where highest suitability and sustainability occurs in the vicinity of extant longleaf.

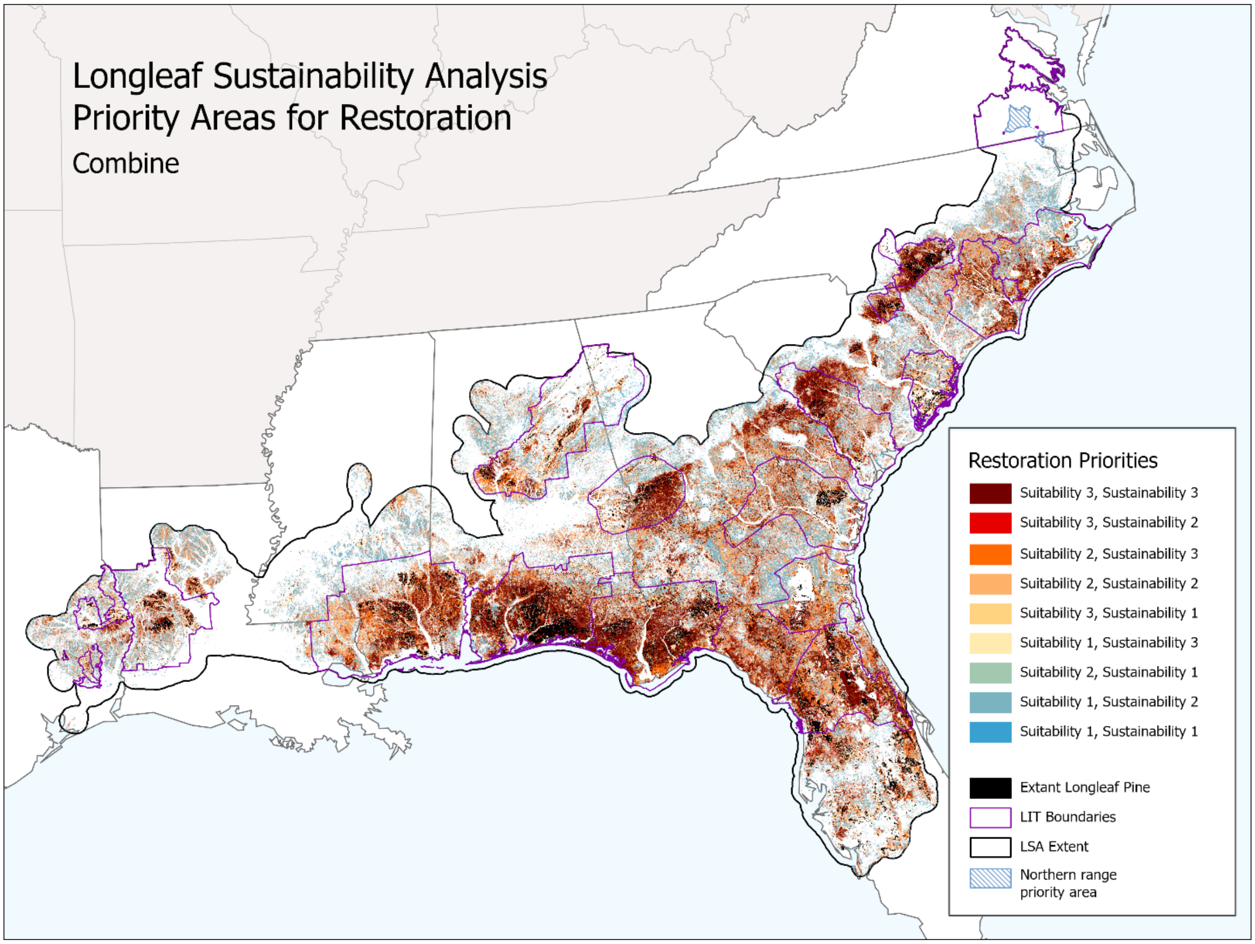

Figure 10. Restoration combination matrix (Combine method) for longleaf pine based on habitat suitability and sustainability.

Threat of Conversion

The Threat of Conversion is intended for use as a separate overlay with other maps. It provides information about probable urbanization through 2050, which can support decisions related to sustainability. Decisions about whether to take action to mitigate the threat or instead to avoid investment in high-threat areas will depend on user perspective. Figure 11 shows an example of conversion threat overlaid on the extent of LSA restoration priority areas in central Florida.

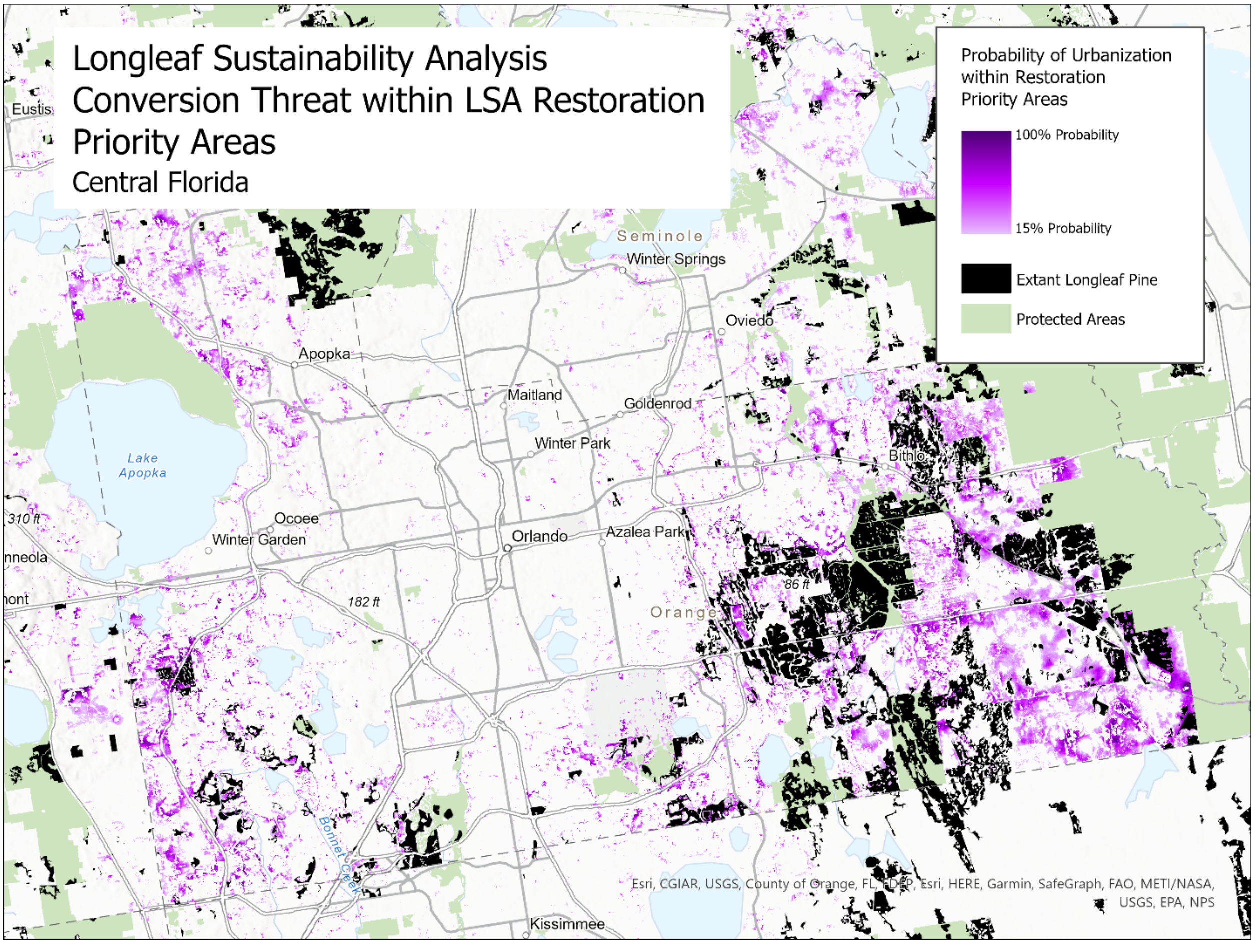

Figure 11. Probability of urbanization overlapping the LSA restoration results.

SUMMARY AND NEXT STEPS

The LSA maps are intended to provide range-wide decision support for longleaf restoration and management. The methods build off the work and expertise of other regional prioritization projects like the SE Conservation Blueprint (SECAS 2022), Florida Critical Lands and Waters Identification Project (Oetting et al. 2016), TNC's Resilient and Connected Landscapes (Anderson et al. 2016b), and Prioritizing Landscapes for Longleaf Pine (Grand and Kleiner 2016). The LSA is unique, however, because it is longleaf-centric, range-wide, and takes advantage of recent projects, e.g., the LEO GDB and SE Fire Map, that facilitate spatial analysis of longleaf pine occurrence –extant and restorable areas – and ecological condition. It also integrates multi-faceted sustainability into the priority maps.

The LSA v.1 map layers highlight areas for strategic investment of restoration and management resources, a need identified by ALRI in the Range-Wide Conservation Plan. We recognize that implementation of plan goals will follow multiple strategies and therefore provide different map formats and all component datasets to facilitate understanding and flexibility in use of these products. We expect this work to be evolve over time as additional data become available, new analyses are conducted, and additional vetting occurs. The next steps below describe expected refinements in future iterations of the LSA.

Data Access

The map figures in this report are snapshot illustrations of analysis results but are not sufficient resolution for most uses and are subject to misinterpretation. The LSA map layers were developed as raster datasets (.tif format) at 30m resolution. These GIS datasets are available to ALRI partners working in longleaf conservation, through a license agreement with FNAI and NRCS. The license will cover both the LEO GDB and LSA products. See Appendix A - LSA User Guide for additional details.

Limitations

The LSA is a complex set of analyses that by design creates and combines modeled data in various ways. All models have uncertainty, and these uncertainties can be compounded by combining them. Although we solicited technical review from an expert working group, project time constraints precluded quantification of uncertainty or rigorous vetting of all analysis decisions and datasets. In addition, the LSA was designed and conducted at range-wide scale and may not align with local knowledge or priorities. Users are encouraged to review these datasets and provide feedback to inform a next iteration of the LSA.

Limitations of LSA data inputs include the following:

- Primary analyses, including the ELS and Longleaf Suitability model, relied on extant longleaf from the LEO GDB. Field data collection for LEO GDB v.2 (private lands outside of LITs) was ongoing and not completed at the time of the LSA. Longleaf data for Virginia also was not integrated in time for the LSA resulting in under-representation of priorities in that LIT. Other omissions in LEO include some public and private lands that are known to support longleaf pine but for which spatial stand-level data for longleaf occurrence do not exist. A detailed list of LEO limitations is included with the LEO GDB v.1 report (FNAI 2022).
- The SE Fire Map v.1 also informed both the ELS and Longleaf Suitability model. Validation and accuracy improvements are expected with SE Fire Map v.2.
- The species distribution models used in the wildlife value layer were created using several different sources, each of which used different modeling algorithms and methodology. Although these models are based on vetted observational and high-resolution environmental datasets, they have not been field-validated.
- Land cover datasets (NLCD and LANDFIRE Existing Vegetation Type), used in several LSA analyses, have known classification errors, as is the case with any land use/land cover classification.
- Historical (LANDFIRE Historical Fire Frequency and Historical Vegetation Type) and projected future datasets (TNC Climate Resilience and FUTURES) are difficult to validate and contain inherent uncertainties.

- TNC Resilient Terrestrial Landscapes considers resiliency of biodiversity at the landscape level and not specifically for longleaf pine ecosystems. The extent to which future suitability for longleaf and landscape level resiliency are correlated is not known, and this relationship could vary across the LLP range.
- The pace of development and other forms of land conversion is rapid in some parts of the project study area, and therefore areas identified as high priority may not match current land condition in cases where development or conversion has occurred since the age of land cover and related GIS data used in this project.
- Mapping resolution is consistent with regional level analysis and planning, but GIS data results from this project should not be considered adequate representations of exact or precise boundaries of potential priority areas for conservation planning or other forms of land use planning.

Next Steps

Our intent is to build upon and enhance this initial analysis as funding permits. Potential recommendations for future iterations include:

1. Incorporate data updates throughout the LSA including expected updates to the LEO GDB and SE Fire Map.
2. Refine the Longleaf Pine Suitability analysis
    a. Include a range-wide longleaf soils dataset, in development by NRCS, as an addition to or component of the longleaf suitability model.
    b. Replace the categorical LANDFIRE EVT datasets used as model inputs with continuous-value rasters that represent distance to relevant EVT classes.
    c. Explore stratifying the LSA extent by ecoregions and/or LLP type (e.g., Atlantic Coastal Plain, Mountain, Piedmont).
    d. Explore ensemble modeling.
    e. Explore projecting a future scenario of the model, considering climate change and/or development projections.
3. Conduct additional connectivity analyses such as:
    a. Mapping wildlife corridor connectivity for selected focal species.
    b. Continue to develop additional connectivity assessment approaches including Linkage Mapper, resistant kernel, and Circuitscape.
    c. Conduct network analysis to identify priority connections between extant LLP sites and potential high priority restoration sites.
    d. Apply a network analysis for focal species with limited dispersal capabilities to identify potential restoration areas in small local or regional subsets of the study area.
    e. Consider connectivity of co-landscape types such as existing and high priority restoration LLP sites with large complexes of wetlands or other natural community

    classes that more specifically identify functional landscapes beyond more general approaches such as the Landscape Integrity Index.
    f. Where applicable, assess how LLP ecological connectivity priorities match with other sources of wildlife corridor, ecological network, and/or ecological greenway proposals throughout the study area.
    g. Continue to work with the various products from analysis with Omniscape, Circuitscape, and other ecological connectivity modeling tools to determine best ways to use results to identify explicit wildlife corridor/ecological connectivity protection and restoration projects.
    h. Identify high priority areas for ecological connectivity that cross state borders within the study area.
4. Explore additional analyses for threat of future land conversion to include land uses such as agriculture and solar farms. The current dataset used in the LSA only incorporates threat of future urbanization.
5. Stratify fire frequency by LLP ecosystem type (e.g., LLP Flatwoods have different fire frequency thresholds than hydric LLP).
6. Refine the ‘Ability to Burn’ dataset by using factors other than just distance to urban areas.
7. Refine the LLP condition component of the Extant Longleaf Significance dataset. Consider a separate condition analysis of public vs. private lands to take advantage of the relatively complete LEO field assessments for private lands.
8. Explore using Zonation, Marxan or other toolsto prioritize sites.
9. Conduct these analyses at different scales, e.g., for an individual LIT,, considering that range-wide priorities might differ from local or regional priorities. A pilot project could focus on one LIT with detailed LLP condition data.
10. Consider how to incorporate co-benefits and ecosystem services such as water quality and quantity, carbon sequestration, recreation, and air quality.

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Appendix A. Longleaf Sustainability Analysis v.1 User Guide

How to Access the Data

Fill out and return the LEO and LSA Data License Agreement to:

Amy Knight (aknight@fnai.fsu.edu); or Carly Voight (cvoight@fnai.fsu.edu)
You will receive a link via email to access the LSA data files.

Note that if you also requested the LEO GDB that will be a separate download and documentation, although both are covered by the same license.

Select folders and download. Folders will download as zip file format and contain all files and subfolders within them. To download the full LSA, you can choose download without a selection.

Extract the zip.

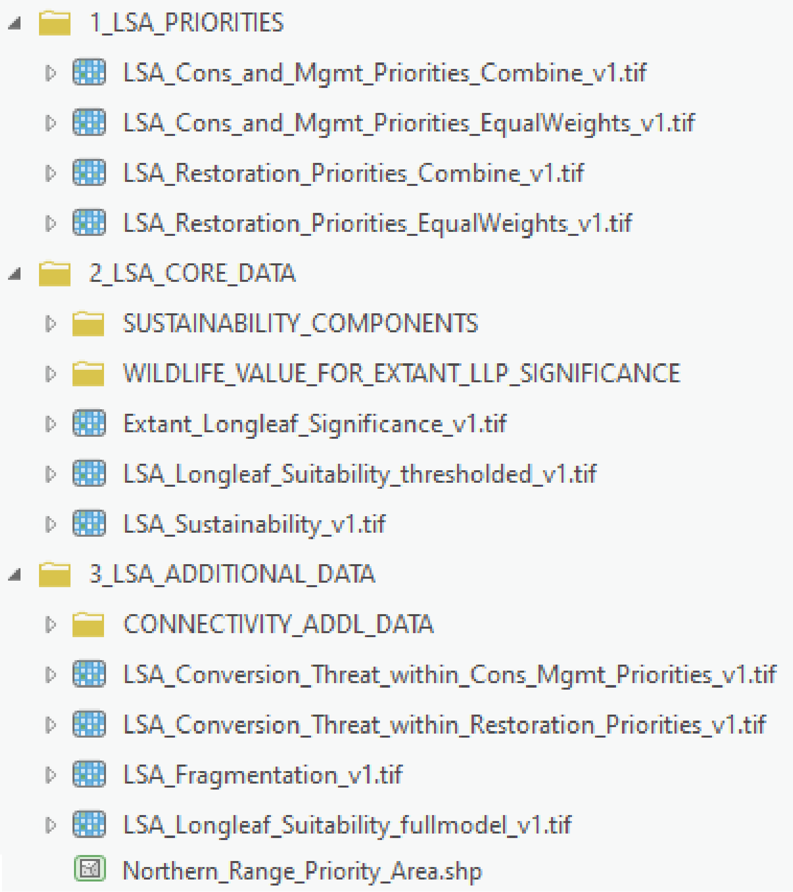
The contents are a set of tif raster datasets, corresponding .lyrx files for use in ArcPro 3.x, and related content.

You may load the LSA datasets into your own GIS maps.

Users are encouraged to refer to the metadata associated with each raster and the LSA v.1 report for details about methods and attributes.

Overview maps and descriptions of the contents are included in this guide.

For technical data questions please contact: Amy Knight or Carly Voight (see contact info above).



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  - WILDLIFE_VALUE_FOR_EXTANT_LLP_SIGNIFICANCE
  - Extant_Longleaf_Significance_v1.tif
  - LSA_Longleaf_Suitability_thresholded_v1.tif
  - LSA_Sustainability_v1.tif
- 3_LSA_ADDITIONAL_DATA
  - CONNECTIVITY_ADDL_DATA
  - LSA_Conversion_Threat_within_Cons_Mgmt_Priorities_v1.tif
  - LSA_Conversion_Threat_within_Restoration_Priorities_v1.tif
  - LSA_Fragmentation_v1.tif
  - LSA_Longleaf_Suitability_fullmodel_v1.tif
  - Northern_Range_Priority_Area.shp

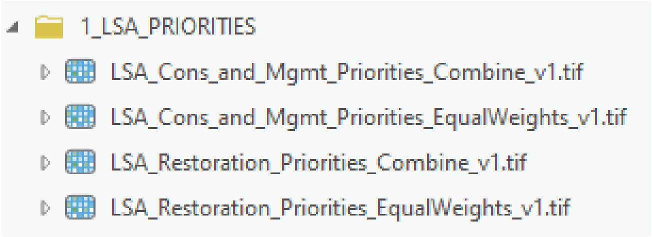
Download Sizes

Folder Level	Zipped
LSA (Main folder)	7.5 GB
1_LSA_PRIORITIES	935 MB
2_LSA_CORE_DATA	1.3 GB
3_LSA_ADDITIONAL_DATA	5.2 GB

LSA Contents

The document describes the datasets included in the LSA v.1 GIS data library. The **LSA Priorities** represent the primary products of the LSA; the **LSA Core Data** are the datasets that were used to create the LSA Priorities; **Additional Data** were created as part of the LSA project but did not inform the final priorities. Users should review the LSA v.1 report for details on development and best use of these data. Full page maps follow this section; links to each map are enabled in the dataset name.

1_LSA_PRIORITIES folder



1_LSA_PRIORITIES
- LSA_Cons_and_Mgmt_Priorities_Combine_v1.tif
- LSA_Cons_and_Mgmt_Priorities_EqualWeights_v1.tif
- LSA_Restoration_Priorities_Combine_v1.tif
- LSA_Restoration_Priorities_EqualWeights_v1.tif

LSA_Cons_and_Mgmt_Priorities_Combine_v1.tif

A combination matrix of priority classes for extant longleaf, derived from the overlap of extant longleaf significance and sustainability. The Combine is best suited when users want to understand the contribution of the input components and potentially have flexibility in interpreting priorities.

LSA_Cons_and_Mgmt_Priorities_EqualWeights_v1.tif

Priority classes for extant longleaf, derived from the overlap of extant longleaf significance and sustainability. The Equal Weights is best suited for use as a range-wide prioritization.

LSA_Restoration_Priorities_Combine_v1.tif

A combination matrix of priority classes for restorable longleaf ecosystems, derived from the overlap of longleaf habitat suitability and sustainability. The Combine is best suited when users want to understand the contribution of the input components and potentially have flexibility in interpreting priorities.

LSA_Restoration_Priorities_EqualWeights_v1.tif

Priority classes for restorable longleaf ecosystems, derived from the overlap of longleaf habitat suitability and sustainability. The Equal Weights is best suited for use as a range-wide prioritization.

2_LSA_CORE_DATA folder

- 2_LSA_CORE_DATA
  - SUSTAINABILITY_COMPONENTS
    - Ability_to_Burn_v1.tif
    - Landscape_Connectivity_v1.tif
    - Landscape_Integrity_v1.tif
    - TNC_Climate_Resilient_Sites.tif
  - WILDLIFE_VALUE_FOR_EXTANT_LLP_SIGNIFICANCE
    - LSA_Wildlife_Value_v1.tif
  - LSA_Extant_Longleaf_Significance_v1.tif
  - LSA_Longleaf_Suitability_thresholded_v1.tif
  - LSA_Sustainability_v1.tif

LSA_Extant_Longleaf_Significance_v1.tif

A map layer of extant longleaf sites ranked for resource importance and viability. Factors related to longleaf pine stand condition, wildlife value, and landscape context were combined using a weighted sum. The highest ranked sites are those where conservation is critical to maintain functional longleaf ecosystems range-wide.

LSA_Longleaf_Suitability_thresholded_v1.tif

Longleaf pine suitability model with threshold applied to exclude very low probability values and with raw probability values reclassified into 10 discrete priority classes.

LSA_Sustainability_v1.tif

A map layer of range-wide sustainability based on the weighted overlay of 4 sustainability factors including 3 developed for the LSA (Connectivity, Landscape Integrity, and Ability to Burn) and TNC Resilient Sites.

SUSTAINABILITY_COMPONENTS folder

Ability_to_Burn_v1.tif

A map layer of combined value of present and simulated future ability to burn in the landscape, based on urban density and proximity.

Landscape_Connectivity_v1.tif

A map layer of range-wide connectivity of extant and potentially restorable longleaf pine patches across landscape. Modeled using Omniscape and based on the cumulative current flow output.

Landscape_Integrity_v1.tif

A map layer for a Landscape Integrity Index (LSI) based two interrelated landscape indices that evaluate ecological integrity in relation to land use intensity (LUI) and patch size index (PSI). The highest priorities are large areas of natural and seminatural land use.

TNC_Climate_Resilient_Sites.tif

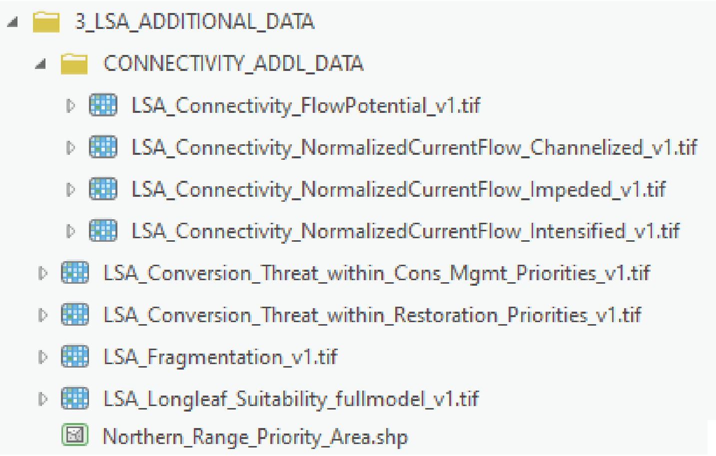
A map layer derived from The Nature Conservancy's (TNC) Resilient and Connected Network Analysis – Resilient Terrestrial Sites (Anderson et al. 2016), which measures climate resilience through landscape diversity.

WILDLIFE_VALUE_FOR_EXTANT_LLP_SIGNIFICANCE folder

LSA_Wildlife_Value_v1.tif

A map layer of wildlife value for longleaf based on two components: a broad biodiversity rarity-weighted richness model and a set of focal species models associated with longleaf habitats. This layer was a component of Extant Longleaf Significance but may also be useful as a stand-alone dataset.

3_LSA_ADDITIONAL_DATA folder



- 3_LSA_ADDITIONAL_DATA
  - CONNECTIVITY_ADDL_DATA
    - LSA_Connectivity_FlowPotential_v1.tif
    - LSA_Connectivity_NormalizedCurrentFlow_Channelized_v1.tif
    - LSA_Connectivity_NormalizedCurrentFlow_Impeded_v1.tif
    - LSA_Connectivity_NormalizedCurrentFlow_Intensified_v1.tif
  - LSA_Conversion_Threat_within_Cons_Mgmt_Priorities_v1.tif
  - LSA_Conversion_Threat_within_Restoration_Priorities_v1.tif
  - LSA_Fragmentation_v1.tif
  - LSA_Longleaf_Suitability_fullmodel_v1.tif
  - Northern_Range_Priority_Area.shp

LSA_Conversion_Threat_within_Cons_Mgmt_Priorities_v1.tif

LSA_Conversion_Threat_within_Restoration_Priorities_v1.tif

These two map layers represent the probability of urbanization in the year 2050 within LSA extant longleaf and the extent of LSA restoration priority areas, respectively. The threat of conversion was developed from the FUTURES model (Petrasova et al. 2023 and Sanchez et al. 2020), thresholded at 0.15 (15% probability). Individual practitioners can use this layer to decide the best strategy to mitigate or address the threat of potential conversion. Only the Conversion Threat with Restoration Priorities is shown in User Guide maps.

Landscape_Fragmentation_v1.tif

Priority classes for the Fragmentation Index, which is a neighborhood spatial analysis of intact landcover to determine the level of habitat fragmentation.

LSA_Longleaf_Suitability_fullmodel_v1.tif

Longleaf pine suitability model developed using Maxent which represents a probability of suitability for longleaf pine based on the relationship of known longleaf pine occurrences and a suite of environmental variables. This layer is intended to identify restoration priorities vs strictly predicting occurrences of extant longleaf. This is the full model with full values 0-1 (e.g., 0.9 indicates 90% probability). The LSA_Longleaf_Suitability_thresholded_v1 layer (CORE DATA folder) was derived from the full model.

Northern Range Priority Area

Longleaf Pine Whole System focal areas selected by The Nature Conservancy (TNC) for Virginia (and slightly into North Carolina). These represent the most important areas for TNC to work to conserve a network of appropriately scaled and representative longleaf forests containing biodiversity, healthy fire management, and natural resilience allowing species to adapt to climate impacts and thrive. Note that LSA restoration priorities are known to be under-represented in Virginia because of data omissions and modeling limitations associated with edges of the longleaf range. The TNC longleaf priority areas are displayed on the map to better reflect conditions in the northern range until this is addressed in a future iteration of the LSA.

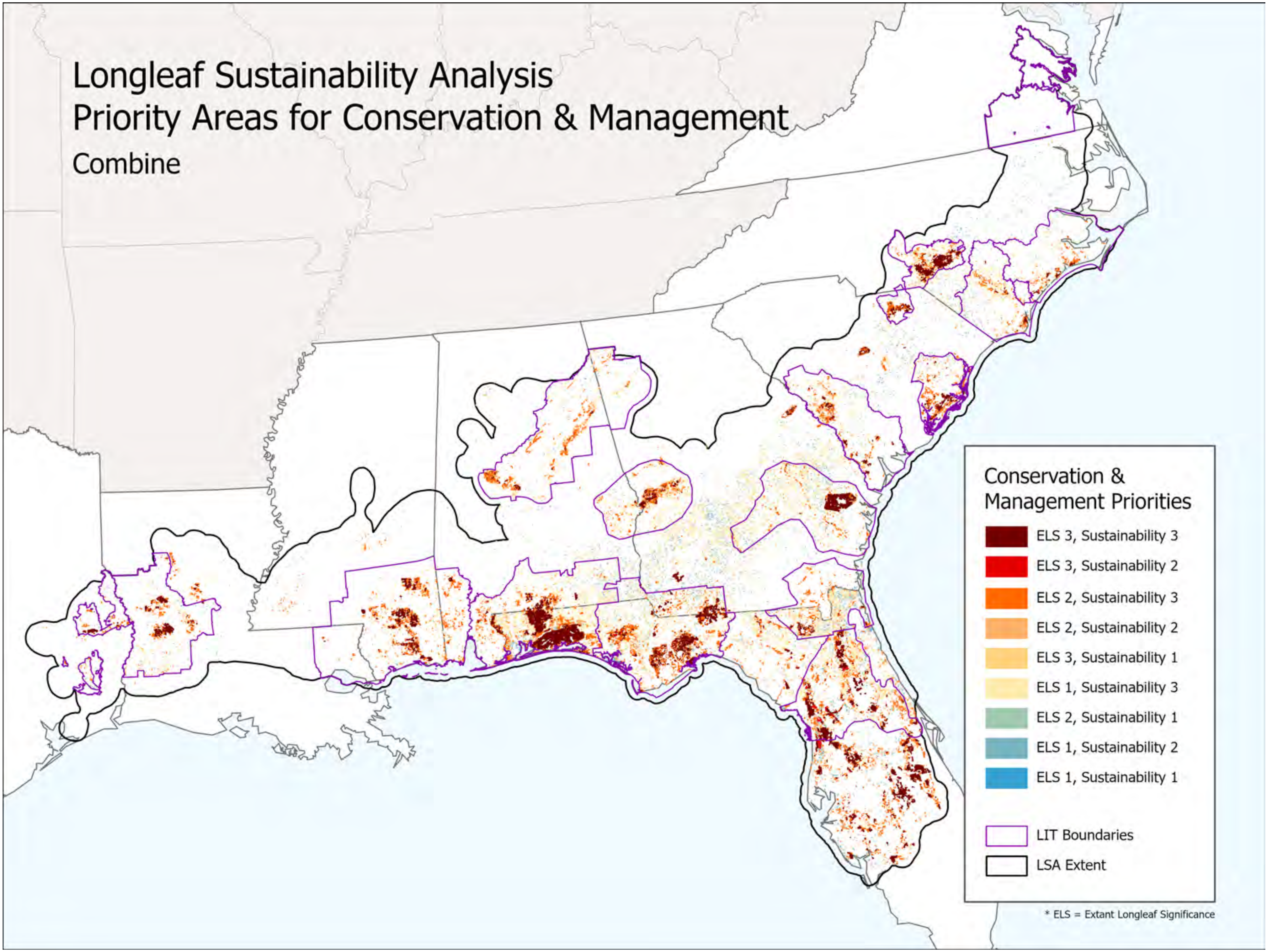
CONNECTIVITY_ADDL_DATA folder [Maps not shown in User Guide.]

LSA_Connectivity_FlowPotential_v1.tif

The flow potential is an additional output of the connectivity model described in Core Data. It depicts current flow under "null" resistance conditions and shows what the current would look like if it weren't constrained by barriers and resistance.

LSA_Connectivity_NormalizedCurrentFlow_Channelized_v1.tif; LSA_Connectivity_NormalizedCurrentFlow_Impeded_v1.tif; LSA_Connectivity_NormalizedCurrentFlow_Intensified_v1.tif

The channelized, impeded, and intensified flow are additional output of the connectivity model described in Core Data. These are derivatives of normalized flow and depict the most severe bottlenecks (>2.0 SD), impediments (<0.5 SD), and intensified restrictions (1 to 2 SD) to flow.



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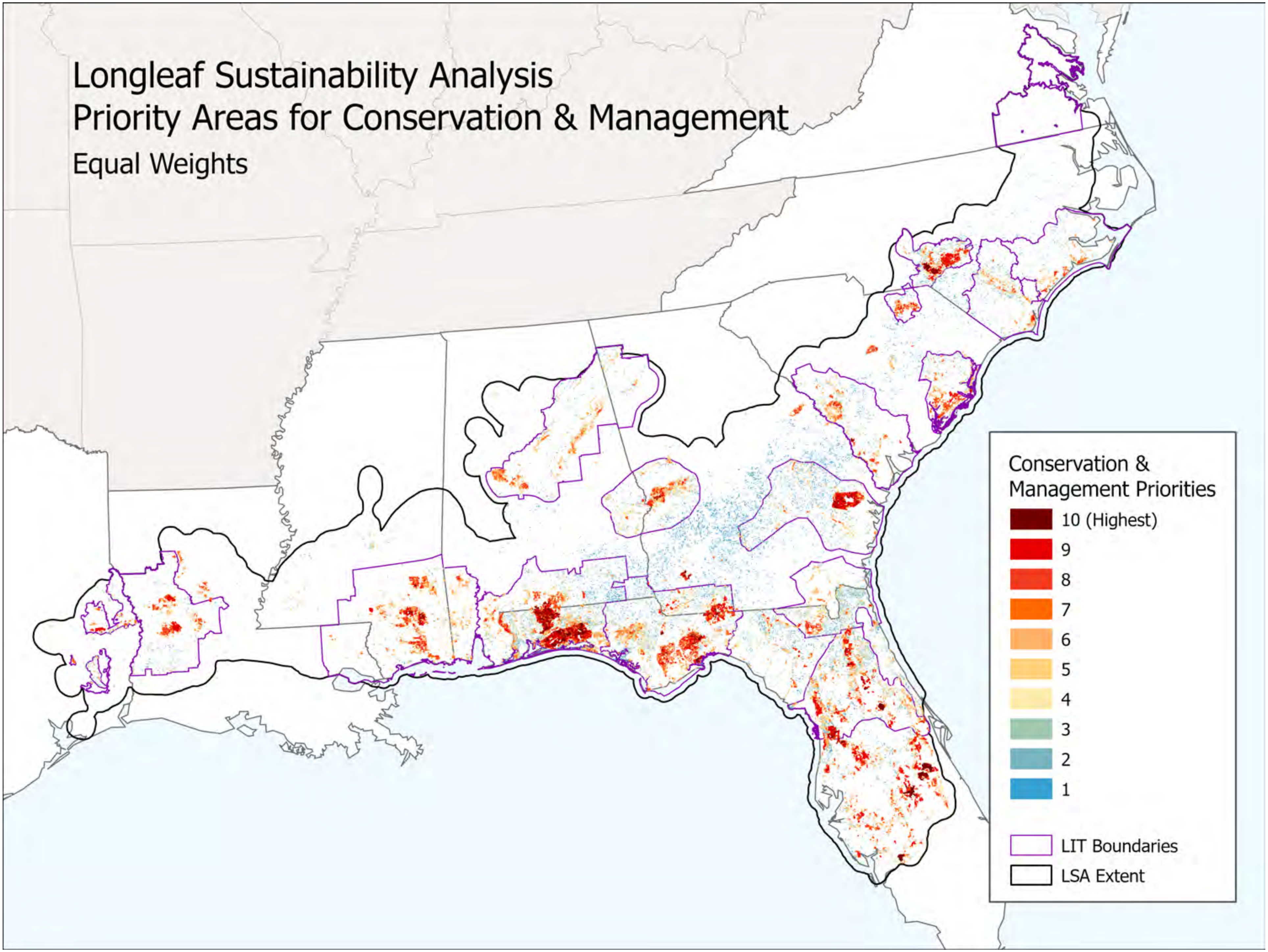

Longleaf Sustainability Analysis
Priority Areas for Conservation & Management
Equal Weights

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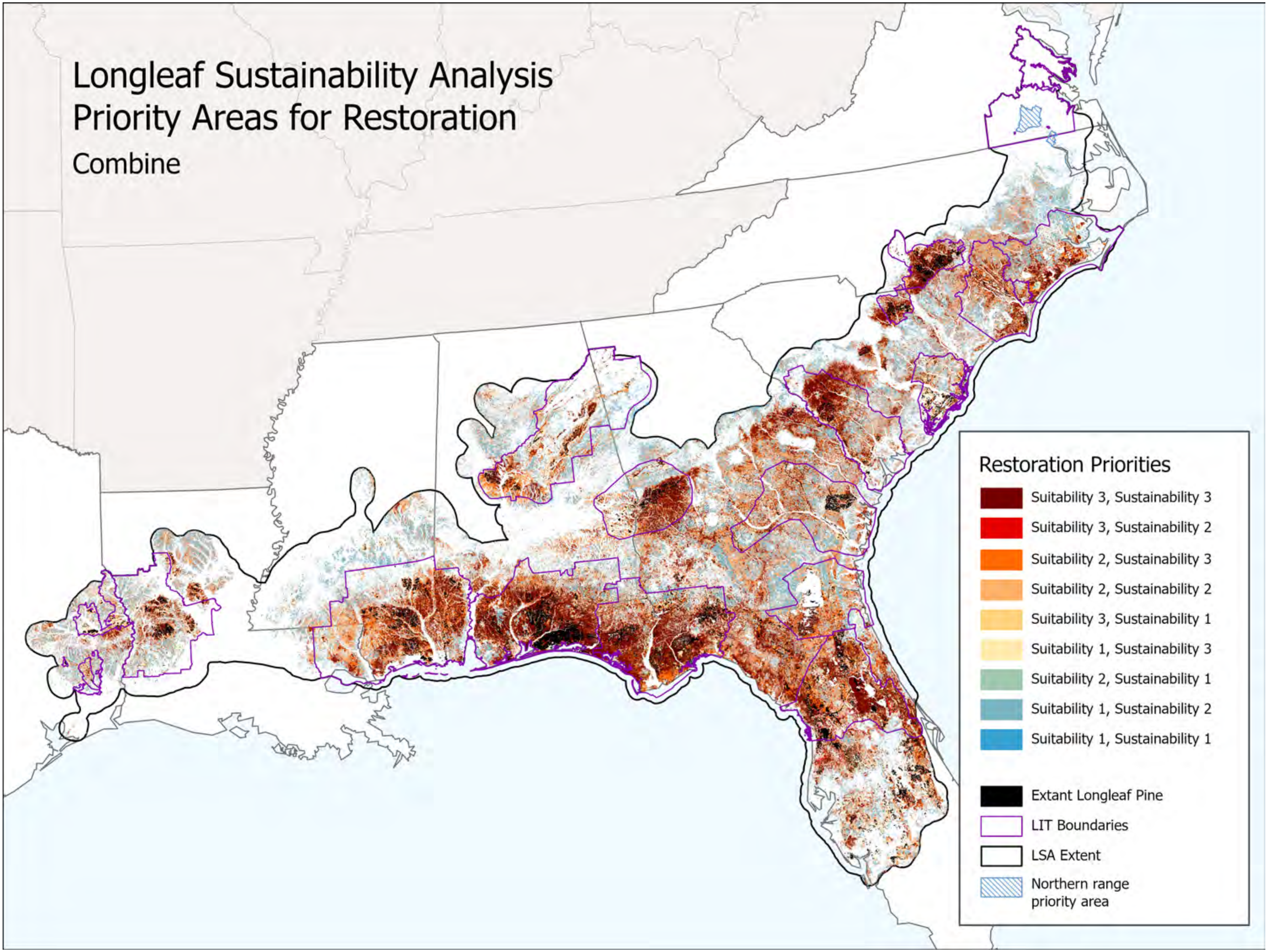

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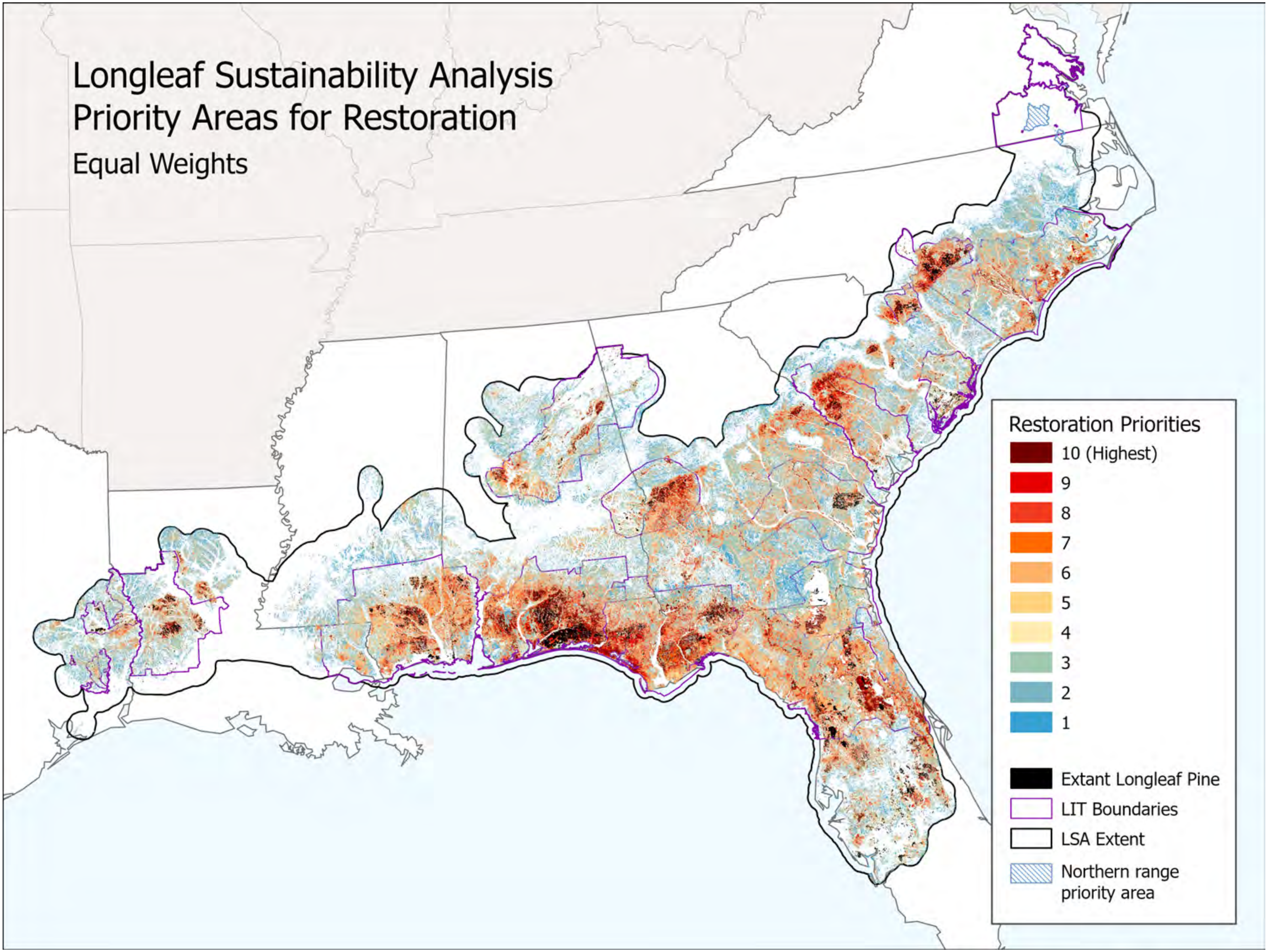
For information about TNC Northern Range Priority Areas see 3_ADDITIONAL_DATA (p. 4)



Longleaf Sustainability Analysis
Priority Areas for Restoration

Equal Weights

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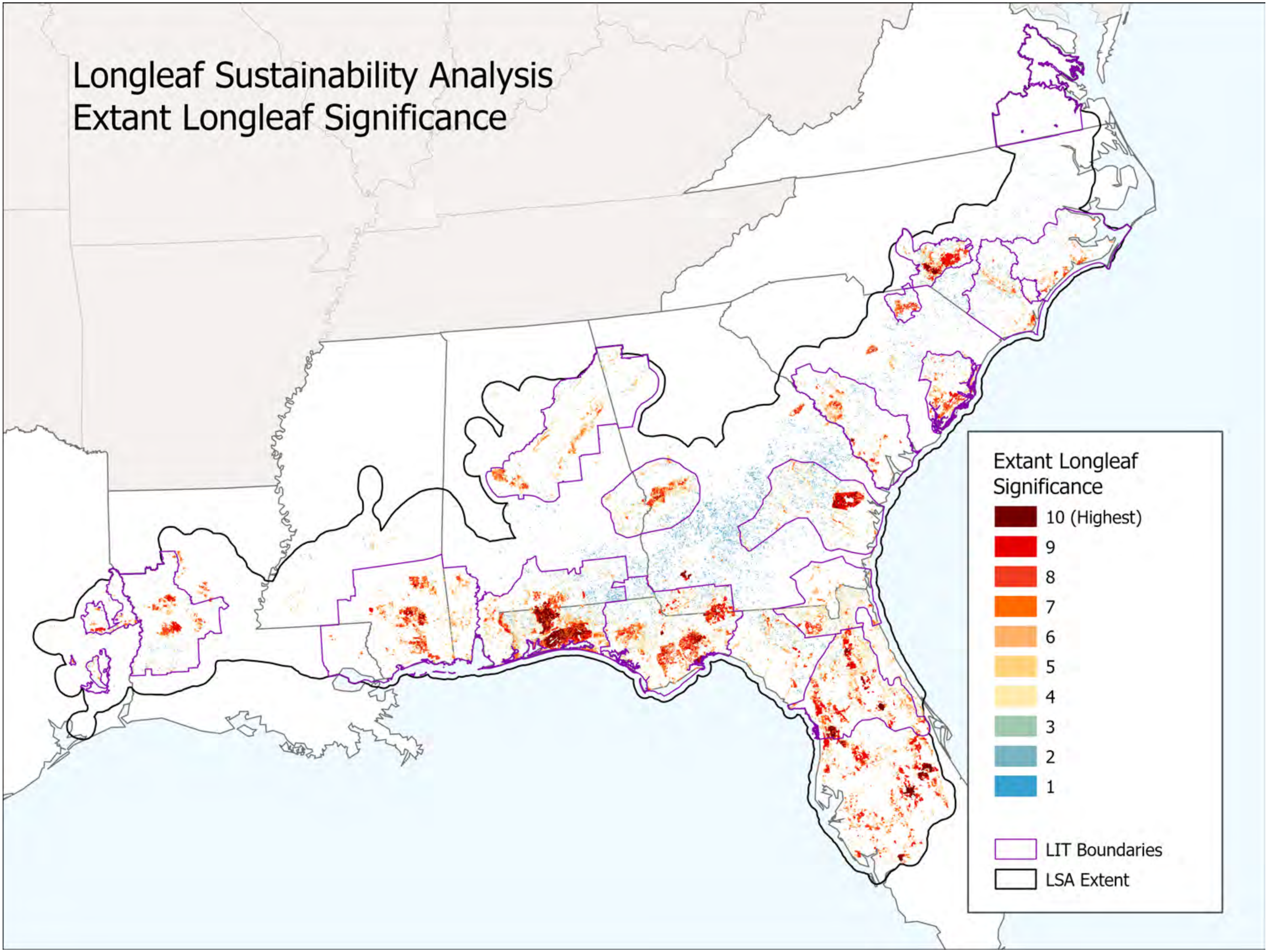
For information about Northern Range Priority Area see 3_ADDITIONAL_DATA (p. 4)



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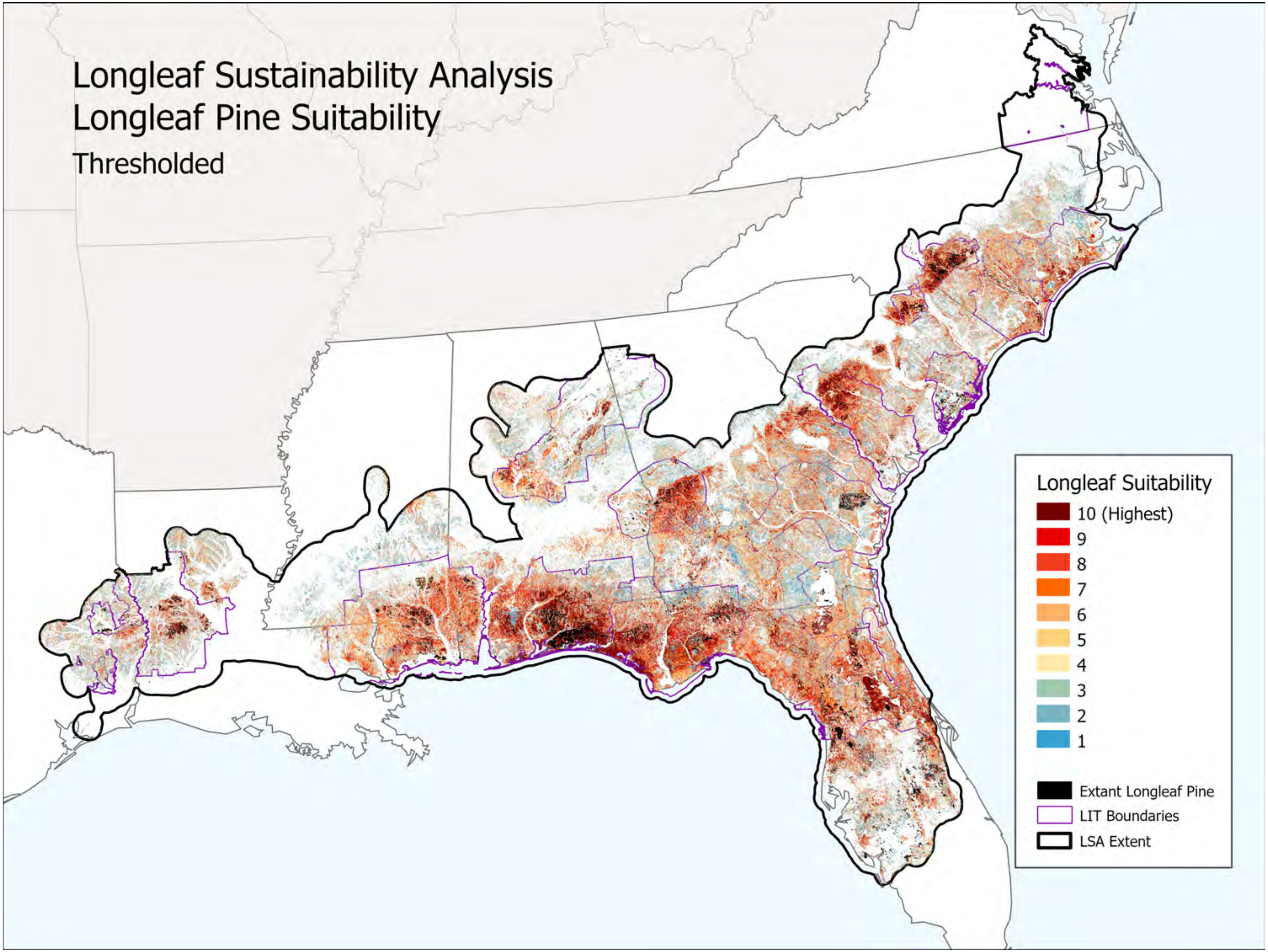

Longleaf Sustainability Analysis
Longleaf Pine Suitability
Thresholded

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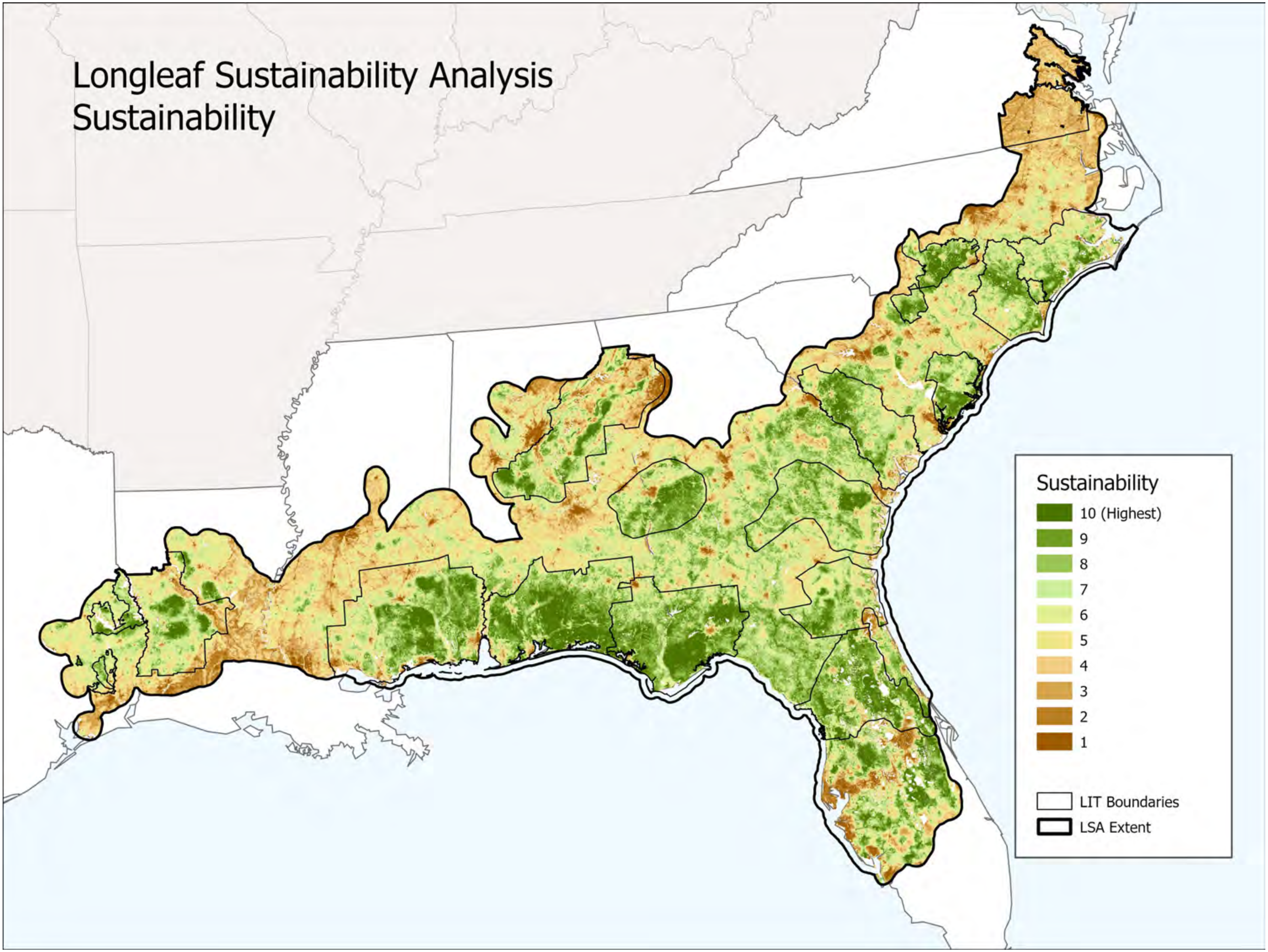

Longleaf Sustainability Analysis
Sustainability

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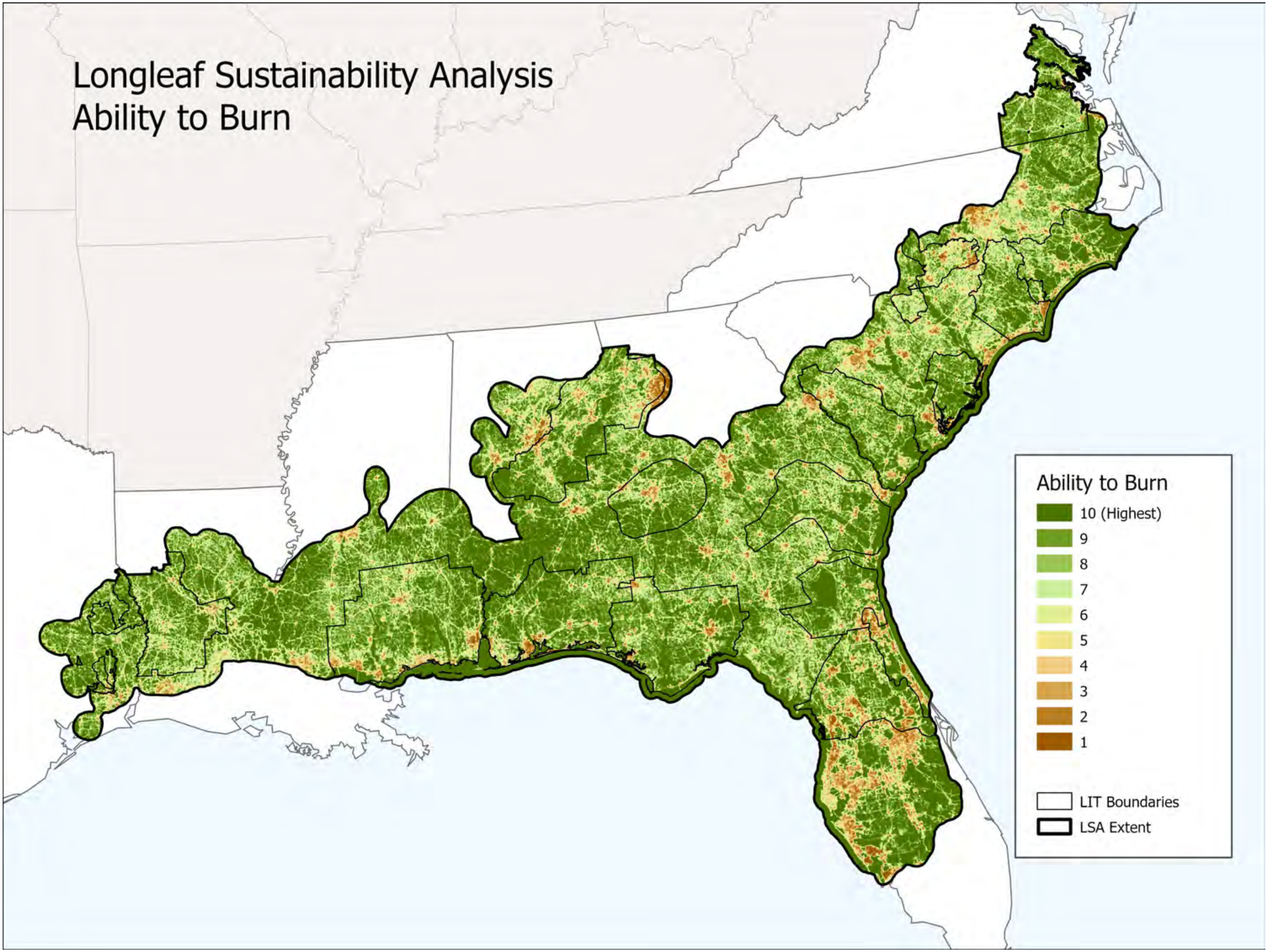

Longleaf Sustainability Analysis
Ability to Burn

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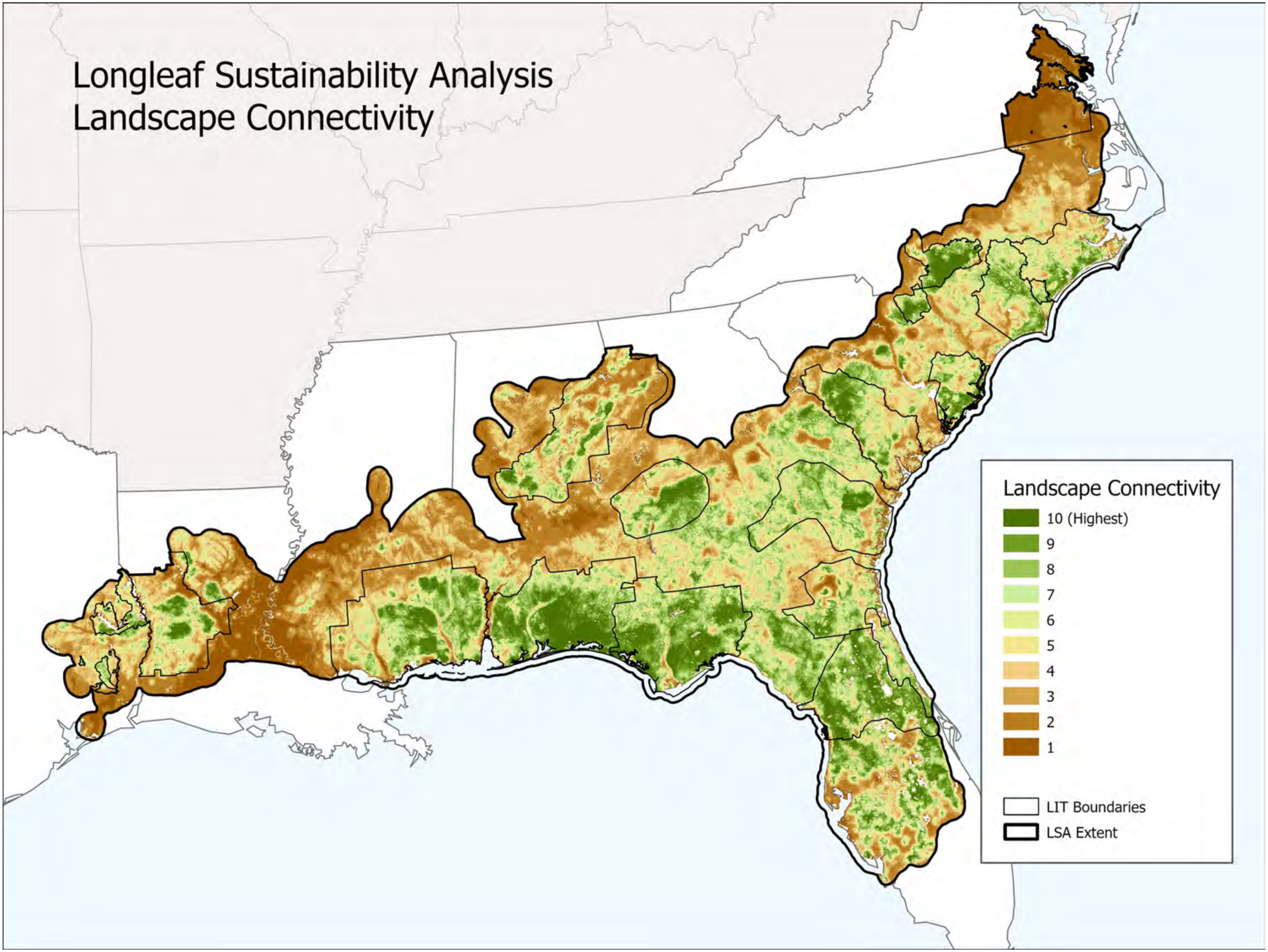

Longleaf Sustainability Analysis
Landscape Connectivity

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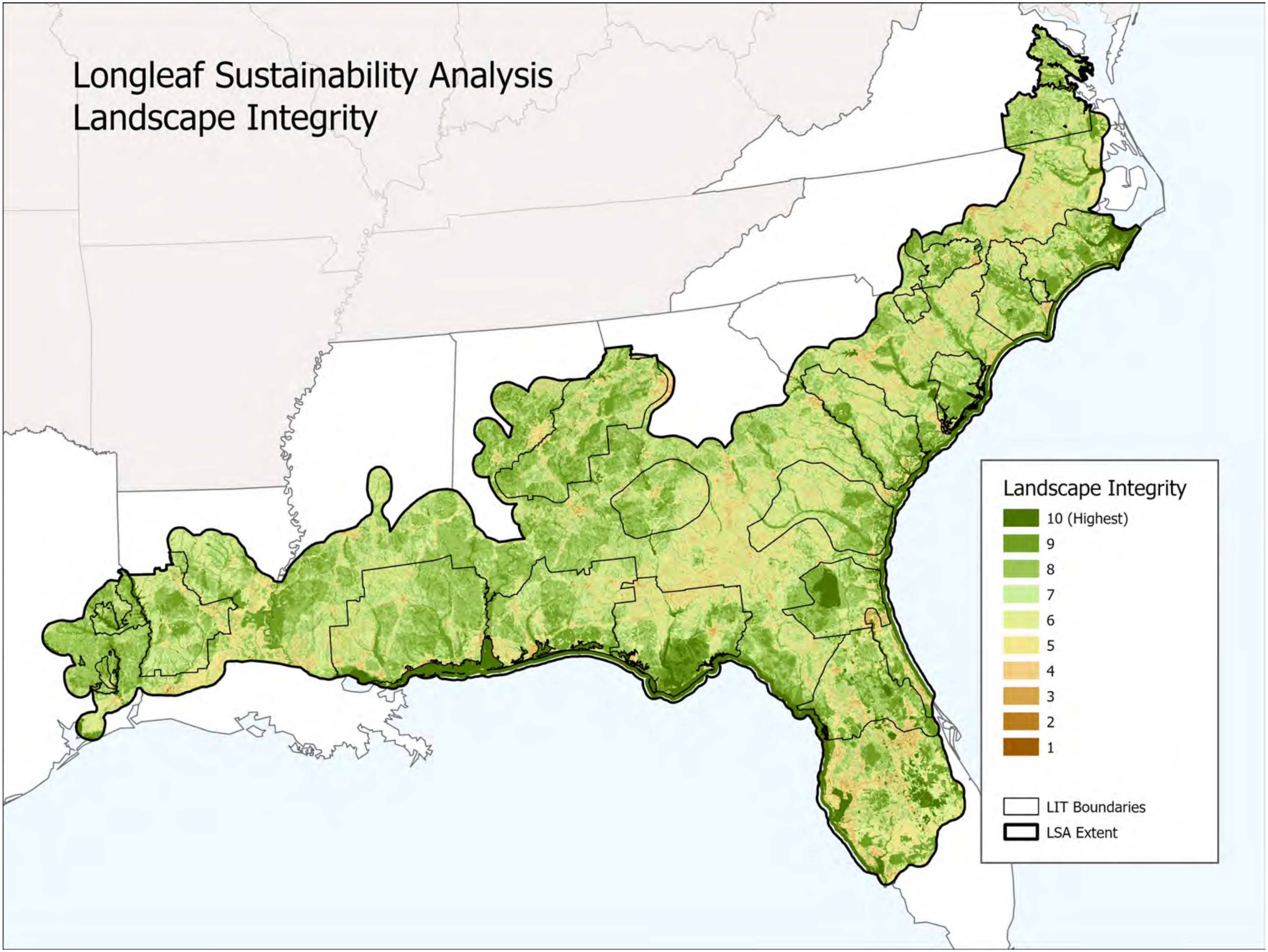
Longleaf Sustainability Analysis
Landscape Integrity

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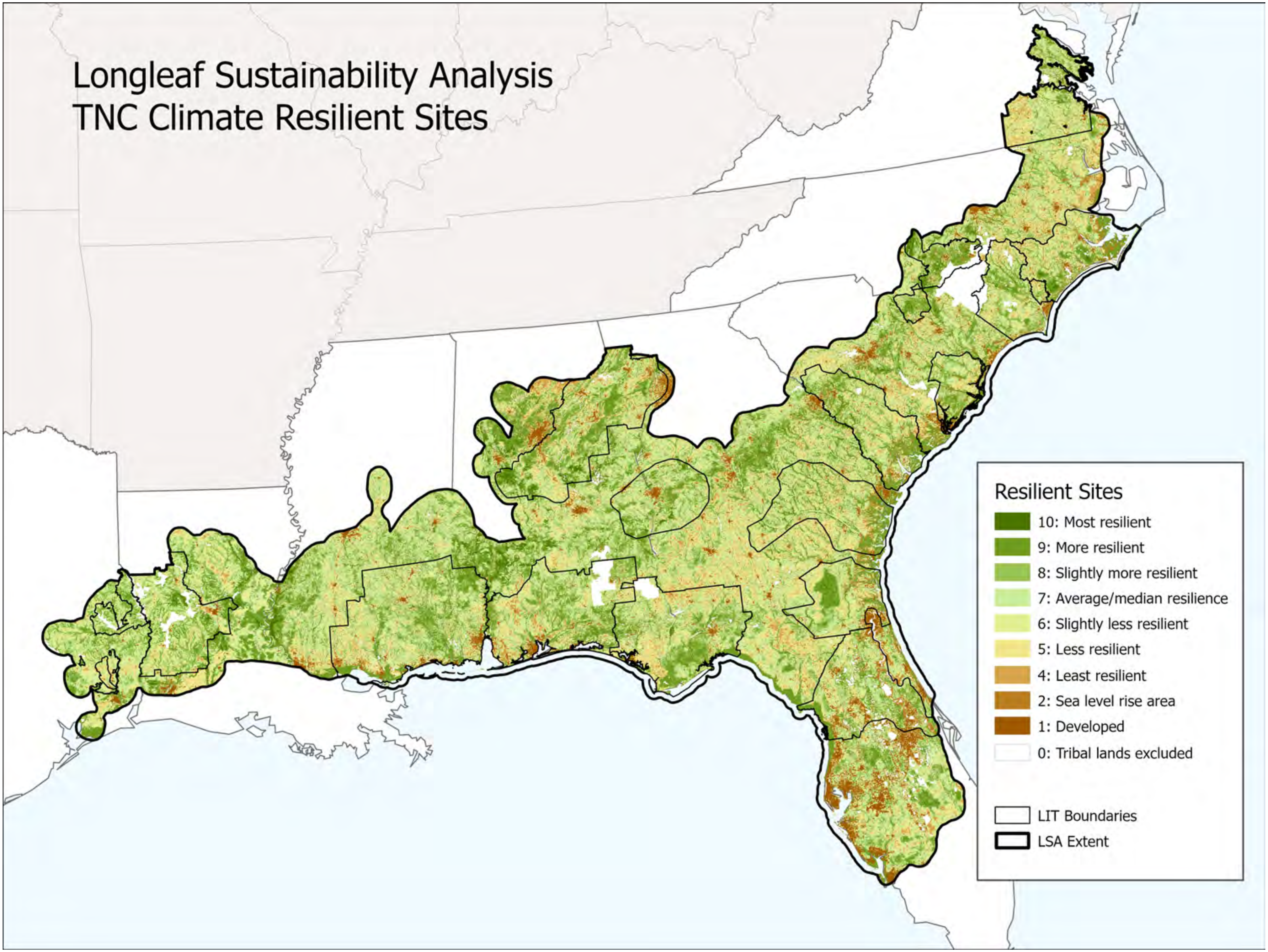

Longleaf Sustainability Analysis
TNC Climate Resilient Sites

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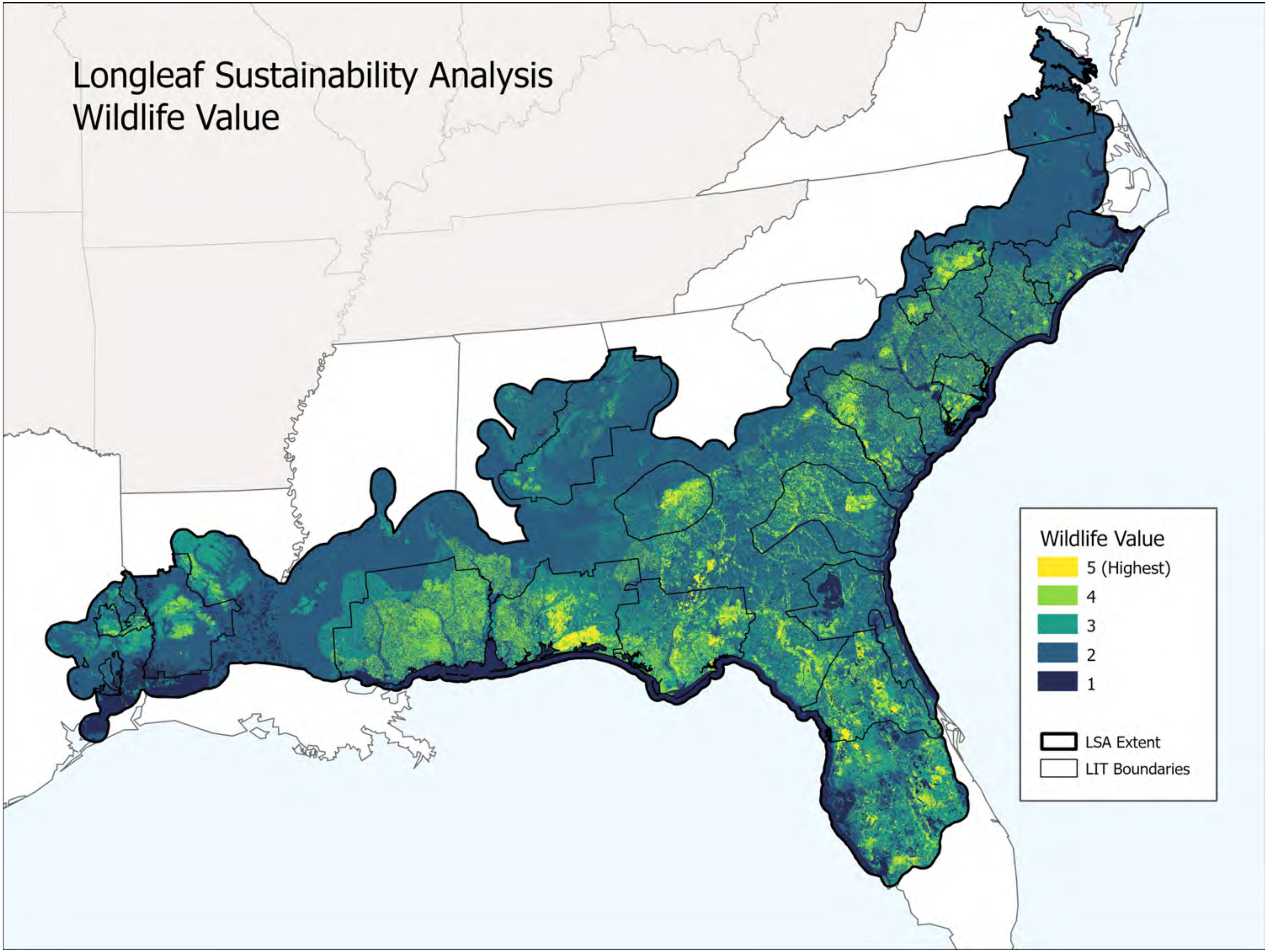

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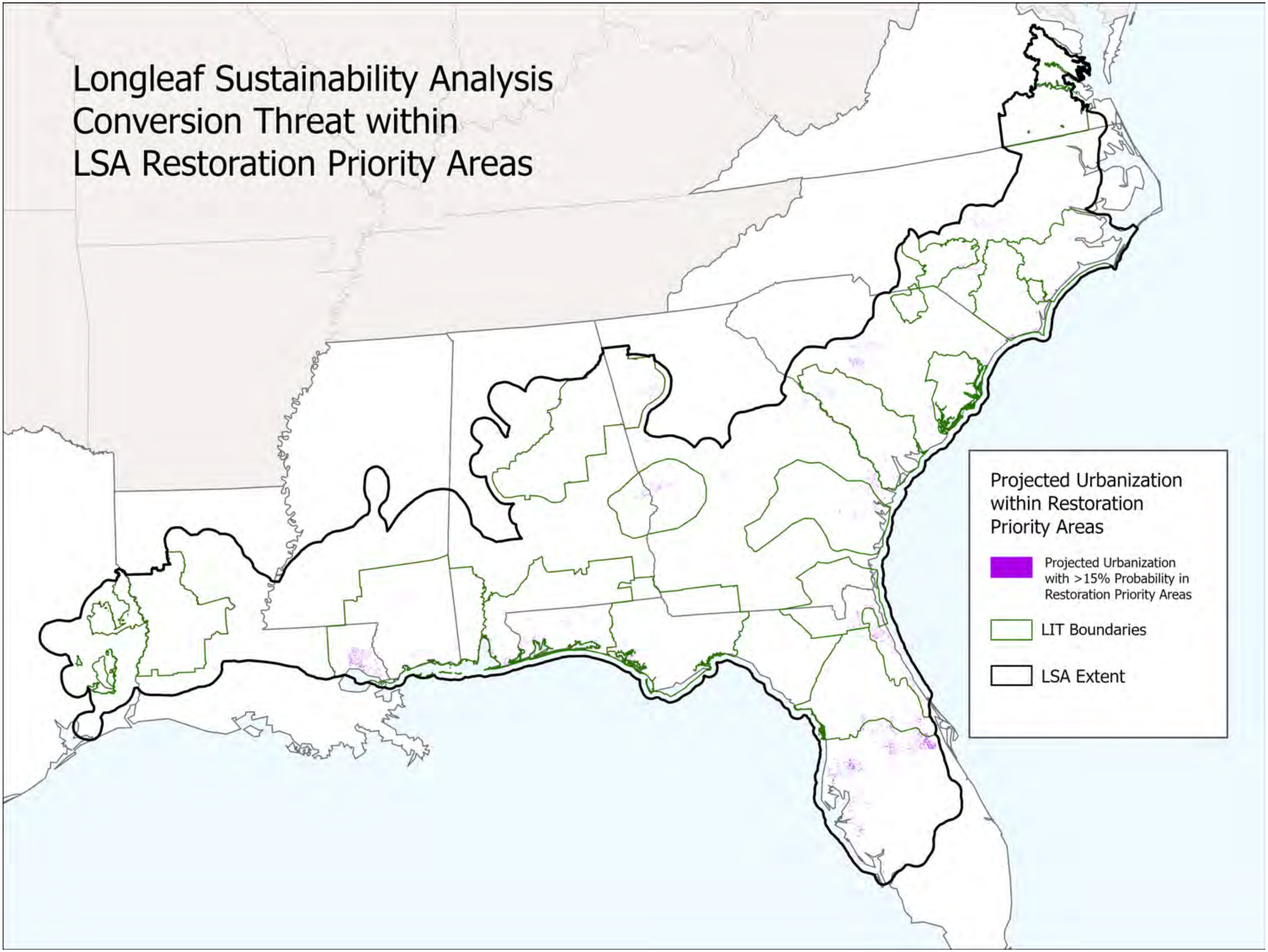

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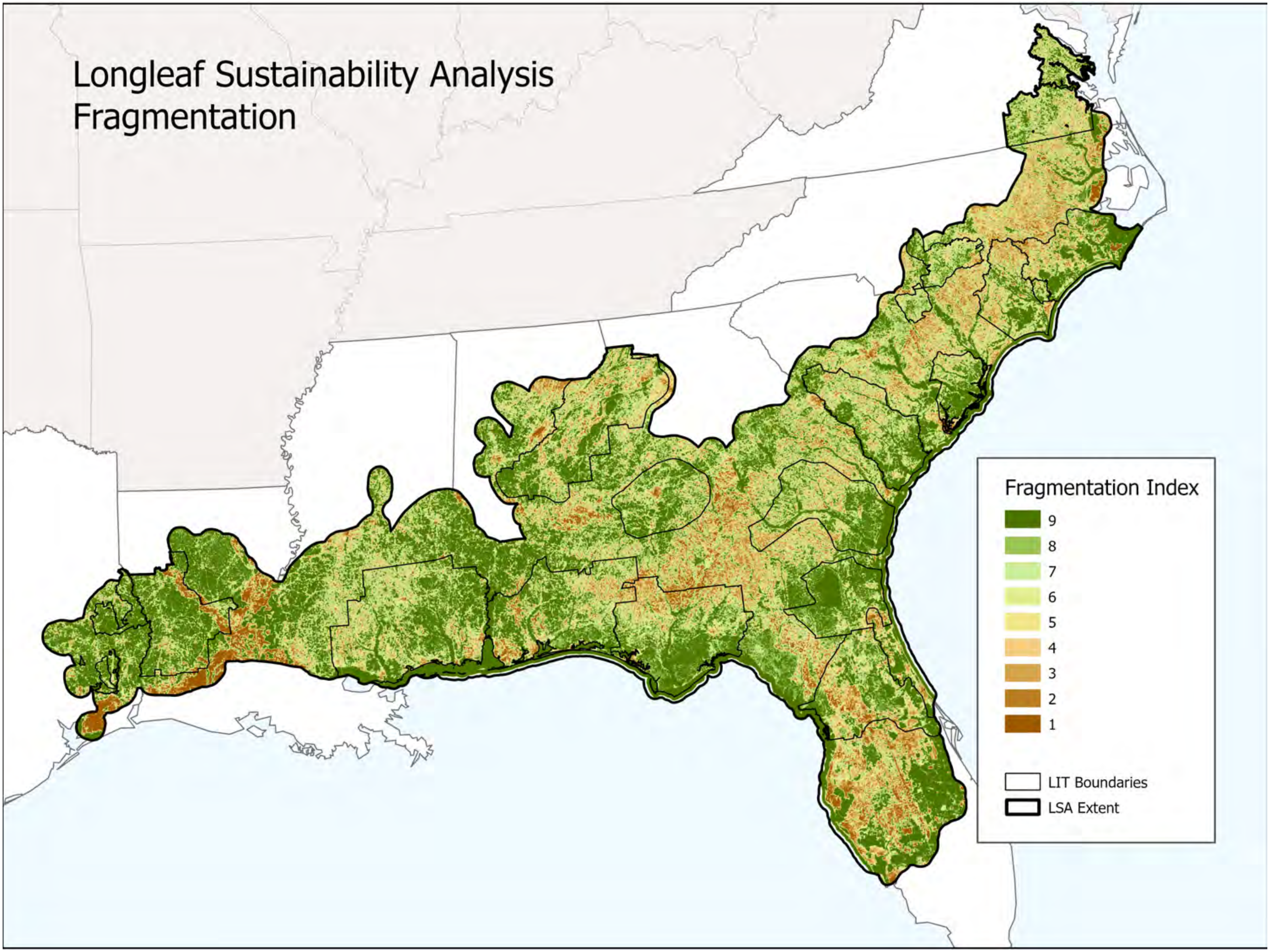

Longleaf Sustainability Analysis
Fragmentation

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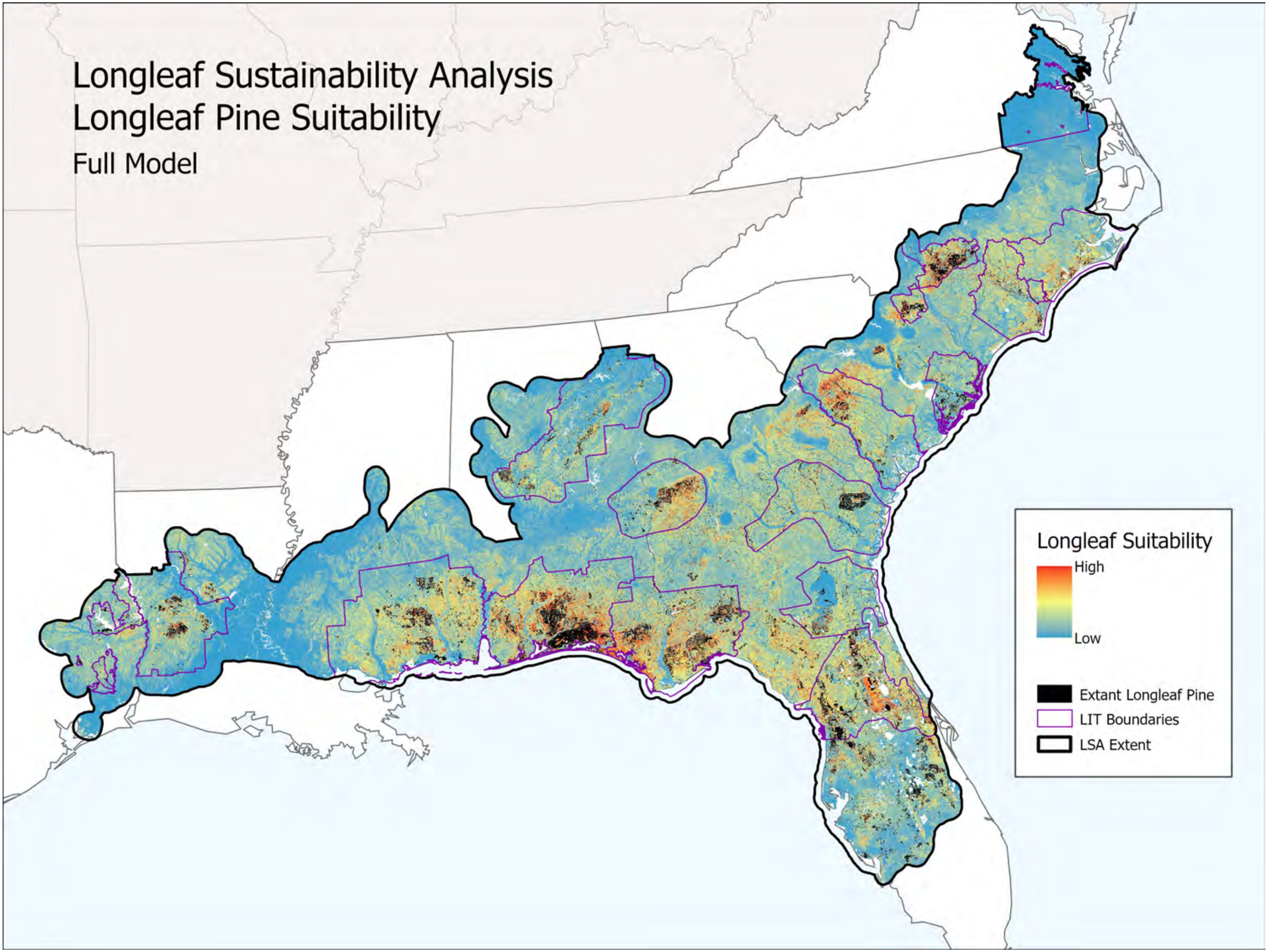

Longleaf Sustainability Analysis
Longleaf Pine Suitability
Full Model

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Appendix B.

Longleaf Pine Suitability (Maxent Model)
Variable Importance Results

Table B-1. Analysis of variable contributions for longleaf pine suitability model.

Variable	Percent contribution	Permutation importance
Current fire frequency (SE Fire Map)	31.8	7.7
Existing vegetation type (LANDFIRE)	19.3	30.4
Historical fire frequency (LANDFIRE)	14	3.6
Percent sand (Soils) (Polaris)	11.2	17.4
Soil drainage (SSURGO)	6.6	7.8
Annual precipitation (PRISM)	4.8	10.5
Annual mean soil moisture (Vergopolan et al. 2021)	3.3	3
Climatic water deficit (PRISM)	3.1	4.8
Annual mean temperature (PRISM	2.9	7.3
Historical vegetation type (LANDFIRE)	1.6	3.5
Soils and bedrock (Anderson et al. 2016)	1.4	4.1

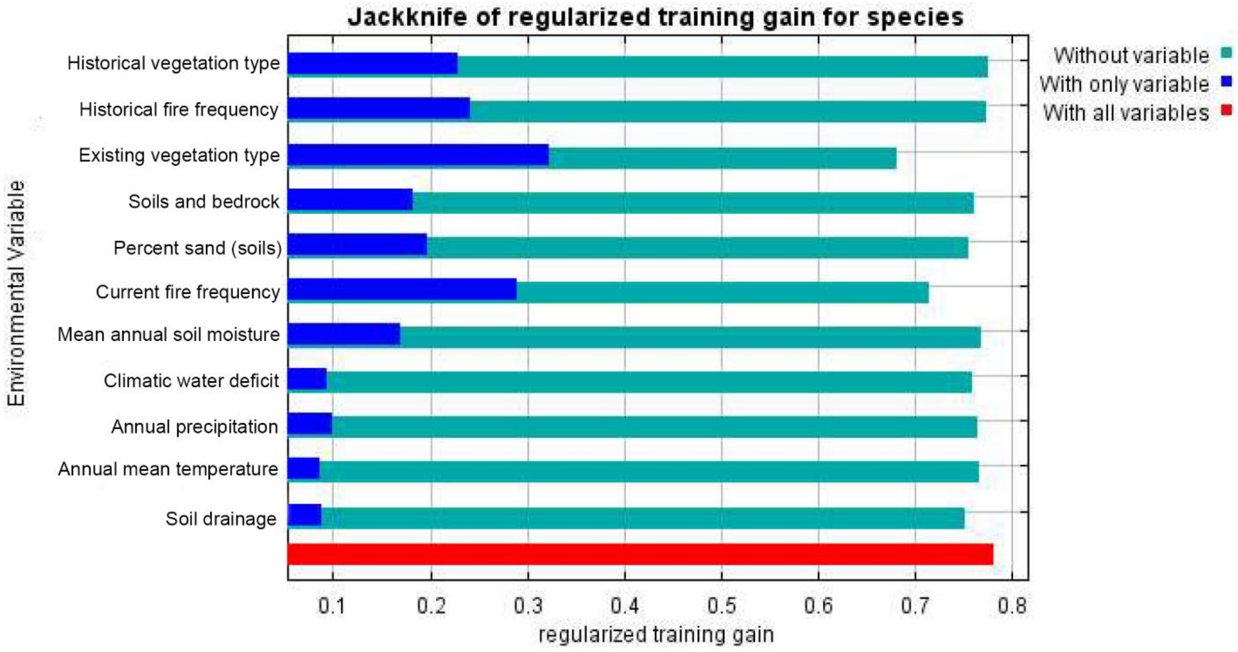

Figure B-1. Jackknife of regularized training gain for longleaf pine suitability model.