A Site Prioritization for Shortleaf Pine Restoration in Duke Forest

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EXECUTIVE SUMMARY

Shortleaf pine forests once covered tens of million acres in the United States. Today, shortleaf pine (*Pinus echinata*) is in significant decline—shortleaf pine-dominated forests remain on only 10 percent of their historic range. Much of this loss of shortleaf pine has occurred east of the Mississippi river in states like North Carolina, which has seen a 60 percent drop in shortleaf pine acreage since 1990. There are several reasons for the serious decline, including lack of fire, land use changes from forest to urban-suburban development, and disease and pests.

Because of this loss, Duke Forest is seeking to restore shortleaf pine on its land. This Master's project fulfills an important first step in that restoration process: site prioritization. For this project, key site characteristics of Duke Forest parcels are collected, analyzed, and compared to historical data using geospatial analysis and habitat suitability modeling. The analysis is then used to identify candidate restoration sites for shortleaf pine within Duke Forest's Durham and Korstian divisions.

The objectives of this Master's project were to identify where shortleaf pine grew historically and where it has persisted within Duke Forest's Durham and Korstian divisions; create spatial datasets for key physical site attributes in the Durham and Korstian divisions; conduct exploratory data analyses and habitat suitability modeling for shortleaf pine based on differences in the key site attributes; and develop a site prioritization for potential shortleaf pine restoration sites in Duke Forest's Durham and Korstian divisions, based on model results.

This site prioritization involved extensive research and literature review; stakeholder and expert interview; data collection, creation, and analysis in ArcGIS Pro; and exploratory analysis and habitat suitability modeling in R. Historic and current shortleaf pine acreage data (acreage from 1931 and 2019) formed the basis of the analysis. Expert interviews and research were conducted to determine key physical site attributes for a habitat suitability analysis. The key physical site attributes were then developed in GIS for the two Duke Forest divisions, and attribute data was sampled for historic and sustained shortleaf parcels as well as for random sites. Exploratory data analysis and habitat suitability modeling using a classification and regression tree (CART model) were then used to identify suitable habitat for shortleaf restoration. Several maps were developed in GIS based on the model results for use by Duke Forest staff.

All of these steps ultimately helped create a list of potential candidate parcels for shortleaf restoration in Duke Forest. The resulting maps offer two different options for restoration site selection. It is recommended that Duke Forest chooses restoration sites based on the map/model results that are more selective. The more selective map resulted from analysis of sites where shortleaf pine both grew in 1931 and still grows today in the forest—shortleaf pine that has persisted over time.

Ultimately, this site prioritization creates the foundation for a successful restoration project of shortleaf pine in Duke Forest. Its staff can now conduct site visits to further

refine where to restore shortleaf pine; they will need to decide which candidate parcels highlighted in this Master's Project best meet other project needs and constraints, such as road access and boundary considerations. Once Duke Forest has finalized its site selection, it can begin the next steps of the restoration process.

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I. Introduction

Historically, shortleaf pine (*Pinus echinata*) forests spanned some 70 to 80 million acres in the United States (Anderson, 2016). Since then, forest cover has declined dramatically. Today, less than 6 million acres of shortleaf pine-dominated forest remains in the U.S.—a more than 90 percent decline in its historic extent (figure 1; Guldin & Black, 2018). About 50 percent of this decline has occurred since 1980 (Guldin & Black, 2018). Moreover, experts voice concern that the majority of shortleaf today fall in larger diameter size classes (72% of the total acreage) and that there is a worrisome lack of smaller diameter trees (Anderson, 2016). Most of the remaining shortleaf pines grow west of the Mississippi river; significantly fewer of these trees grow in the eastern U.S. compared to their historic presence in the region (Anderson, 2016). North Carolina alone has seen a 60 percent decline in shortleaf pine acreage since 1990. According to the *Shortleaf Pine Restoration Plan*, shortleaf pine is now "one of the nation's most threatened legacy forests." (Anderson, 2016)

Restoring shortleaf pine is not an easy task. It requires a nuanced understanding of the way a forest ecosystem works, its original structure and function prior to its degradation or destruction, its current condition, and more. Then comes the task of actually restoring shortleaf pine and then assessing whether a project has met its short-term and long-term goals. Ultimately, an environmental manager will want to know whether a shortleaf pine population has returned to a healthy, sustainable restored state. There are multiple steps in the restoration process, outlined in the *Background* section below, and each should be followed to help ensure a successful project.

Before any of these steps can be taken, ecologists and conservationists must determine *where* is the most suitable place to restore a species. According to Hof et al. 2021, "…the initial state of the sites chosen for restoration may determine how fast and perhaps also if restoration goals will be, or are, accomplished." This Master's Project fulfills an important first step in the restoration process: site prioritization. In this project, site characteristics of Duke Forest parcels are collected and analyzed and the data is then used to identify candidate restoration sites for shortleaf pine within Duke Forest's Durham and Korstian divisions. In essence, this site prioritization sets the stage for a successful restoration project of shortleaf pine in Duke Forest.

Shortleaf Pine Ecological History & Current Status

There are several causes of shortleaf pine's dramatic decline. As early as the Revolutionary War, the species served as a major timber source (Anderson, 2016). Americans used it domestically to build structures such as houses and dockyards, and they also exported it to places such as Britain and the West Indies. Because people relied on shortleaf pine so heavily for timber at that time, the species was almost completely wiped out in the U.S. by the mid-1800s. Over the past couple centuries, land use changes from forest to urban-suburban development and loss of open range livestock grazing have also harmed shortleaf pine populations. More recently, a demand for loblolly pine timber has caused people to preferentially plant loblolly (Guldin & Black, 2018; Anderson, 2016). Not only has this trend meant shortleaf pine habitat is being converted to intensive loblolly's pine plantations, but experts also report increasing hybridization between shortleaf and loblolly, in what is called genetic swamping. Diseases and pests—in particular, the Southern pine beetle and the fungal-caused littleleaf disease—have also hit shortleaf pine hard.

Perhaps the biggest source of shortleaf's decline recently is lack of fire (Guldin & Black, 2018; Anderson, 2016). The species makes up one of the three fire-adapted pine ecosystems in the U.S., along with ponderosa pine and longleaf pine (Anderson, 2016). Shortleaf requires frequent, low-intensity fire for natural regeneration, on an approximately two-to twenty-year return interval. The tree possesses adaptations to survive and re-sprout after being top-killed by fire, and fire has a positive effect on regeneration and seedling vigor response (Guldin & Black, 2018; Anderson, 2016). On a longer timescale, shortleaf requires fire to help maintain its populations. Without fire as a recurring natural disturbance, hardwoods take over the landscape through succession and outcompete shortleaf pines. Due to the U.S. Forest Service's fire suppression management tactics in the 20th century, the natural fire regime has been profoundly altered throughout the country. As a result, forest communities that historically held shortleaf have shifted dramatically, and these lands now support more shade tolerant hardwood species such as maples.

The decline in shortleaf pine and degradation of habitats where it still exists is troubling. The species acts as a structural habitat element where it grows, and provides habitat diversity (Masters, 2007). Forests with shortleaf support numerous wildlife species, such as Bachman's sparrow, northern bobwhite, the endangered red-cockaded woodpecker, wild turkey, white-tailed deer, small mammals, several rare species of butterflies, and more. Wildlife species that depend on open, fire-maintained habitat—which forests with shortleaf provide—have suffered the most. In addition, because forests with shortleaf pine tend to have an open structure, they also offer ideal conditions for "rare and restricted" understory plant species, according to the Shortleaf Pine Initiative. This means that the loss of shortleaf habitat has hurt those rare plant species as well. Lastly, the Shortleaf Pine Initiative notes that shortleaf pine's decline is a lost economic opportunity. Shortleaf pine is a valuable resource; its wood can be turned into products including lumber, pulpwood and poles, and other building materials. Thus, experts say the restoration of shortleaf pine is desperately needed, particularly in areas east of the Mississippi in states that have experienced a dramatic loss of shortleaf pine, like North Carolina (Anderson, 2016).

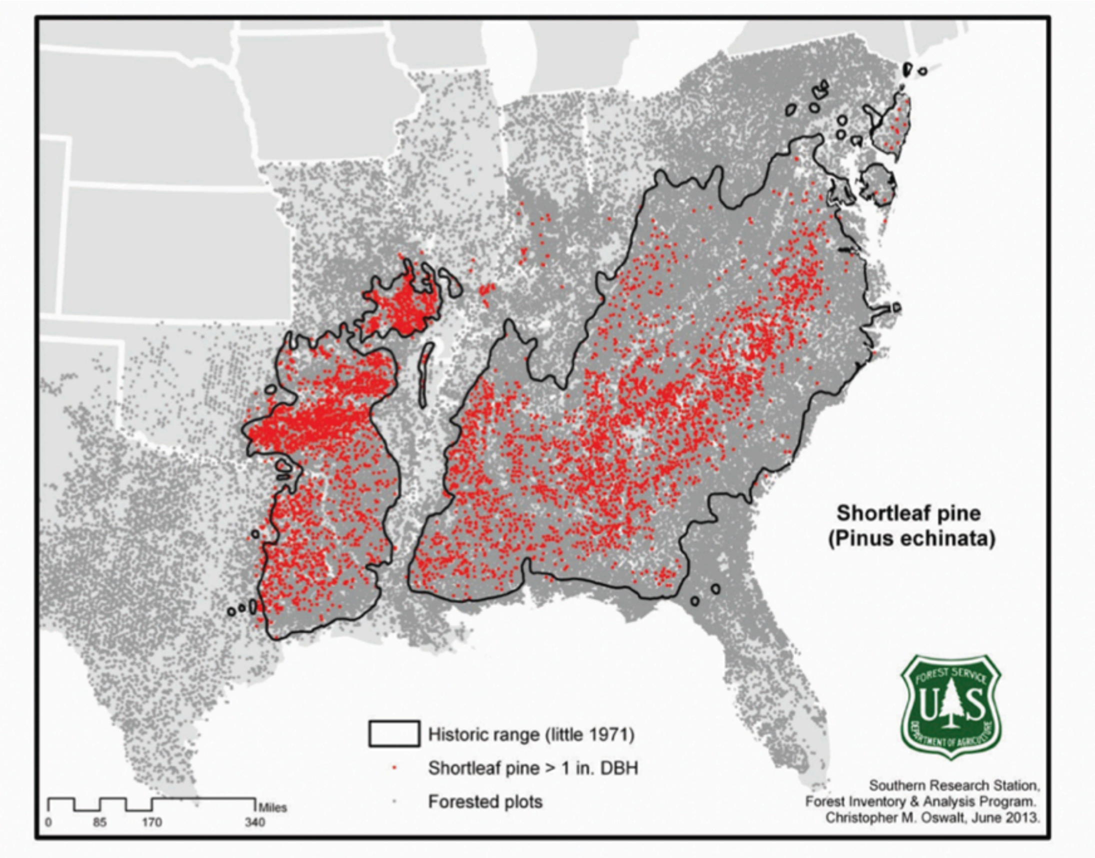


Figure 1: Distribution of shortleaf pine on Forest Service lands within the species' historic range (as of 2012). Source: http://shortleafpine.org/shortleaf-pine-initiative/shortleaf-pine-restoration-plan/shortleaf-pine-restoration-plan

Project Goals and Objectives

Due to shortleaf pine's decline locally and regionally, Duke Forest wants to create and implement a restoration project designed around shortleaf pine. However, the loss of shortleaf pine is not the sole reason that Duke Forest aims to restore shortleaf. With climate changes, shortleaf is expected to perform as good as, if not better than, some other tree species in the region, and so restoring the species may help with climate change adaptation (Anderson, 2016; S. Childs, personal communication, 2021). According to Sara Childs, Director of Duke Forest, their ultimate goal is to determine, "in the places shortleaf pine still exists, what can we do to maintain it or create the full complement of shortleaf ecosystem components. In the places it's missing, what are our opportunities for restoring it there."

This Master's Project will establish an evidence-based process for restoration site prioritization, which can also be applied to other tree species, either in Duke Forest or elsewhere. While some restoration projects may already have a chosen site for restoration due to limited land, others require stakeholders to select sites within a larger area of land, as is the case for Duke Forest. In these instances, restoration site selection should be based on ecological criteria as much as possible (Hof, 2021). This will increase the chances of success, and help organizations and agencies use limited resources more efficiently.

As Hof et al. note in their 2021 study, "When the aim is to reintroduce and preserve a specialist species, the target species' ecological requirements are central to the selection of restoration sites." Ultimately, selecting an appropriate site for species restoration will help determine whether a restoration project succeeds or fails.

This Master's Project identifies candidate sites for shortleaf pine restoration in Duke Forest. The selection is based on key physical attributes of the Duke Forest landscape that experts cited as important for shortleaf pine (attributes listed in Table 1 below).

The objectives of this Master's Project are:

1. Identify where shortleaf pine grew historically and where it has persisted within Duke Forest's Durham and Korstian divisions.
2. Create spatial datasets for key physical site attributes in the Durham and Korstian divisions; these spatial datasets can be used for both this Master's Project as well as for other uses by Duke Forest in the future, if useful.
3. Conduct habitat suitability modeling for shortleaf pine based on differences in key site attributes; comparisons will be done between sites with historic shortleaf, sustained shortleaf pine, and random sites in the divisions.
4. Develop a site prioritization for potential shortleaf pine restoration sites in Duke Forest's Durham and Korstian divisions, based on model results.

From this point, Duke Forest can then select sites from this list, create a restoration plan, and begin pursuing the next steps of shortleaf restoration in these areas. The overall restoration process and species-specific restoration methods are outlined in the following section.

II. Background

Restoration Process & Shortleaf Pine Restoration Methods

Due to the enormous complexity of restoration, researchers and practitioners have developed guidelines for the overall process of ecosystem restoration (Holl, 2020). They are typically conducted sequentially as follows:

1. Set goals and objectives of the project, which are general goals paired with specific objectives (often called Desired Future Conditions or performance criteria)
2. Establish a reference model and perform a pre-treatment baseline inventory of the restoration site
3. Determine a design plan, which includes details on the restoration methods, monitoring, maintenance, budget, timeline, and more
4. Project implementation/treatment
5. Monitoring to evaluate project success
6. Maintenance

Experts advocate using an adaptive management approach to restoration, which follows an iterative process of taking action (such as restoration treatment), evaluating the results, and adjusting management actions in order to achieve a project's goals.

Researchers and practitioners use many different techniques and tools to restore shortleaf pine, though the methods tend to fall within the same general categories. The main approaches are natural generation and/or artificial regeneration; prescribed fire; midstory reduction; thinning of other tree species in mixed stands; and sometimes herbicides.

One study by Guldin (2019) gives an overview of shortleaf restoration tools. The study outlined three general elements of silvicultural practice needed to restore this habitat. The first element is artificial regeneration. For sites where shortleaf pine previously existed but has now disappeared, artificial regeneration, or planting, is the primary method that restorationists use to re-establish the species. There are some difficulties with this approach, however. There is limited supply of shortleaf pine seedlings as well as a risk that shortleaf pine seed orchards may sell hybrid loblolly-shortleaf pine seedlings. There's another, broader issue: planted shortleaf pine stands will take decades to grow before they offer the habitat desperately needed by other species.

The second element of shortleaf restoration is prescribed fire. "Shortleaf pine is a fire-demanding species," Guldin wrote in the study. For artificially regenerated pine, Guldin recommended starting prescribed burns early for the new cohort—ideally in the second growing season, though it could occur in the third. Prescribed burns need to continue cyclically after this, at a rate of every three growing seasons. Regular burns prevent the encroachment of hardwood trees and promote native understory grasses and other plant species. This allows the closed forests to return to more open woodlands. Prescribed burns also support greater structural diversity in these forest stands. An added benefit of this tool: fires kill off hybrid loblolly-shortleaf seedlings, helping protect shortleaf's genetic integrity.

The third element of shortleaf restoration involves forest stands with a minor pine component—mixed pine or oak-pine stands with less than 50 percent of basal area in shortleaf pine. Guldin noted an opportunity to make shortleaf pine dominant in these ecosystems through a mix of selective thinning of non-shortleaf pine trees, prescribed fire, targeted application of herbicides to hardwoods, and planting to supplement natural regeneration. This approach could restore open shortleaf pine woodlands in as little as a decade, according to Guldin, which provides an advantage over the planting approach described above. "We have all of the management tools we need to bring back longleaf and shortleaf pine. They're well known and widely used," said Guldin in a Forest Service article about the study. "Combining these practices—cyclic, prescribed fires plus thinning and releasing pines in mixed stands where they still exist—will restore functional habitat for the different flora and fauna of concern in these ecosystems" (Restoration of Southern Pine Ecosystems, 2020).

Other studies follow or recommend similar approaches. Hedrick et al. (2004) looked at shortleaf pine-bluestem habitat restoration in the Interior Highlands of Arkansas—

specifically, the Ouachita Mountains. The authors describe restoration of 155,000 acres of unburned shortleaf pine stands, which consisted of removing most midstory hardwoods, reintroducing frequent surface fires (prescribed burns every one to three years), and thinning from below in midstory and overstory pines. The researchers report that "these treatments have been effective in restoring many underrepresented species in the landscape," including the endangered red-cockaded woodpecker.

A follow-up paper by Hedrick et al. (2007) described shortleaf pine-bluestem restoration as part of the Ouachita National Forest Plan. Here, researchers based their restoration reference site on historic photographs and tree count records of the area. Restoration method varied depending on whether a site had native second-growth shortleaf pine or artificial plantations of loblolly pine. For the former, restoration involved selectively thinning the forest to a residual basal area of ~60 ft squared per acre, cutting down most of the woody midstory stems, and prescribed burns every three to four years. The authors said this approach would significantly restore the shortleaf pine-bluestem habitat in ~10 years. For artificial loblolly pine plantations, restorationists thinned them to the same residual basal area and used the same prescribed burn schedule until the loblolly grew to a certain size. At this point, the plantation was clear-cut for timber and the land planted with shortleaf pine.

Guldin (2007) reviewed the restoration of shortleaf pine in pure and mixed stands. Guldin stressed that in some sites, no natural seed source of shortleaf pine may exist. In such scenarios, restorationists need to use artificial regeneration. Another critical element of shortleaf seedling survival and success is site preparation—specifically, ripping or subsoiling (plowing a 1- to 1.5-foot-deep furrow in the soil prior to planting). Experts hypothesize that furrows help protect shortleaf seedlings from extreme temperatures and drought during their first growing season. For already established immature and mature shortleaf pine stands, restoration involves: 1) thinning trees to mimic the natural disturbance regime, 2) using prescribed fire, and 3) cutting out midstory hardwoods that have taken over the forest in the absence of fire due to human suppression. All three of these methods are needed for successful restoration.

Schnake et al. (2016) examined the survival and growth of restored, underplanted shortleaf pine seedlings in the North Carolina Piedmont, just outside of Durham, NC. Its findings may somewhat challenge conventional beliefs about shortleaf. The researchers found that retaining at least a low level of residual overstory basal area helped planted shortleaf pine seedling survival and growth in the first growing season, compared to just clearcutting a forest stand and planting shortleaf pine there. The authors suggest this might be due to harsh microclimatic conditions in a clear-cut site, as well as fiercer competition from herbaceous vegetation after clearcutting. Essentially, they hypothesize that retaining some of the overstory creates a less competitive, less harsh environment for shortleaf pine seedlings to become established. However, in the second growing season, greater overstory basal area reduced shortleaf seedling growth. Additionally, the researchers found that when planting shortleaf pine for site restoration, containerized shortleaf pine seedlings survived better than the bareroot stock—perhaps due to containerized seedlings possessing a more intact root system and higher root mass.

Clabo & Clatterbuck (2019) looked at restoration of shortleaf pine-hardwood mixtures (these forest types have declined by 52 percent since 1980). The researchers assessed the establishment and early growth of shortleaf pine when using artificial regeneration, different site preparations, and varied release treatments. They compared different treatments among four sites: a control site, a site with prescribed burning, a site with herbicide treatment, and a site that received both herbicide and prescribed burning. They found that after artificial regeneration, the greatest shortleaf growth occurred in the site with both herbicide and prescribed burn treatments. They note that "burning alone without applying herbicides may not improve natural hardwood and pine composition on previously forested sites."

Guldin & Black (2018) described the recommended restoration tools for different parts of shortleaf's native range. They note that shortleaf habitat varies both geographically and by forest type, so experts need to apply different restoration methods based on the region. The techniques noted in Guldin's 2019 paper (described above) are highlighted in this paper as well. Guldin & Black note that "natural regeneration under even-aged rotation using the shelterwood method is known to be successful in shortleaf pine… modifications of the seed tree and shelterwood methods that lead to two-aged stands are ideal for the recovery of the endangered red-cockaded woodpecker." They also advise that prescribed burns are easier to conduct if the restoration site has homogeneous topography or sits within a larger piece of land that is burned as well.

Lastly, Stambaugh et al. (2007) examined which fire frequency is best for shortleaf pine regeneration and survival (and thus, restoration). They based their analysis on a 400-year historic shortleaf pine growth and fire scar database, as well as on-the-ground analyses from prescribed burns and a vegetation dynamics model. The researchers emphasize that there's a difference between the best fire frequency for shortleaf regeneration versus the best frequency for shortleaf survival, as those life phases have different needs. Long-term frequent burning (every one to four years) creates the most shortleaf regeneration, but hurts shortleaf survival. A burn interval of eight to fifteen years favors the highest rates of survival and recruitment in the overstory. Thus, balancing these needs is key. "Fire management prescriptions that incorporate both frequent burning and longer intervals will likely provide for the most long-term regeneration and recruitment success," the study authors write.

Study Area & Client Overview

Duke Forest is considered a living laboratory, and Duke University has used the forest for teaching and research since 1931. The forest is currently owned and managed by the university, and it covers over 7,000 acres of forest and open fields (Duke Forest: About, n.d.).

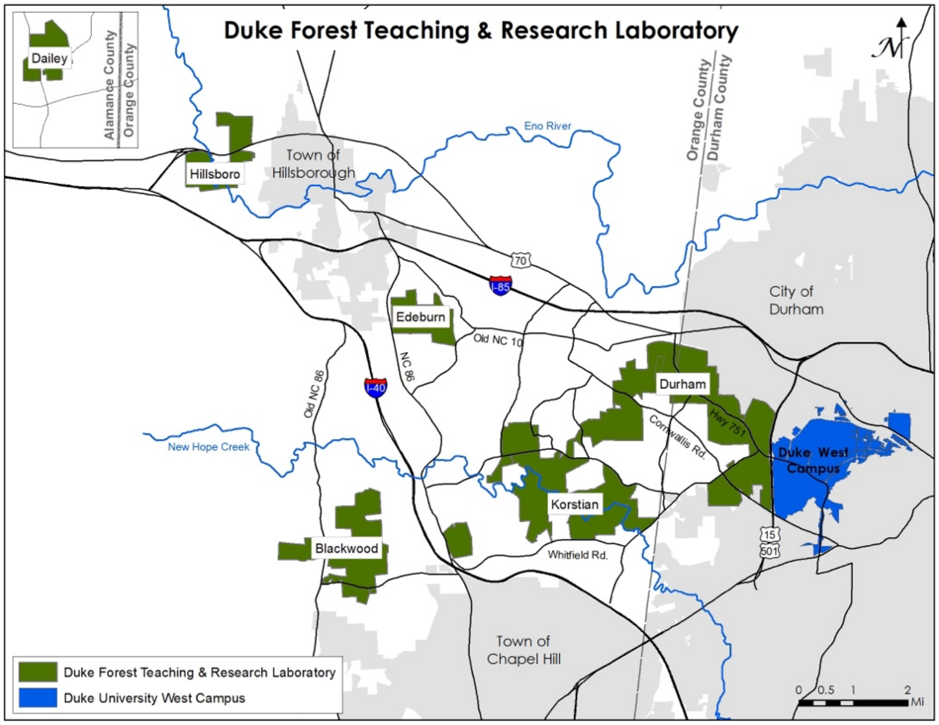
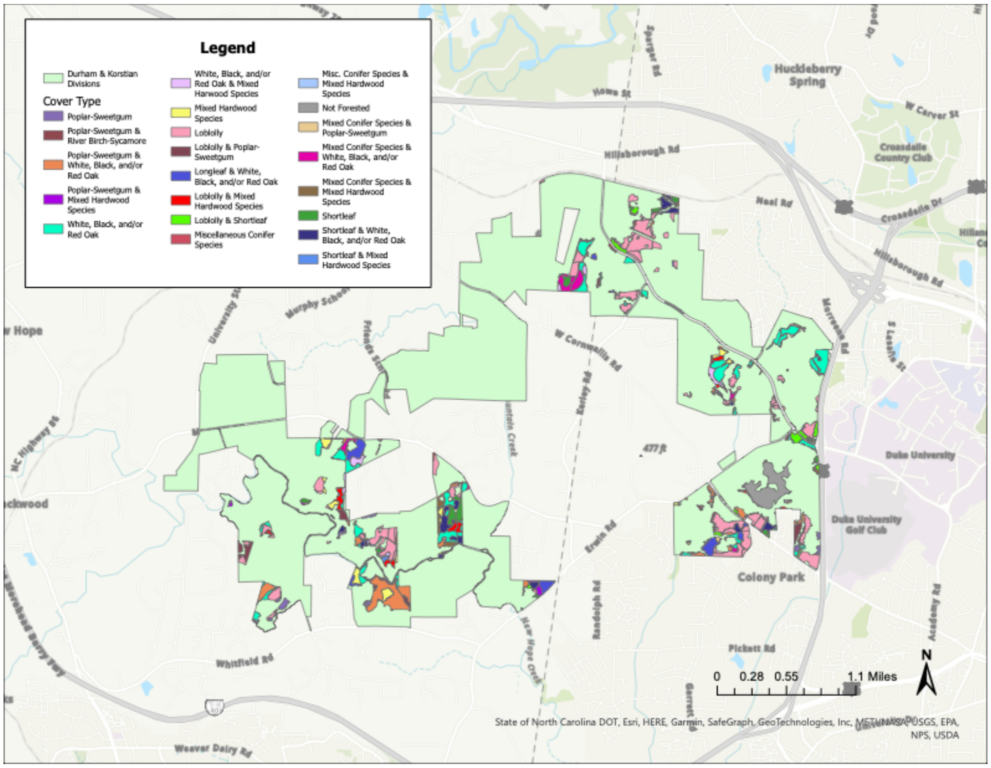


Figure 2: Map of Duke Forest divisions in 2022 (Source: https://dukeforest.duke.edu/recreation/maps/)

Remnant shortleaf pine habitat exists today in Duke Forest (S. Childs, personal communication, 2021). Although shortleaf pine acreage in the forest is unknown prior to 1931, the stands were assessed when Duke Forest was established in 1931. That year, it evaluated its forest stands and reported 1,760 acres of shortleaf pine growing in its Durham and Korstian divisions, where shortleaf pine was either the dominant or co-dominant species in the stand (figure 3). These divisions covered much of the full extent of Duke Forest land at the time. My Master's Project focuses solely on the Durham and Korstian divisions, as those are the divisions for which we have historic spatial data for shortleaf. (Note: The division boundaries have changed over time; the 1,760 acres in 1931 was calculated for the Durham and Korstian divisions based on the current boundary lines. This allowed for a direct comparison of shortleaf acreage change between 1931 and 2019.)

As of 2019, only 96.9 acres of the original 1931 shortleaf pine stands remain in the Durham and Korstian divisions (again, for stands where shortleaf was the dominant or co-dominant species) (figure 4). Within the two divisions, there is a total of 162.5 acres of shortleaf dominant or co-dominant stands because some new areas of shortleaf have grown since 1931. However, the total acreage of shortleaf pines in these divisions is still far below the 1931 level. It is important to note that in the Piedmont region, shortleaf pine often grows in a scattered manner within habitats like oak-hickory forests and may not be a dominant part of a stand—thus, both the 1931 and 2019 stand assessments may not reflect the full numbers of shortleaf pine on Duke Forest lands. Still, it is evident that shortleaf pine has severely declined in this area of Duke Forest as well as across its native range in the eastern U.S. (Anderson, 2016).



State of North Carolina DOT, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA

Figure 3: Map of where the historic (1931) Duke Forest shortleaf pine parcels occurred, with their current cover type (as of 2019). Coverage of shortleaf in 1931 was 1,760 acres in the Durham and Korstian divisions.

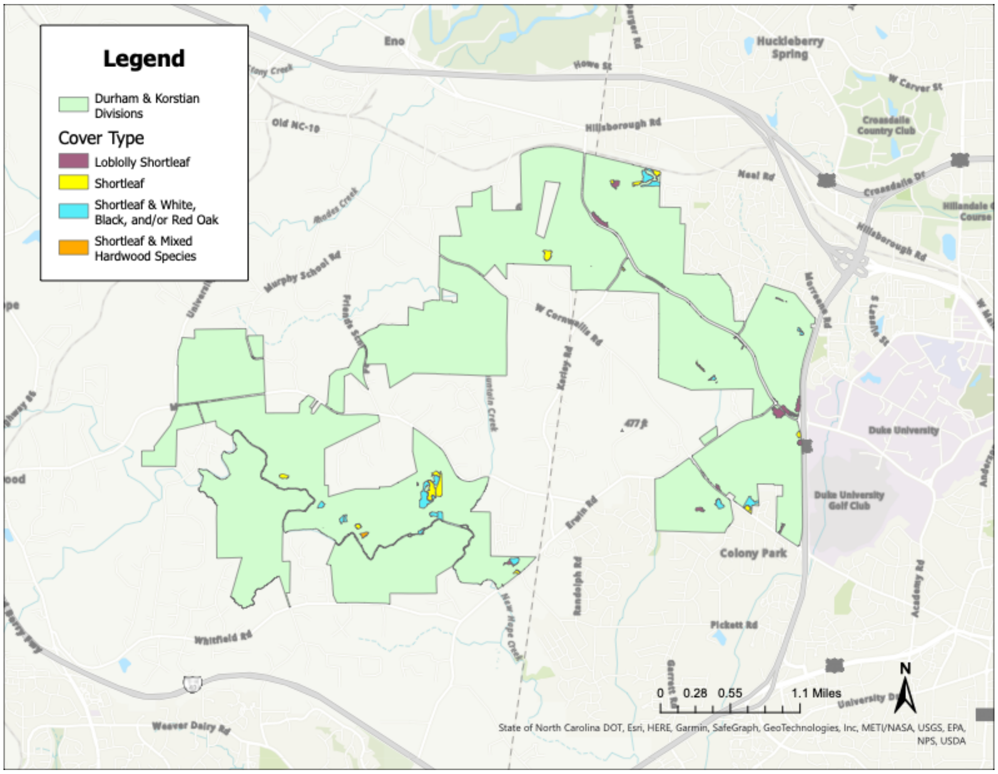


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Figure 4: Map of parcels where shortleaf pine was present in both 1931 and 2019 (shortleaf parcels that have persisted over time) in the Durham and Korstian divisions. Coverage of shortleaf is currently 96.6 acres in the two divisions.

II. Methods

a. Approach

This project's approach to site prioritization had two components: 1) expert opinion and 2) habitat suitability modeling using a classification and regression tree, or CART model (described in the Analysis section below). Expert interviews and research were conducted to select key physical site attributes for the analysis. Key site attributes were then developed for the Durham and Korstian divisions in Duke Forest in GIS. Subsequent spatial analyses in GIS and habitat suitability modeling in R were performed to see whether the expert recommendations held true for Duke Forest land. In addition, the GIS analysis and habitat suitability modeling resulted in predictions about suitable sites for shortleaf restoration. The predictions were based on comparisons of physical site characteristics for historic and sustained shortleaf pine populations versus habitat characteristics overall in the Durham and Korstian divisions. The model results were then used to develop maps of candidate parcels for shortleaf restoration. The sections below describe this project's materials and methods.

Meetings with Duke Forest Client

Meetings were held with the Director of Duke Forest (Sara Childs) and the Forest Supervisor (Tom Craven) beginning in the summer of 2021 through fall 2022. Meetings helped determine the goals and needs of Duke Forest for a potential shortleaf pine restoration project. Childs and Craven also provided forest knowledge and technical input and advice to help define the scope of the project and support GIS data analysis. Meetings were sometimes held on a regular basis, and other times as needed.

Expert Interviews

Expert interviews were conducted to gain general knowledge of shortleaf pine ecosystems, their restoration, and input on this Master's Project and its approach. Researchers and practitioners provided local expertise about shortleaf pine in the Piedmont, how they differ from shortleaf pine ecosystems in other areas (such as Arkansas), and what appropriate restoration might look like. Multiple phone interviews and email interviews were conducted with the following experts:

- David Schnake, Natural Climate Solutions Forester at The Nature Conservancy
- Mike Schafele, terrestrial ecologist at the North Carolina Department of Natural & Cultural Resources
- Lesley Starke, Plant Conservation Program Manager at the North Carolina Department of Agriculture and Consumer Services
- Johnny Randall, Director of Conservation Programs at the North Carolina Botanical Garden

In addition, a site visit was done with David Schnake at the Picture Creek Diabase Barrens in Butner, NC to view the shortleaf pine restoration project undertaken by the State of

North Carolina, as well as to identify a potential shortleaf reference site for Duke Forest. A second site visit was done with Johnny Randall on the North Carolina Botanical Gardens lands to see another potential reference site for shortleaf and view the Botanical Garden's forest restoration work. Extensive interviews regarding shortleaf ecology and restoration were conducted during both site visits.

Determination of Site Selection Criteria

Based on expert interviews, client discussions, advisor recommendations, and research, I selected several physical site attributes to form the basis of site prioritization in Duke Forest. These attributes were aspect, relative slope position, slope, slope configuration, topographic relative moisture index (TRMI), and two types of soils data, available water capacity and forest productivity (tree site index). Together, these attributes help determine important site characteristics of a given parcel of land. See Table 1 below for definitions of these variables.

b. *Data*

Due to the client's preference, it was decided to analyze only Duke Forest land where shortleaf pine previously grew in 1931 (the earliest year for which Duke Forest has forest stand data). The client's reasoning was that if this is where shortleaf pine grew previously, then it may be a site where it can succeed today. It's also a common practice in ecological restoration to restore a species where it grew historically. As a result, the analysis was restricted to land within the Durham and Korstian divisions of Duke Forest and site selection was further limited to where shortleaf pine grew within these two divisions in 1931. The following explanations describe how data was collected and created for the key physical site attributes listed above.

Initial Data Collection

Elevation data (digital elevation models, or DEMs) for Durham and Orange counties were downloaded from North Carolina's Spatial Data Download (NC Floodplain Mapping Program, n.d.). For this analysis, DEMs with a spatial resolution of 20 feet were used for both counties. This data was the foundation for creating datasets of the following site characteristics: aspect, relative slope position, slope, slope configuration, and topographic relative moisture index.

Soil data was obtained from the Web Soil Survey (U.S.D.A Natural Resources Conservation Service, n.d.). Spatial data for an "area of interest" that encompassed the Duke Forest Durham and Korstian divisions was selected and downloaded, along with data for two soil site characteristics of the area: available water capacity and forest productivity (tree side index) for shortleaf pine.

Spatial data for Duke Forest parcels came from the Duke Forest server. For this analysis, forest parcel spatial data in the Durham and Korstian divisions were used.

Table 1: Key physical site attributes variables used in the site prioritization analysis

Variable Name	Definition	Units	Resolution	Data Source
Aspect	The orientation or direction that a topographic slope faces (north-south, east-west)	Degrees*	20 feet	North Carolina spatial data download (DEMs)
Relative Slope Position	The relative position of a site along a slope (i.e. valley bottom, lower slope, middle slope, upper slope, ridge)	Unitless (percentage)	20 feet	North Carolina spatial data download (DEMs)
Slope	The steepness of a slope (angular degrees of rise over run)	Degrees	20 feet	North Carolina spatial data download (DEMs)
Slope Configuration	The shape of a slope (concave, concave/straight, straight, convex/straight, or convex)	Unitless (categorical)	20 feet	North Carolina spatial data download (DEMs)
Topographic Relative Moisture Index (Parker, 1982)	The potential moisture level of a site	Unitless (accumulative range 0-60)	20 feet	North Carolina spatial data download (DEMs)
Available Water Capacity (Soil Data)	The amount of water soil can store for use by plants	Centimeters per centimeters	0.4 meters	Web Soil Survey
Forest Productivity – Tree Site Index (Soil Data)	The mean height that dominant and codominant trees of a species grow in a certain number of years	Feet	0.4 meters	Web Soil Survey

*Aspect was transformed for the analysis, calculated as: -1.0 *cos(aspect*pi/180 – 45*pi/180). The resulting values ranged from -1 (northeast-facing slopes) to 1 (southwest-facing). The transformation is used as a proxy for radiation loading (after Beers et al 1966). .

c. *Analysis*

Data Preparation in GIS

Cover type spatial data for 1931 and 2019 from the Duke Forest server was pulled into GIS, along with Duke Forest boundary data, soils spatial data, and the DEMs. A mask was created from the Durham and Korstian Duke Forest boundary data for later use. Cover type spatial data for the Durham and Korstian divisions in 1931 was merged and then parcels that contained shortleaf (categorized as “S” and “PHB” in the spatial data) were selected and used to create a new spatial layer for analysis. The 2019 Duke Forest cover type data was then clipped using the new S/PHB 1931 spatial layer as a mask. This allowed for analysis of what currently grows on parcels that held shortleaf pine in 1931. Within the clipped 2019 cover type data, shortleaf pine parcels were then selected and used to create another new spatial layer. This layer represents parcels where shortleaf pine both grew in 1931 *and* where shortleaf still grows today in Duke Forest, as of 2019.

Soils data—available water capacity and forest productivity—were joined to a spatial map for the study area. This soils spatial data was then turned into a raster so that it could be sampled.

TRMI Analysis: The DEMs for Durham and Orange counties were merged into one spatial data layer. A topographic relative moisture index (TRMI) was then developed within GIS based on the DEMs. A TRMI is an index that combines several site variables—relative slope position, slope steepness, aspect, and slope configuration—to create a single value for a given point within a site (Parker, 1982). The range of values is between 0-60, and they represent the potential moisture level of any point within the site. Low values (those closer to zero) represent potentially xeric, or dry, sites while high values (those closer to 60) represent mesic, or moist, sites. The development of the TRMI also created site-wide data for the other critical site variables needed for this site prioritization: relative slope position, slope, slope configuration, and aspect.

Zonal Statistics Analysis: Zonal statistics were calculated on a parcel level for each of the site variables (TRMI, relative slope position, slope, slope configuration, aspect, forest productivity, and available water capacity). The zonal mean was used for all the variables, except for the categorical variable slope configuration, which was calculated using the median. This was performed for parcels that were shortleaf pine in both 1931 and 2019 (named "Is Pine"), as well as for all parcels that were shortleaf in 1931 but are various cover types today (named "Was Pine"). Statistics for all the variables in each parcel were assembled as data tables in Excel for subsequent analysis.

Random Points Generation and Sampling: A thousand random points were generated within the Durham and Korstian divisions with a 100-meter exclusion distance. All the site variables (slope, TRMI, etc.) were then sampled at each of the 1,000 randomly generated points. Results were assembled as a data table in Excel for further analysis. Random sampling was performed to develop a habitat suitability model, so that sites with shortleaf pine could be compared to these random sites, i.e. sites where shortleaf pine might occur if it grew randomly on the landscape.

Resulting datasets**:** The GIS analysis resulted in the following datasets, which were then used for statistical analysis:
"Is Pine": Parcels in the Durham and Korstian divisions where shortleaf pine grew in both 1931 and 2019
"Was Pine": Parcels in the Durham and Korstian divisions where shortleaf pine grew in 1931, but where various tree species grow today (includes shortleaf and non-shortleaf species)

"Random": The 1,000 random points generated within the Durham and Korstian forest parcels

All geospatial analyses were conducted in ArcGIS Pro version 3.0.1 (ESRI, Redlands, CA).

Exploratory Data Analysis

An initial exploratory analysis was performed in R (R Core Team 2022). The exploratory analysis produced boxplots and analyses of variance (ANOVA) for each of the key physical attribute variables (table 1), using comparisons among the three datasets created. The comparisons encompassed:

1. "Is Pine" vs. "Was Pine"
2. "Is Pine" vs. "Random"
3. "Was Pine" vs. "Random"

Habitat Suitability Modeling

A classification and regression tree (CART) model was used to determine suitable habitat for shortleaf pine restoration. A CART model is a nonparametric, tree-based model and thus does not make assumptions about underlying distributions of the data. It is predictive statistical approach that uses tree-based splitting rules to define group differences—in this case, differences between the "Is Pine," "Was Pine," and "Random" datasets (De'Ath & Fabricius, 2000). Comparisons were the same three as listed above in the Exploratory Data Analysis section. This type of model was chosen because it was consistent with the way my experts talked about shortleaf pine habitat. Model trees and confusion matrices were generated using the R package RPART and recorded for each of the comparisons (Therneau & Atkinson, 2022). Confusion matrices were tallied to summarize model classification successes versus misclassifications (Table 2).

Table 2: Confusion matrix example

	Data (+)	Data (-)
Model (+) predictions	True positive	False positive
Model (-) predictions	False negative	True negative

Final Site Prioritization in GIS

Results from the CART models were translated into GIS format. This allowed the creation of maps showing where potentially suitable habitat for shortleaf pine restoration exists.

Shortleaf pine parcels that existed in both 1931 and 2019 were overlaid on the map, as were parcels of new shortleaf pine (i.e. those existing in 2019 but not 1931).

III. Results

a. Exploratory Analysis Findings

The results of the ANOVAs were significant for the following comparisons:

1. Is Pine vs. Random was significantly different for transformed aspect ($p = 0.0014$); pines occurred on sites with a more southerly aspect than random sites. Is Pine vs. Random was also significantly different for slope configuration ($p = 0.0033$); pines occurred on sites that were more convex. All other variables were not significant at $p = 0.05$.

2. Was Pine vs. Random was significantly different for transformed aspect ($p < 0.001$); pines occurred on sites with a more southerly aspect than random sites. Was Pine vs. Random was also significantly different for forest productivity ($p < 0.001$); pines occurred on sites with lower forest productivity than random sites. Was Pine vs. Random was also significantly different for slope configuration ($p < 0.001$); pines occurred on sites that were more convex. All other variables were not significant at $p = 0.05$.

3. Is Pine vs. Was Pine was significantly different for TRMI ($p = 0.0249$); "Is Pine" occurred on sites with a lower TRMI (i.e. on drier sites) than "Was Pine" did. Is Pine vs. Was Pine was also nearly significantly different for relative slope position ($p = 0.0538$); "Is Pine" occurred on sites with a higher relative slope position than "Was Pine." All other variables were not significant at $p = 0.05$.

b. CART Habitat Suitability Model Findings

The following are the results of the CART models for each of the three comparisons listed below. Site types described below correspond to individual branches/terminal nodes in the CART model tree.

1. Is Pine vs. Random

The sites with the following characteristics are where the model predicts there is suitable habitat for shortleaf pine, using parcels with persistent shortleaf (i.e. shortleaf present in both 1931 and 2019) as compared to random sites.

Site Type 1: Pine occurs on sites with relative slope position from a middle-upper slope downward, southerly aspect, soils with a forest productivity value for shortleaf of ~65.5 feet and higher, convex slope configuration, a TRMI that ranges from relatively dry to wet, and a slope of moderate steepness to extremely high steepness

Site Type 2: Pine occurs on sites with relative slope position from middle-upper slope downward, southerly aspect, soils with a forest productivity value for shortleaf of ~65.5 feet and higher, convex slope configuration, a TRMI that ranges from relatively dry to wet, and a slope of moderate steepness to gentle/no slope

Site Type 3: Pine occurs on sites with relative slope position from middle-upper slope downward, southerly aspect, soils with a forest productivity value for shortleaf of ~65.5 feet and higher, convex slope configuration, a TRMI that ranges from relatively dry to very dry, and extremely steep slopes

Site Type 4: Pine occurs on sites with relative slope position from middle-upper slope downward, southerly aspect, soils with a forest productivity value for shortleaf of ~65.5 feet and higher, convex slope configuration, a TRMI that ranges from relatively dry to very dry, and slopes that range from steep to extremely steep

Site Type 5: Pine occurs on sites with middle-upper relative slope position, aspect that range from mostly southerly to northernly, soils with a forest productivity value for shortleaf that ranges from ~65.5 feet to 67 feet, and a TRMI that ranges from relatively dry to very wet

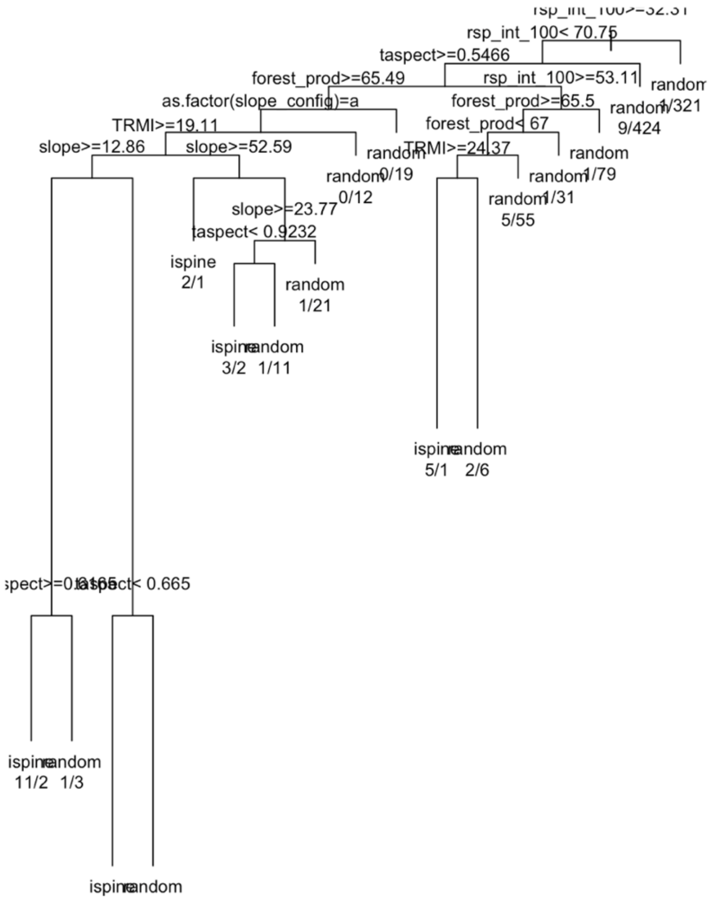


Figure 5: Graphic of CART tree model results for "Is Pine vs. Random." Note: There were technical issues with creating a clear graphic rendering of the tree in R; see author for written results with numbers from model.

The accuracy for the "Is Pine vs. Random" CART model was 97.2%, the sensitivity was 52.1%, and the specificity was 99.4% (table 3). The model's accuracy was very high because nearly all of the random sites were classified correctly; it should be noted that only a little over half of the pine sites were correctly classified.

Table 3: Confusion matrix for "Is Pine vs. Random" comparison in habitat suitability (CART) modeling

	Is Pine	Random
Is Pine	25 (52.1%)	6 (0.6%)
Random	23 (47.9%)	994 (99.4%)

2. Was Pine vs. Random

The sites with the following characteristics are where the model predicts there is suitable habitat for shortleaf pine, using parcels where shortleaf pine historically grew in Duke Forest (but may or may not still be present today), when compared with random sites:

Site Type 1: Pine occurs on sites with relative slope position from middle-lower slope downward, a TRMI that ranges from relatively dry to very dry, and an aspect that ranges from somewhat southerly to northerly

Site Type 2: Pine occurs on sites with relative slope position that ranges from mid-slope to middle-lower slope, a slope configuration that is either convex, convex/straight, or straight, and a TRMI that ranges from dry to very dry

Site Type 3: Pine occurs on sites with relative slope position that ranges from mid-slope to middle-lower slope, a slope configuration that is either convex, convex/straight, or straight, a TRMI that is quite dry, a northerly aspect, and soils with a forest productivity value for shortleaf of ~62.4 feet and higher

Site Type 4: Pine occurs on sites with relative slope position that ranges from mid-slope to middle-upper slope, a slope configuration that is either convex, convex/straight, or straight, a TRMI that ranges from quite dry to wet, a northerly aspect, and soils with a forest productivity value for shortleaf of ~62.4 feet and higher

Site Type 5: Pine occurs on sites with relative slope position that ranges from close to ridge tops down to middle-lower slope, a slope configuration that is either convex, convex/straight, or straight, a TRMI that ranges from quite dry to wet, a northerly aspect, and soils with a forest productivity value for shortleaf less than ~62.4 feet

Site Type 6: Pine occurs on sites with relative slope position that ranges from close to ridge tops down to middle-upper slope, a slope configuration that is either convex, convex/straight, a TRMI that is quite dry, an aspect that ranges from somewhat northerly to southerly, and a slope of moderate to gentle steepness

Site Type 7: Pine occurs on sites with relative slope position that ranges from close to ridge tops down to middle-lower slope, a slope configuration that is either convex, convex/straight, a TRMI that is quite dry, an aspect that ranges from somewhat northerly to southerly, and a slope of moderate steepness to extremely high steepness

Site Type 8: Pine occurs on sites with a middle-lower relative slope position, a slope configuration that is either convex, convex/straight, a TRMI that ranges from dry to wet, an aspect that ranges from somewhat northerly to southerly, and a slope of moderate steepness to extremely high steepness

Site Type 9: Pine occurs on sites with relative slope position that ranges from close to ridge tops down to middle-lower slope, a slope configuration that is either convex,

convex/straight, a TRMI that ranges from dry to wet, and an aspect that ranges from somewhat northerly to southerly

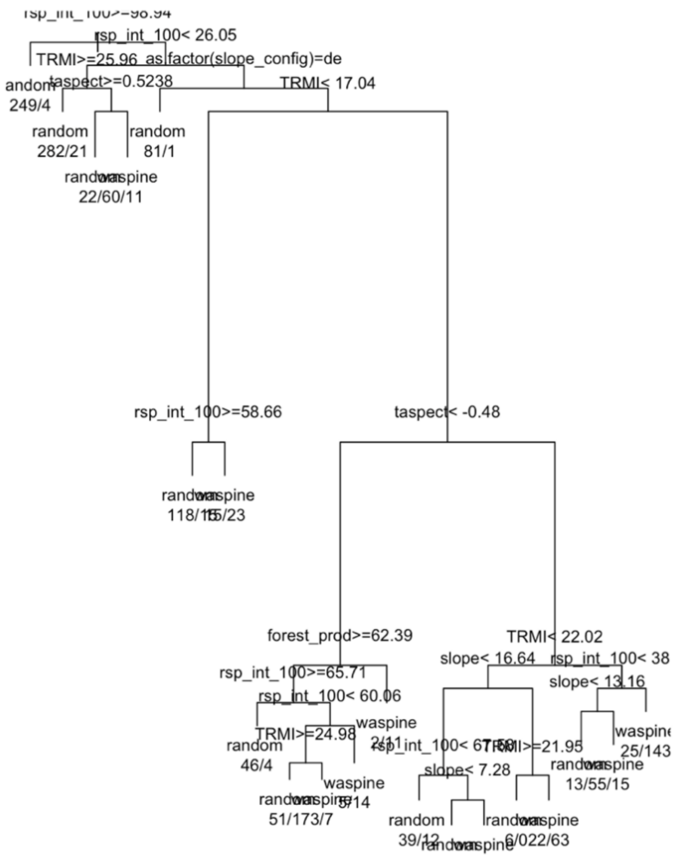


Figure 6: Graphic of CART tree model results for “Was Pine vs. Random.” Note: There were technical issues with creating a clear graphic rendering of the tree in R; see author for written results with numbers from model.

The accuracy for the “Was Pine vs. Random” CART model was 87.7%, the sensitivity was 77.9%, and the specificity was 91.5% (table 4). As with the “Is Pine vs. Random” CART model, the model’s accuracy was very high in large part because almost all the random sites were correctly classified correctly; in this case, however, approximately three quarters of the pine sites were correctly classified.

Table 4: Confusion matrix for “Was Pine vs. Random” comparison in habitat suitability (CART) modeling

	Was Pine	Random
Was Pine	307 (77.9%)	85 (8.5%)
Random	87 (22.1%)	915 (91.5%)

3. Is Pine vs. Was Pine

The sites with the following characteristics are where the model predicts persistent shortleaf pine (i.e. shortleaf present in both 1931 and 2019) should grow in Duke Forest when compared to sites where shortleaf pine historically grew in Duke Forest but may or may not still be present in 2019:

Site Type 1: "Is Pine" occurs on sites with relative slope position from mid-slope downward

Site Type 2: "Is Pine" occurs on sites with relative slope position from mid-slope upwards, a TRMI that ranges from quite dry to extremely dry, and an aspect that ranges from somewhat southerly to northerly

Site Type 3: "Is Pine" occurs on sites with relative slope position from mid-slope upwards, a TRMI that ranges from dry to extremely dry, and on gentle/no slopes

Site Type 4: "Is Pine" occurs on sites with relative slope position from mid-slope to middle-upper slope, a TRMI that ranges from quite dry to dry, and on soils with a forest productivity value for shortleaf that ranges from ~ 69.2 feet to ~70.8 feet

Site Type 5: "Is Pine" occurs on sites with relative slope position from mid-slope to middle-upper slope, a TRMI that ranges from quite dry to dry, on soils with a forest productivity value for shortleaf that ranges from ~ 66 feet to ~69.2 feet, and an aspect that ranges from somewhat northerly to northerly

Site Type 6: "Is Pine" occurs on sites with relative slope position from mid-slope to middle-upper slope, a TRMI that ranges from quite dry to dry, on soils with a forest productivity value for shortleaf that ranges from ~ 66 feet to ~69.2 feet, an aspect that ranges from somewhat southerly to southerly, and on gentle/no slopes

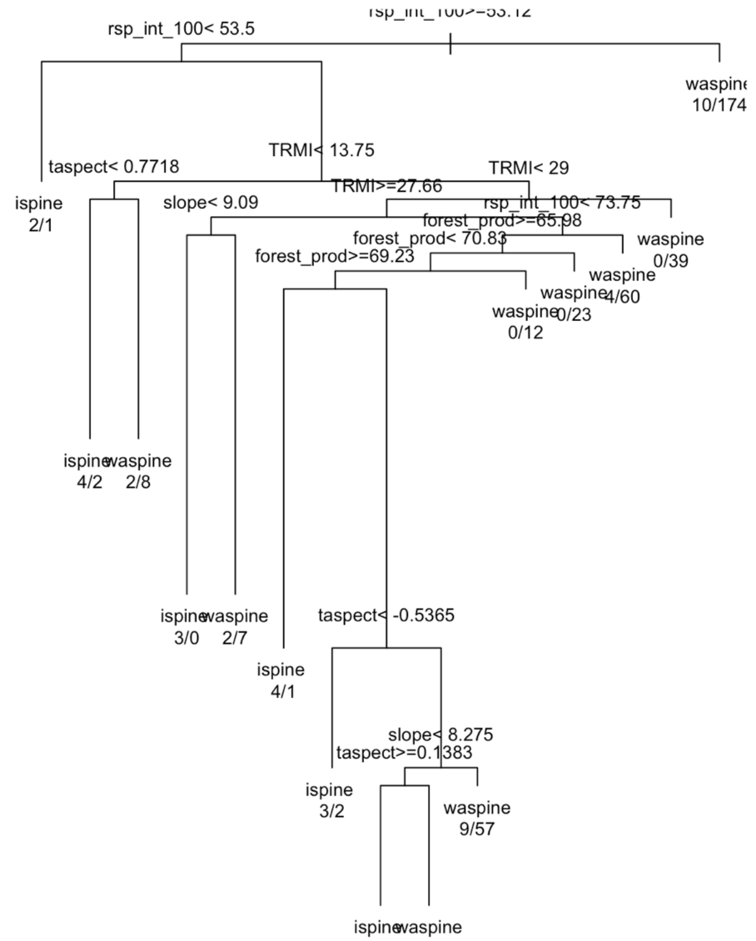


Figure 7: Graphic of CART tree model results for "Is Pine vs. Was Pine." Note: There were technical issues with creating a clear graphic rendering of the tree in R; see author for written results with numbers from model.

The accuracy for the "Is Pine vs. Was Pine" CART model was 91.6%, the sensitivity was 43.8%, and the specificity was 97.5%. (table 5). The model's accuracy was high because nearly all of the "Was Pine" sites were classified correctly, whereas only a little under half of the "Is Pine" sites were correctly classified.

Table 5: Confusion matrix for "Is Pine vs. Was Pine" comparison in habitat suitability (CART) modeling

	Is Pine	Was Pine
Is Pine	21 (43.8%)	10 (2.5%)
Was Pine	27 (56.2%)	384 (97.5%)

For all comparisons, relative slope position appeared to be the most useful variable in determining differences; it was always the first split in the CART model trees**.** Aspect, TRMI, forest productivity, and slope were other variables that showed up in all of the trees, indicating they were also useful in determining differences. Slope configuration was also present in both comparisons with the random dataset.

c. *Final Site Prioritization*

The following maps show the results of each of the habitat suitability model comparisons. The "Is Pine vs. Random" and "Was Pine vs. Random" maps show the site differences between those categories versus randomly selected sites, and represent areas of potentially suitable shortleaf habitat. The "Is Pine vs. Was Pine" comparison and resulting map shows how those two categories of parcels differ in terms of habitat. Persistent shortleaf pine parcels (those present in both 1931 and 2019) were overlaid on all maps.

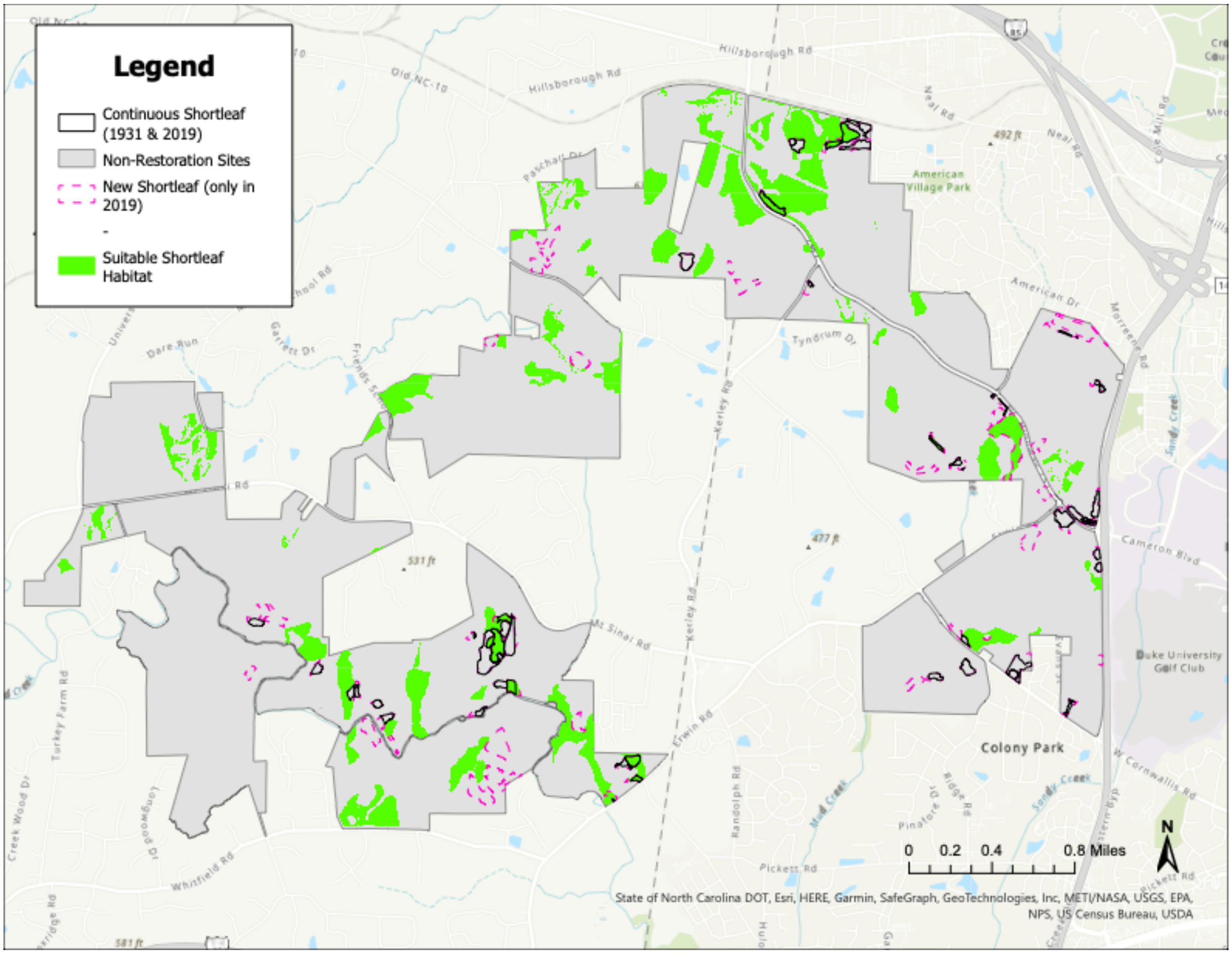


Figure 8: "Is Pine vs. Random" map of habitat suitability model results. Green parcels represent suitable shortleaf pine habitat, as predicted by the model. Parcels in black outlines represent areas that have had persistent shortleaf (present in both 1931 and 2019). Parcels outlined in dashed pink lines represent areas of new shortleaf (present in 2019 but not 1931).

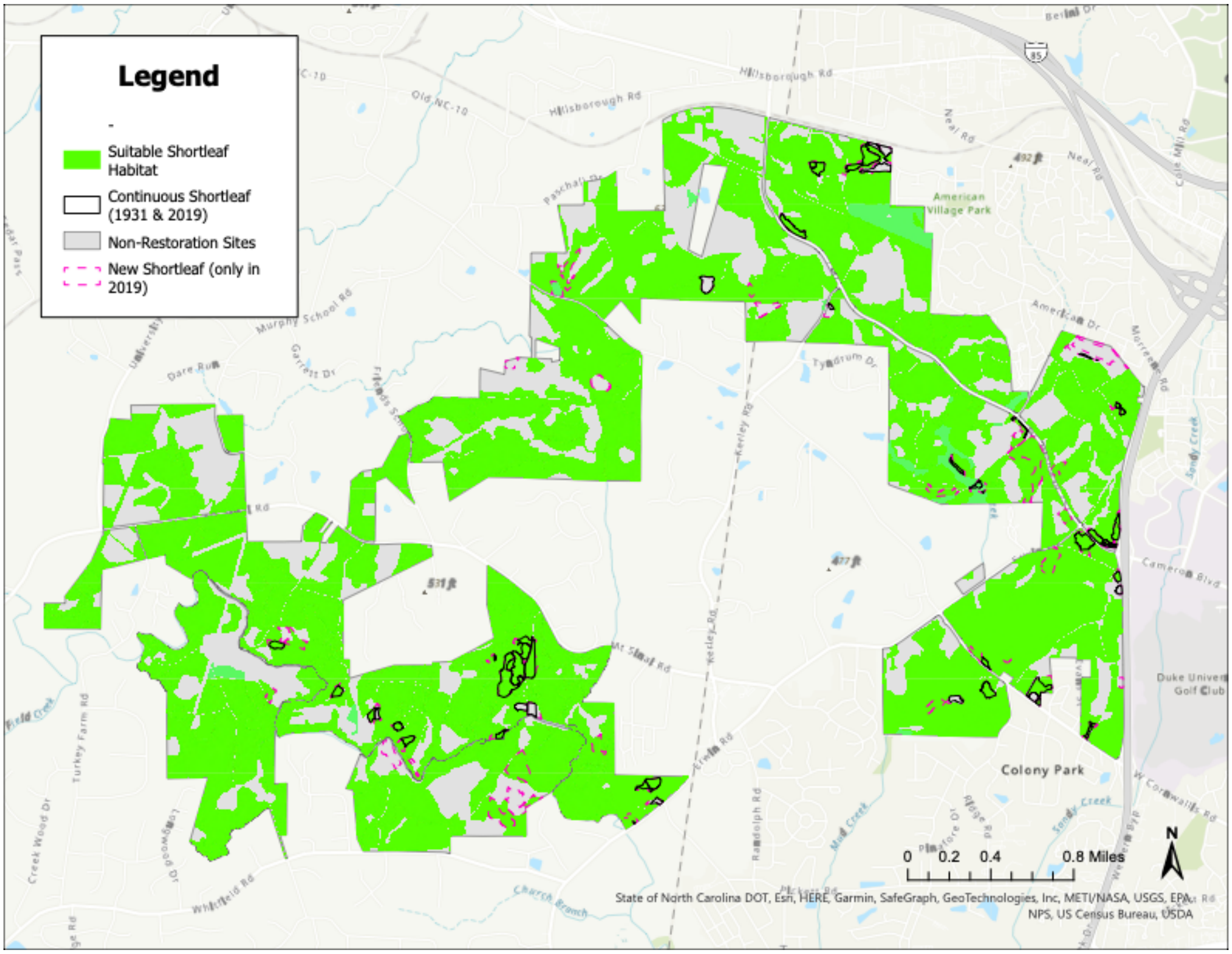
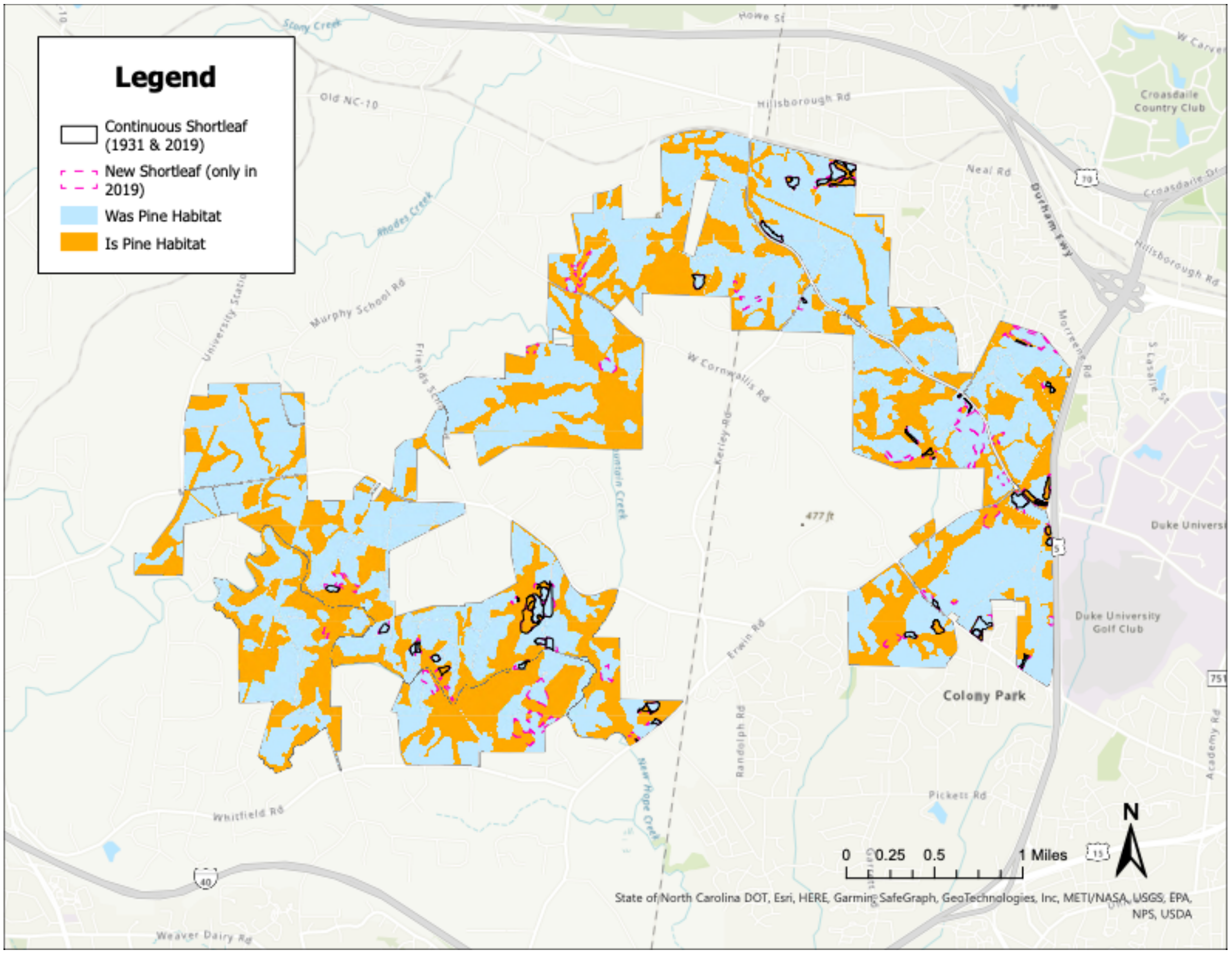


Figure 9: "Was Pine vs. Random" map of habitat suitability model results. Green parcels represent suitable shortleaf pine habitat, as predicted by the model. Parcels in black outlines represent areas that have had persistent shortleaf (present in both 1931 and 2019). Parcels outlined in dashed pink lines represent areas of new shortleaf (present in 2019 but not 1931).



State of North Carolina DOT, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA

Figure 10: “Is Pine vs. Was Pine” map of habitat suitability model results. Blue and orange parcels represent site differences between “Is Pine” (persistent shortleaf) compared to “Was Pine” (areas with shortleaf in 1931 that may or may not have shortleaf today). Parcels in black outlines represent areas that have had persistent shortleaf (present in both 1931 and 2019). Parcels outlined in dashed pink lines represent areas of new shortleaf (present in 2019 but not 1931).

IV. Discussion

The CART model results and resulting maps show that there are meaningful differences between habitat that either had shortleaf pine historically (“Was Pine”) or sites that have had persistent shortleaf pine (“Is Pine”), as compared to randomly selected habitat sites. This would suggest that shortleaf pine habitat does not occur randomly, and thus shortleaf restoration sites should not be chosen randomly either.

“Is Pine vs. Random” and “Was Pine vs. Random” can both be used as guides for selecting candidate sites, as they both represent areas of suitable habitat for shortleaf pine. However, the results of the “Was Pine vs. Random” CART model are much more expansive—the majority of parcels within the Durham and Korstian divisions were assigned as “suitable habitat” for shortleaf pine under this model (figure 9). This is perhaps not surprising, since there was originally a much larger number of parcels for “Was Pine” than “Is Pine” and today, there are many other species growing in these parcels. All of these facts indicate the site conditions for “Was Pine” are likely much broader than desired for restoration site selection. Thus, I recommend Duke Forest uses the “Is Pine vs. Random” map (figure 8) for picking shortleaf restoration sites, as the model results appear much more selective.

The CART model results for sites with suitable shortleaf pine habitat (“Is Pine vs. Random and “Was Pine vs. Random”) are both consistent and inconsistent with what my experts said about ideal shortleaf pine habitat. Experts said that shortleaf pine would have the best chance of restoration success in sites that have south- and west-facing slopes; upper slope positions and ridges; low moisture; and dry, rocky soil. Overall, experts recommended restoring shortleaf pine in low productivity sites so that they wouldn’t be outcompeted by other tree species, such as maple and beech trees (D. Schnake, personal communication, 2022; M. Schafele, personal communication, 2022). In my model results, each of the site types listed above in “Is Pine vs. Random” and “Was Pine vs. Random” included some attribute values that matched what experts recommended, but also included values for other attributes that did not match. For instance, Site Type 5 for “Is Pine vs Random” specifies that pines occurs on sites with middle-upper relative slope position, aspect that ranges from mostly southerly to northernly, soils with a forest productivity value for shortleaf that is a middling value (~65.5 feet to 67 feet), and a TRMI that ranges from relatively dry to very wet. Some of the attribute values in this description agree with experts’ recommendations while others do not, or they have a range of values that only partially agree with expert opinion.

It should be noted that one measure of dryness, available water capacity, did not show up in any of the CART model results; however, another measure of dryness, TRMI, was present in all CART trees. In addition, my analysis included several attributes, such as slope configuration, that were not mentioned by experts at all. At the same time, my analysis did not account for certain site characteristics mentioned by experts, such as western vs. eastern aspect (my aspect variable only accounted for northerly and southerly exposures).

Lastly, the model results for “Is Pine vs. Was Pine” reveal that these categories are meaningfully different, and also show how they differ. This outcome is consistent with what several of the experts I spoke with said (D. Schnake, personal communication, 2022; M. Schafele, personal communication, 2022). They noted that in North Carolina, there was widespread abandonment of agricultural fields in the 19th century and early 20th century. In many instances, shortleaf pine was a common and early successful invader of these abandoned fields, which led to many stands of shortleaf pine where they might not otherwise naturally occur (Christensen, 1989). Experts cautioned, then, that the Duke Forest 1931 data may not be the best representation of sites suitable for shortleaf pine. This is another reason that the “Is Pine vs. Random” comparison is likely better suited for restoration site selection, as it represents areas where shortleaf pine has persisted over time; it is not just a snapshot of the forest as it stood in 1931 when human abandonment of agricultural fields may have heavily influenced the presence of shortleaf pine in Duke Forest.

Assumptions and Limitations

This “old field abandonment” phenomenon is also a potential limitation of this project and its findings. Restoration efforts often aim to restore ecosystems to their previous state, but if the modeling is based on historic data for a system that’s heavily influenced by humans, then using it as a reference may be problematic. In this case, if the site prioritization is based on where shortleaf pine occurred historically in Duke Forest, then agricultural field abandonment may represent historic data that doesn’t show natural trends, but rather a large increase in shortleaf pine due to human actions. Moreover, there is an ongoing debate in the restoration ecology field over what is the right historic period to use as a frame of reference when restoring a species or ecosystem—what, exactly, a natural system should be restored to, or if it even makes sense to do this at all (Higgs et al., 2014). Lastly, this project also assumes that the key physical site attributes (aspect, slope, etc.) have not changed between 1931 and today. However, there is a chance that some physical traits within the divisions have shifted, such as locations where soils have eroded or construction has occurred. These potential changes are not accounted for in this analysis.

Next Steps

These maps present Duke Forest staff with a list of candidate parcels for restoration. As mentioned in the section above, I recommend using the sites highlighted in the “Is Pine vs. Random” map (figure 8). These maps can be accessed in GIS files and parcels with their identifying information can be found in the attribute tables. From there, Duke Forest will need to assess the list of candidates; they will then narrow the list based on other important considerations, such as road access and proximity to boundaries. Proximity to boundaries may be a particularly important issue, since prescribed burning is a critical part of shortleaf pine restoration. Restoration sites will likely need to occur a certain distance from boundaries to ensure they don’t impact schools, hospitals, and other important sites. Duke Forest staff will also need to decide the scale of restoration—i.e. how many acres of shortleaf pine habitat they want to restore.

Once Duke Forest staff have narrowed the list of candidate restoration sites, I recommend they conduct site visits to assess and ground truth this project’s findings. The sites were selected based on mean parcel values of the key physical site attributes, so there will undoubtedly be variation in these physical attributes within parcels. Duke Forest staff can use either the CART model results or the expert recommendations, or a combination of the two, when demarcating exact restoration sites within parcels. Alternatively, it is possible to create within-parcel predictions of suitable habitat based on the CART model results; these predictions select land on a pixel level in GIS, rather than on a parcel level. One of these was developed in GIS based on the “Is Pine vs. Random” model results, though it is not included in this report. These within-parcel predictions can be used to identify specific areas inside parcels that seem particularly suitable for restoration. It may also be helpful to set up one or multiple initial experimental shortleaf restoration site(s), in order to measure if site selection was successful and to test out different shortleaf restoration techniques. Once restoration sites are selected, Duke Forest staff can pursue next steps of restoration process: setting goals and objectives, establishing a reference model and performing a pre-treatment baseline inventory of the restoration site, creating a restoration plan, project implementation, monitoring, and maintenance (Holl, 2020).

V. Conclusion

This site prioritization identifies suitable habitat for shortleaf pine restoration in Duke Forest based on physical site attributes of the forest landscape as well as historic data on shortleaf. This prioritization provides Duke Forest staff with a list of candidate parcels where they can restore, and helps lay the groundwork for a successful shortleaf pine restoration project in the forest.

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