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# A Species Distribution Modeling Informed Conservation Assessment of Bog Spicebush

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September 2016

Source of cover illustrations: U.S. Department of Agriculture (USDA) Forest Service, http://www.fs.fed.us/wildflowers/plant-of-the-week/lindera_subcoriacea.shtml

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Final Report



Prepared for Headquarters, U.S. Army Corps of Engineers
Washington, DC 20314-1000

Under Work Unit C6JB27

# Abstract

Bog Spicebush (*Lindera subcoriacea*) is a U.S. Department of Defense (DoD) Species at Risk (SAR) that has recently been proposed for listing under the Endangered Species Act. Roughly 60% of all known Bog Spicebush populations are found on five DoD installations: Fort Bragg, Camp Mackall, Fort Jackson, Eglin Air Force Base (AFB) and Camp Shelby Joint Forces Training Center (JFTC). This recently described species has been reported to occupy a variety of plant communities that have varying disturbance dependence, suggesting the habitat suitability of occupied sites is spatially and temporally dynamic. Additional information about Bog Spicebush habitat requirements and potential distribution is needed to inform assessments of the species' conservation status and management needs. This project used MaxEnt, a widely applied species distribution modeling approach to generate a range-wide habitat suitability map. This map was also used to identify: (1) sites warranting targeted surveys for novel populations, (2) suitable habitat for conservation and management, and (3) sites suitable for population (re)introduction.

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# Preface

This study was conducted for Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology, ASA(ALT) under Program Element 332112, Work Unit C6JB27, U.S. Department of Defense (DoD) Legacy Program, "14-760 Averting the Impacts of Recent U.S. Endangered Species Act (ESA) Listing Petition for Bog Spicebush with Species Distribution Modeling." The technical monitor was Alison A. Dalsimer, DoD Deputy Director, Natural Resources Program.

This work was conducted by the Ecological Processes Branch (CNN), Installations Division (CN), Construction Engineering Research Laboratory (CERL), Engineer Research and Development Center (ERDC). The CERL principal investigator was Matthew G. Hohmann. Dr. Chris Rewerts was Chief, CEERD-CNN, and Michelle J. Hanson was Chief, CEERD-CN. The associated Technical Director was Alan Anderson, CEERD-ZT. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. COL Bryan S. Green was Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

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# 1 Introduction

## 1.1 Background

Land management agencies increasingly recognize the utility of species distribution modeling (SDM) for rare plant conservation planning and management (e.g., Elith and Burgman 2002, Williams et al. 2009, Gogol-Prokurat 2011). Knowledge about species' habitat requirements and the spatial distribution of available habitat are critical for designing and implementing many conservation actions, but oftentimes this knowledge is incomplete for rare plants. Species distribution modeling can provide insights about habitat requirements and availability, which in turn can be used to:

1. Guide targeted surveys that enhance discovery of previously unknown populations
2. Prioritize land management and acquisition initiatives to better support species conservation and recovery
3. Foster additional opportunities for sharing conservation responsibilities among Federal, state, and Nongovernmental Organization (NGO) land management partners
4. Confidently select sites suitable for population (re)introductions.

Bog Spicebush (*Lindera subcoriacea*) is a rare, dioecious, avian dispersed, woody shrub of southeastern wetlands. The species was only identified and described in 1983, based on leaf morphology and odor; previously it had been included under the more widespread Northern Spicebush (*Lindera benzoin*) (Wofford 1983). The known range of Bog Spicebush spans seven southeastern states, with a large number of populations occurring only in North Carolina and Mississippi. It is reported to occupy habitats having varying disturbance dependence, namely Atlantic white cedar forests, coastal plain small stream swamps, streamhead pocosins, and sandhill seeps in North and South Carolina (Sorrie, Gray, and Crutchfield 2006; Wall et al. 2013), and the wettest portions of sphagnous bogs in Mississippi and Florida (Gordon, Jones, and Wiseman 1986).

Published studies for Northern Spicebush (Cipollini, Wallace-Senft, and Whigham 1994; McEuen and Curran 2006) and preliminary demographic work (Wall and Hohmann, unpublished data 2016) suggest that Bog Spicebush populations are likely dynamic, with metapopulation processes affecting recruitment into sites that vary in suitability over time and space. Although Bog Spicebush has roughly the same state and global conservation ranks as the Federally endangered Pondberry (*L. melissifolia*) (NatureServe 2013), comparatively limited information is available in the published literature regarding the species' biology, population dynamics, habitat requirements, or distribution.

Bog Spicebush was included in a recent court settlement that mandates the U.S. Fish and Wildlife Service (USFWS) to make a determination of listing under the Endangered Species Act (ESA). In addition, it is identified by the U.S. Department of Defense (DoD) as a Species at Risk (SAR) (NatureServe 2011, 2014). The majority (~60%) of all known Bog Spicebush populations occur on five DoD installations, with roughly 47% and 10% on Fort Bragg/Camp Mackall (NC) and Camp Shelby JFTC (MS), respectively. The species is also found on Fort Jackson (SC) and Eglin Air Force Base (AFB) (FL). Unfortunately, long-term prospects for Bog Spicebush are not optimistic without concerted management intervention. It is projected that the number of populations in North Carolina, which were recently estimated to have suffered a 28% decline over the last 30 years, will undergo additional declines given that many of the small populations (20% had ≤2 individuals) are at risk of extirpation (Wall et al. 2013).

The rarity, small size, and declining number of Bog Spicebush populations, as well as limited information about the species' ecology, indicate species distribution modeling would be invaluable for informing the listing decision, conservation planning, and proactive management.

## 1.2 Objectives

The objectives of this effort were to:

1. Model the potential distribution of the species
2. Provide land managers with a three-part strategy for Bog Spicebush conservation by:
    a. identifying sites warranting additional survey effort
    b. prioritizing sites for protection/management
    c. identifying sites suitable for potential (re)introduction efforts.

## 1.3 Approach

The objectives of this work were accomplished in three primary tasks: (1) data acquisition and preparation, (2) model development, and (3) conservation assessments, based on model outputs.

Secondary tasks associated with model development included: (1) generating training and testing datasets, (2) defining the spatial extent, spatial thinning distance and number of pseudoabsences, (3) reducing the number of environmental predictors and assessing overfitting, and (4) running the finalized model.

## 1.4 Scope

This effort modeled *Lindera subcoriacea* habitat suitability across seven southeastern states using occurrence data and a diverse suite of environmental predictors, including: climate, topography, fire regime, vegetation, and soils. Conservation assessments based on the model output emphasized not only DoD installations known to support populations of *L. subcoriacea*, but also the myriad public and private land managers that might serve as potential conservation partners.

# 2 Methods

## 2.1 Model Development

### 2.1.1 Species occurrence data

Species occurrence data were acquired as point and polygon files from the Natural Heritage Programs of six of the seven states where *L. subcoriacea* is known to occur. Unfortunately, Louisiana was unable to release the location of the single population within its boundaries due to a limited disclosure agreement with the property owner. Collectively, 126 extant *L. subcoriacea* populations were available for potential use in model development. These occurrence data generally have a high level of quality control, and in many cases there are herbarium records associated with the populations.

### 2.1.2 Environmental data

For each 900 $m^2$ grid cell in the study extent, values for 52 initial environmental predictors representing climate, soils, vegetation, topography, and fire regime were calculated. Climate data were obtained from WorldClim version 1.4 (Hijmans et al. 2005). This dataset includes 19 bioclimatic indicators that represent a range of temperature and precipitation summaries (e.g. trends, seasonality, and extremes) at a 1 km resolution (appendix A). These data were resampled using a simple cell assignment to match the 30 m resolution of the other environmental variables. Sixteen initial soil variables were included from the gSSURGO (2014) soil database (Appendix A), a rasterized version of SSURGO (USDA 2015). Additional vegetation, topographic, and fire regime variables were obtained from LANDFIRE* version 1.3 (USDOI 2013).

### 2.1.3 MaxEnt model building

The maximum entropy method was used as implemented in MaxEnt (Phillips, Anderson, and Schapire 2006) to construct predictive models of *L. subcoriacea* relative probabilities of presence (interpreted as habitat suitability) across the southeastern United States. Maximum entropy is a machine learning approach to constructing predictive models that attempts to maximize the entropy, or uncertainty, of the probability distribution estimated from the data. The maximum entropy method has numerous advantages, not the least of which is that it allows the modeling of presence-only data. At

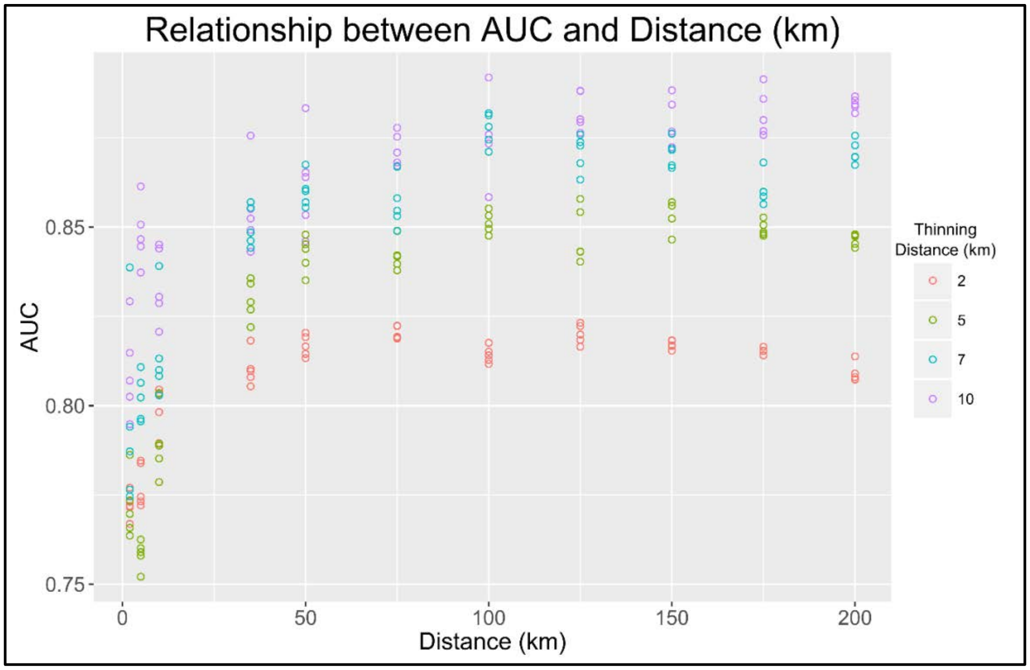
* Landscape Fire and Resource Management Planning Tools (LANDFIRE)

the present time, maximum entropy is the most popular method for SDM and performs well relative to other techniques (Elith et al. 2006).

Because no independent testing datasets were available, 5-fold cross validation was used to partition the dataset into training and testing groups using ENMeval version 0.21 (Muscarella et al. 2014) within R (R Core Team 2013). The area under the curve (AUC) of a receiver operating curve (ROC) was used as a threshold-independent metric for assessing model performance. AUC values range from 0-1, and represent the probability that the model ranks a random presence location higher than a random background site (Phillips, Anderson, and Schapire 2006; Phillips and Dudík 2008). Overall, the AUC metric provides an assessment of how accurately the model predicts the probability of occurrence for a species within a given area. Models with AUC values greater than 0.75 may be useful for identifying the potential distribution of a species (Swets 1988, Elith et al. 2006).

Potential sampling bias (Araújo and Guisan 2006, Wintle and Bardos 2006, Veloz 2009, Hijmans 2012, Syfert, Smith, and Coomes 2013), number of pseudoabsences (McPherson, Jetz, and Rogers, 2004; Mateo et al. 2010, Iturbide et al. 2015), and background extent (VanDerWal et al. 2009, Barbet-Massin et al. 2012) are all known to influence model performance. Thus, the initial modeling of the training data and full set of 52 environmental predictors consisted of assessing the effects of altering the minimum distance between presence observations, pseudoabsences and the sampling extent on the AUC values. Spatially thinned datasets were created with presence and randomly-placed pseudoabsence points thinned to 2, 5, 7, and 10 km from the nearest neighbor using the R package spThin (Aiello-Lammens et al. 2015). The number of pseudoabsences were limited to twice as many as the presence points. The effect of background extent on AUC at different distances ranging from 2 to 200 km from presences was assessed. The background extent of pseudoabsence point selection was determined by observing the distance at which increases in AUC were minimal (VanDerWal et al. 2009, Iturbide et al. 2015). This process identified an optimal thinning distance of 10 km and a background extent encompassing the area representing 100 km from presences (Figure 1). After identifying an appropriate thinning distance, sampling extent, and number of pseudoabsences with the full set of environmental predictors, the full set of environmental predictors was reduced to avoid overfitting. A stepwise process was used in which predictors that had a <1% mean contribution and Pearson's correlation coefficients >|0.9| were excluded, and the correlated predictor with the highest contribution score was retained (Jueterbock et al. 2015). The process was continued until the contribution scores of all predictors were greater than 1% and the mean AUC did not drop below the arbitrary AUC threshold of 0.80. In addition, model overfitting was assessed by examining the difference between training and test data AUC. Warren and Seifert (2011) suggest that overfit models should generally perform well on training data, but poorly on test data. Consequently, when the training and test data AUC exhibit little difference, it is unlikely one's model is over-parameterized such that it is overly specific to the training data.

Figure 1. Evaluation of the influence of potential sampling bias and background extent on model performance.




## 2.2 Model application

### 2.2.1 Areas warranting additional survey effort

Several approaches for identifying locations to target for new population discovery have been proposed, but they invariably rely on identifying some minimum threshold of habitat suitability. One approach is to use an independent dataset to identify thresholds of suitability associated with known occurrences (e.g., Williams et al. 2009, Crall et al. 2013, Wang et al. 2014). However, truly independent datasets of species occurrences are rarely available; even occurrences thinned during model development are not suitable for this intended use. Alternately, threshold values have been identified by examining suitability values of known occurrences used for model development, or based on some arbitrarily proportion (e.g. top decile or quartile) of suitability values (e.g., Williams et al. 2009). Because independent data on *L. subcoriacea* occurrences were not available, the upper quartile (top 25%, >0.73) of suitability values associated with occurrences used for model development to identify a minimum threshold. Although somewhat arbitrary, this threshold value provided a balance between over- and under-estimating potential survey effort, by limiting the area and locations that might be targeted for surveys.

Additionally, this work sought to place emphasis on highly suitable habitat that occurs in areas that have not been subjected to extensive anthropogenic degradation and fragmentation. Therefore, an index of local connectedness was also used as an additional criterion to identify sites warranting survey effort. Local connectedness characterizes whether the connections within natural ecosystems are diminished due to anthropogenic barriers (i.e. land cover conversion) of variable permeability. Specifically, the metric used was one developed by The Nature Conservancy (TNC), which assigns resistance weights to different land cover types based on the degree to which natural processes have likely been modified (Anderson et al. 2016). The weighting scheme assigns low resistance to any adjacent natural cover types (e.g., forest, wetland, grassland), and higher values to human altered cover types (Table 1). Land cover data used to develop the metric were primarily roads data from the 2014 Tiger Road dataset (U.S. Census 2014) and the 2011 U.S. Geological Survey (USGS) National Land Cover Data (NLCD), which represents classified Landsat TM* satellite data for the 48 conterminous United States within 16 classes (Homer et al. 2015). For each cell of the resistance grid, the values of neighboring cells were evaluated out to a distance of 3 km using resistance kernel analysis (Compton et al. 2007). Additional details can be found within Anderson et al. (2016). The raster layer of regionally standardized local connectedness generated by TNC using this analysis had a grid cell size of 90 m, which was resampled to match the 30 m resolution of the habitat suitability map. ArcGIS version 10.3.1 (ESRI, Redlands, CA, USA) was used to identify locations having both high suitability (>0.73) and connectedness (> average) as potential targets for new population discovery.

* Thematic Mapper

Table 1. Land cover classes and resistance weights used to estimate local connectedness.

| Land cover description | Resistance score | Source |
|---|---|---|
| Developed, Open Space | 8 | NLCD 2011 |
| Developed, Low intensity | 8 | NLCD 2011 |
| Developed, Medium Intensity | 9 | NLCD 2011 |
| Developed, High Intensity | 20 | NLCD 2011 |
| Barren Land, non-natural | 9 | NLCD 2011 |
| Barren Land, natural | 1 | NLCD 2011 |
| Deciduous Forest | 1 | NLCD 2011 |
| Evergreen Forest | 1 | NLCD 2011 |
| Mixed Forest | 1 | NLCD 2011 |
| Shrub/Scrub | 1 | NLCD 2011 |
| Herbaceous | 1 | NLCD 2011 |
| Hay/Pasture (Coastal Plain & Piedmont) | 3 | NLCD 2011 |
| Hay/Pasture (Mountains) | 5 | NLCD 2011 |
| Cultivated Crops | 7 | NLCD 2011 |
| Woody Wetlands | 1 | NLCD 2011 |
| Emergent Herbaceous Wetlands | 1 | NLCD 2011 |
| Open Water, Shoreline Distance <200 m | 1 | NLCD 2011 |
| Open Water, Shoreline Distance 200-400m | 3 | NLCD 2011 |
| Open Water, Shoreline Distance >400 meters | 5 | NLCD 2011 |
| Major Roads | 20 | Tiger 2014 (U.S.) & Open Street Map 2014 (CA) |
| Minor Roads | 10 | Tiger 2014 (U.S.) & Open Street Map 2014 (CA) |
| Dirt Roads | Resistance +1 | Open Street Map 2014 |
| Transmission Lines | 9 | Ventex 2014 |
| Pipelines | 9 | Ventex 2014 |
| Railroads | 9 | CTS 2015 |
| Unprotected/Private Industrial Forest (U.S.) | 3 | SE GAP, Parcelpoint, OSI* |
| Protected Industrial Forest (U.S.) | 1.5 | SE GAP, Parcelpoint, OSI |
| *Open Systems Interconnection (OSI) | | |

### 2.2.2 Areas for potential conservation and management

Three types of conservation and management efforts were identified as likely to be of interest to public and private entities concerned about conserving known *L. subcoriacea* occurrences. The first two are related to identifying sites for either acquisition or development of conservation agreements, while the third addresses identification of occupied sites potentially needing habitat restoration and/or population monitoring. Occupied sites potentially suitable for acquisition or establishing conservation agreements include those that are of high suitability, unprotected, and having average to high connectedness of natural land cover types. Unoccupied, unprotected sites, having high suitability and average to high connectedness, but near known occurrences (<1 km), can potentially act as conservation buffers and may also be suitable targets for acquisition or establishing conservation agreements. Occupied sites potentially needing habitat restoration and/or population monitoring, are those that are protected as a first priority, having average to high connectedness, but in locations modeled to have moderate to low suitability. ArcGIS was used to identify locations meeting these criteria. Information on land protections was sourced from the USGS, Gap Analysis Program, Protected Areas Database, version 1.4 (http://gapanalysis.usgs.gov/padus/). Data for the other criteria have been described previously.

### 2.2.3 Areas suitable for potential (re)introduction

In addition to managing extant populations, (re)introduction can form an important part of an integrated strategy for rare plant conservation (e.g., Menges and Kennedy 2007, Thorpe and Kaye 2011, Halsey et al 2015). However, lack of knowledge about the suitability of potential sites for (re)introduction can either hinder the willingness of land managers and regulators to adopt the approach, or lower success rates (Godefroid et al. 2011, Drayton and Primack 2012, Questad et al. 2014). Therefore, this work sought to identify sites potentially suitable for (re)introduction to promote the viability of this conservation strategy. Sites potentially suitable for (re)introduction include those that are unoccupied, highly suitable, protected, and having average to high connectedness. ArcGIS was used to identify locations meeting these criteria.

# 3 Results and Discussion

## 3.1 Model performance

The final model provided "good" differentiation between occupied and background locations (Swets 1988); the AUC equaled 0.80. The test of model overfitting also yielded satisfactory results, as the training and testing AUC were comparable ($AUC_{train} = 0.84 \pm 0.01$, $AUC_{test} = 0.80 \pm 0.10$). Twenty environmental predictors representing all five predictor types were retained in the final model after predictor reduction (Appendix A). Among the five types of environmental predictors, vegetation predictors only accounted for four of the final 20, but collectively contributed 42%, while fire regime predictors were the second-most important category, collectively contributing 23% (Table 2). The other three types of environmental predictors (climate, soil, and topography) had lower percent contributions that ranged from 5-15%.

Table 2. Five predictor types, number of predictors retained, and their relative importance in the final *L. subcoriacea* model.

| Predictor type | Number retained | Percent contribution |
|---|---|---|
| Vegetation | 4 | 42.3 |
| Fire regime | 4 | 23.3 |
| Soils | 4 | 14.9 |
| Climate | 5 | 14.0 |
| Topography | 3 | 5.6 |

Considering individual environmental predictors, biophysical settings (BPS) and vegetation condition class (VCC) emerged as the most important. All other predictors contributed <10% in the final model. BPS is a vegetation related predictor while VCC is classified as a fire predictor (Appendix A). BPS was by far the most influential (31.5% contribution), contributing over twice as much as the second most important environmental predictor, VCC. BPS represents the vegetation that may have been dominant on the landscape before European settlement and is based on both the current biophysical environment and an approximation of the historical disturbance regime (USDOI 2013). Locations occupied by *L. subcoriacea* were represented by 14 different BPS categories, but only four categories accounted for >10% of known occurrences (Table 3).

Table 3. Biophysical settings of *L. subcoriacea* populations and their proportional representation.

| Biophysical settings | Percent of *L. subcoriacea* occurrences |
|---|---|
| Atlantic Coastal Plain Fall-line Sandhills Longleaf Pine Woodland | 30.3 |
| East Gulf Coastal Plain Interior Upland Longleaf Pine Woodland | 15.9 |
| Gulf and Atlantic Coastal Plain Small Stream Riparian Systems | 13.6 |
| Atlantic Coastal Plain Streamhead Seepage Swamp-Pocosin-Baygall | 12.1 |
| Atlantic Coastal Plain Dry and Dry-Mesic Oak Forest | 6.8 |
| Atlantic Coastal Plain Mesic Hardwood Forest | 6.8 |
| Southern Coastal Plain Seepage Swamp and Baygall | 3.0 |
| Atlantic Coastal Plain Upland Longleaf Pine Woodland | 2.3 |
| East Gulf Coastal Plain Savanna and Wet Prairie | 2.3 |
| Southern Piedmont Dry Oak(-Pine) Forest | 2.3 |
| Central Atlantic Coastal Plain Wet Longleaf Pine Savanna and Flatwoods | 1.5 |
| Gulf and Atlantic Coastal Plain Swamp Systems | 1.5 |
| Florida Longleaf Pine Sandhill | 0.8 |
| Southern Coastal Plain Mesic Slope Forest | 0.8 |

Additional vegetation-related predictors retained in the final model included environmental site potential (ESP), canopy height (CH), and canopy cover (CC). ESP represents the vegetation that could become established during late or climax stages of successional development at a given site based on the biophysical environment (USDOI 2013). Locations occupied by *L. subcoriacea* represented 12 ESP categories (Table 4), which largely paralleled BPS categories; only the same four categories accounted for >10% of known occurrences. CC and CH at locations occupied by *L. subcoriacea* were highly variable, ranging from 0-100% (median = 60-70%) and 0-50 m (median = 10-25 m), respectively. CC and CH influence light availability (Martens, Breshears, and Meyer 2000), which can affect plant photosynthetic rates, growth, herbivory, water balance, and reproduction. The effects of light availability are well-documented for *L. benzoin* (Niesenbaum 1992, 1993; Luken et al. 1997; Muth et al. 2008), and light availability has also been suggested to affect *L. subcoriacea* plant vigor and reproduction (pers. obs., Tom Patrick). CC and CH not only influence light availability, but also fuels and microclimate, which have been shown to affect fire return interval, behavior and fire-vegetation feedbacks in communities occupied by *L. subcoriacea* (Just, Hohmann, and Hoffmann 2016).

Vegetation-related predictors at locations occupied by *L. subcoriacea* match field-based descriptions of the species' known associations with permanently moist to wet, evergreen shrub-dominated seepage wetlands, namely Atlantic white cedar forests, coastal plain small stream swamps, streamhead pocosins, and sandhill seeps in North and South Carolina (Sorrie, Gray, and Crutchfield 2006, Wall et al. 2013), and the wettest portions of sphagnous bogs in Mississippi and Florida (Gordon, Jones, and Wiseman 1986).

Table 4. Environment site potential categories of *L. sucoriacea* populations and their proportional representation.

| Environment site potential | Percent of *L. subcoriacea* occurrences |
|---|---|
| Atlantic Coastal Plain Fall-line Sandhills Longleaf Pine Woodland | 25.6 |
| East Gulf Coastal Plain Interior Upland Longleaf Pine Woodland | 16.8 |
| Atlantic Coastal Plain Streamhead Seepage Swamp-Pocosin-Baygall | 16.0 |
| Gulf and Atlantic Coastal Plain Small Stream Riparian Systems | 15.2 |
| Atlantic Coastal Plain Dry and Dry-Mesic Oak Forest | 8.8 |
| Atlantic Coastal Plain Mesic Hardwood Forest | 7.2 |
| Southern Coastal Plain Seepage Swamp and Baygall | 3.2 |
| Gulf and Atlantic Coastal Plain Swamp Systems | 2.4 |
| Southern Coastal Plain Mesic Slope Forest | 1.6 |
| Southern Piedmont Mesic Forest | 1.6 |
| Central Atlantic Coastal Plain Wet Longleaf Pine Savanna and Flatwoods | 0.8 |
| Florida Longleaf Pine Sandhill | 0.8 |

The most important fire regime predictor was VCC (12.5% contribution). VCC, which represents a simple categorization of vegetation departure (VDEP), and denotes the degree to which current vegetation differs from historical vegetation reference conditions (USDOI 2013). VDEP at locations occupied by *L. subcoriacea* ranged from 38-81% (mean = 50.5%, sd = ±7.9) Additional fire regime predictors included fire regime groups (FRG) and percentage of replacement severity fires (PRS) (Appendix A). FRG characterizes the presumed historical fire regimes within landscapes based on interactions between vegetation dynamics, fire spread, fire effects, and spatial context (USDOI 2013). Locations occupied by *L. subcoriacea* include three different FRG categories (FRG I, III and V), which span fire return intervals of ≤35 to >200 years. However, the most prevalent category was FRG I, which represents a ≤35-year fire return interval, with low and mixed severity fire. PRS ranged from 0-15% at locations occupied by *L. subcoriacea* (median = 0-5%), with replacement severity defined as greater than 75% average top-kill within a typical fire perimeter for a given vegetation type. Although caution should be taken not to infer causality from the correlative approach used by MaxEnt to predict habitat suitability, it is worth noting that the fire variables retained in the final model and their values match those reported for *L. subcoriacea* (Sorrie, Gray, and Crutchfield 2006, Wall et al. 2013). Fire history is a considerable determinant of the dominant vegetation of wetlands occupied by *L. subcoriacea* (Sorrie, Gray, and Crutchfield 2006), which are estimated to have a fire return interval of 7-50 years (Frost 1998, Stambaugh, Guyette, and Marschall 2011, Just, Hohmann, and Hoffmann 2016).

Soil predictors retained in the final model included field capacity (WTENTHBAR), depth to wet soil layer (WTDEPANNMIN), soil permeability (KSAT), and hydrogen ion activity of soil (PH1TO1H2O). The first three of these predictors are related to soil moisture, while the last reflects soil pH (Table 5). Soil pH affects many aspects of plant physiology, including nutrient balance and growth rates. PH1TO1H2O made the largest contribution at 7.58%, followed by KSAT (3.68%), WTDEPANNMIN (2.17%), and WTENTHBAR (1.42%). Locations occupied by *L. subcoriacea* generally had higher hydraulic conductivity, and a lower depth to the water table (WTDEPANMIN) relative to unoccupied locations, though the differences were not significant. These values match field descriptions of acidic, permanently saturated, high organic matter soils (Gordon, Jones, and Wiseman 1986).

Climate-related predictors retained in the final model included isothermality (BIO3), mean temperature of driest quarter (BIO9), annual precipitation (BIO12), precipitation seasonality (BIO15), and precipitation of the driest quarter (BIO17). As might be anticipated by the species' geographic range, the climate of occupied locations was moist temperate, with modest seasonal variation in temperatures and precipitation (Table 5).

Table 5. Mean, standard deviation and range of continuous soil, topographic and climate environmental predictors at locations where *L. subcoriacea* populations occur.

| Variable | Units | Mean | Standard deviation | Range |
|---|---|---|---|---|
| ASPECT | None | 0.50 | 0.72 | -1-1 |
| BIO12 | mm | 1303 | 184.6 | 1142-1645 |
| BIO15 | None | 18.9 | 2.2 | 12-23 |
| BIO17 | mm | 258 | 38.8 | 215-331 |
| BIO3 | % | 40 | 1.74 | 38-44 |
| BIO9 | °C | 13.8 | 3.4 | 10.4-22.9 |
| KSAT | µm/s | 889.6 | 392.2 | 0-1283 |

| Variable | Units | Mean | Standard deviation | Range |
|---|---|---|---|---|
| PH1TO1H2O | None | 28.8 | 13.4 | 0-88.5 |
| SLOPE | % | 2.63 | 2.49 | 0-13 |
| TPI | None | -0.44 | 1.24 | -3.48 – 4.04 |
| WTDEPANNMIN | cm | 11.7 | 28.7 | 0-122 |
| WTENTHBAR | % | 27.3 | 15.1 | 0-46.8 |

Topographic predictors retained in the final model included slope, aspect, and topographic position index (TPI). Locations occupied by *L. subcoriacea* were predominantly mid-positon, shallow slopes (Table 5), which matches known associations with mid-slope, hillside seepage wetlands in the sandhills region of North and South Carolina (Sorrie, Gray, and Crutchfield 2006, Wall et al. 2013), and level to slightly sloping terrain within the Gulf Coastal Plain of Alabama, Mississippi, and Louisiana. Although considerable variation in the aspect of occupied sites was found, the majority were north-facing (Table 5). Approximately 60% of sites had values close to 1, which corresponds to north, while only 20% were either south-facing, or east-west facing. This association with north-facing slopes is a novel insight about site suitability.

## 3.2 Habitat suitability maps

Potential habitat with high suitability (>0.73) was distributed throughout the region (Appendix B), with 2% of the region identified as highly suitable. Percent area of high suitability ranged from 10% in the Northeastern Piedmont physiographic region to less than .01% in the Mississippi Delta and the Southeastern Coastal Plain physiographic regions (Appendix B). The high values for the Northeastern Piedmont physiographic region are interesting; however most of the area is outside the known historical range of *L. subcoriacea*, with only a few known locations at the southeastern edge of the ecoregion. North Carolina had the highest percentage of suitable habitat (5.0%) and Georgia had the lowest (<0.01%). Mississippi had the highest percentage (24.0%) of high suitability area on protected lands, while Louisiana and North Carolina had the lowest (4.6 and 4.9%, respectively).

Considering DoD installations known to support *L. subcoriacea* populations and the landscapes within a 10 km buffer of the installation boundaries, Eglin AFB and Camp Shelby JFTC were found to have large areas of highly suitable habitat compared to Fort Bragg and Fort Jackson (Tables 6 and 7). Except for Camp Shelby JFTC, much of the highly suitable habitat within the buffers of installations is unprotected. However, there are small amounts of state-protected lands with high suitability near Fort Bragg and Eglin AFB (Table 7).

Figure 2. Ecoregions occupied by *Lindera subcoriacea* in the southeastern United States.

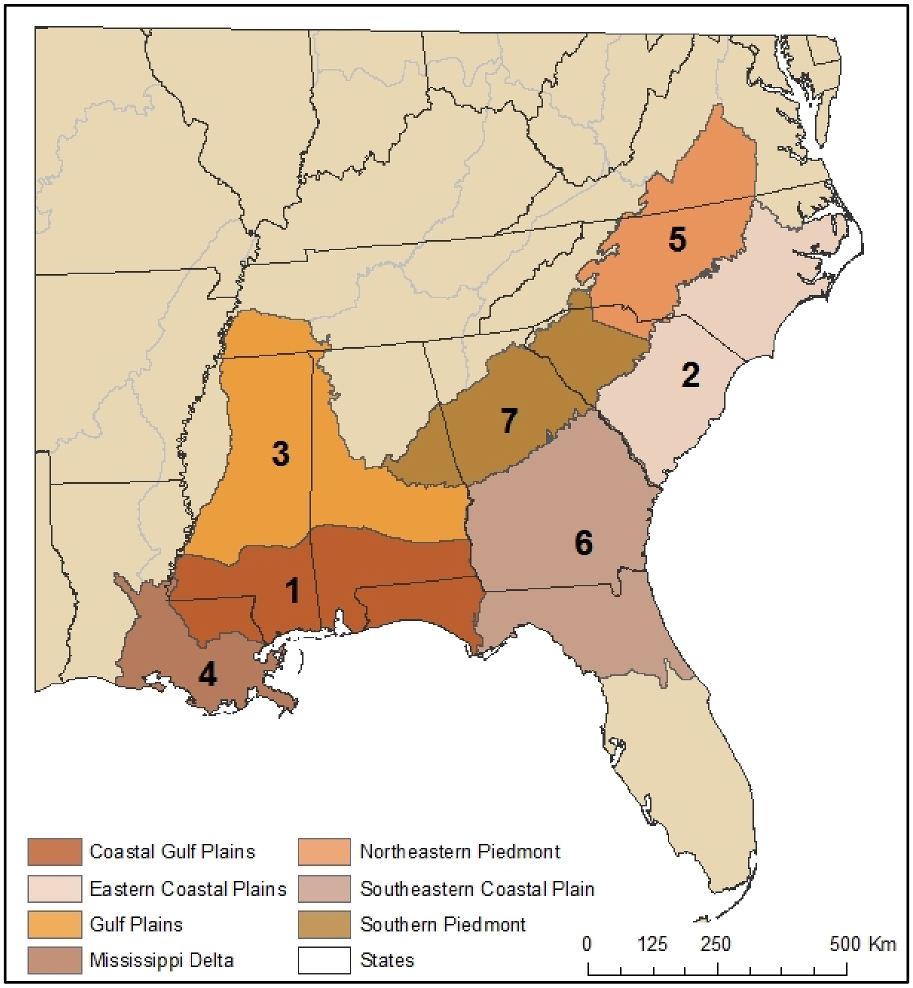



Table 6. Area (Ha) on installations representing highly suitable *L. subcoriacea* habitat, locations warranting additional survey effort, and sites potentially suitable for (re)introduction.

| Installation | Total area | High suitability | Additional survey | (Re)introduction |
|---|---|---|---|---|
| Eglin AFB | 188041.1 | 2644.5 | 1900.3 | 1888.9 |
| Fort Bragg | 65941.0 | 139.1 | 41.0 | 37.6 |
| Camp Shelby | 55995.9 | 1859.0 | 1595.1 | 1489.7 |
| Fort Jackson | 21004.9 | 20.3 | 10.4 | 10.0 |

Table 7. Areas (Ha) within a 10 km buffer of installation boundaries representing highly suitable *L. subcoriacea* habitat, locations warranting additional survey effort and sites potentially suitable for (re)introduction. Values are summarized by type of protection.

| Installation | Protection Type | Total Area | High Suitability | Additional Survey | (Re) Introduction |
|---|---|---|---|---|---|
| Camp Shelby | Federal | 36871.11 | 3237.75 | 3187.8 | 3175.11 |
| | NGO | 1952.19 | 210.78 | 210.78 | 210.51 |
| | None | 108747.45 | 5081.76 | 4110.93 | 0 |
| | Private | 1018.80 | 1.8 | 1.8 | 1.8 |
| | State | 6073.56 | 379.08 | 293.04 | 292.59 |
| | Unknown | 4.95 | 0.18 | 0.18 | 0 |
| | total = | 154668.06 | 8911.35 | 7804.53 | 3680.01 |
| Eglin AFB | Federal | 4710.33 | 1.35 | 0 | 0 |
| | Local | 144.90 | 0.09 | 0 | 0 |
| | NGO | 13.41 | 0 | 0 | 0 |
| | None | 187903.62 | 4535.01 | 1095.12 | 0 |
| | Private | 7418.34 | 1.53 | 0.63 | 0.63 |
| | State | 34575.03 | 282.24 | 98.19 | 97.11 |
| | Unknown | 661.14 | 0.72 | 0.45 | 0.45 |
| | total = | 235426.77 | 4820.94 | 1194.39 | 98.19 |
| Fort Bragg | Federal | 156.69 | 5.58 | 5.58 | 5.58 |
| | Local | 580.95 | 1.26 | 0 | 0 |
| | NGO | 630.54 | 1.53 | 0 | 0 |
| | None | 164145.51 | 681.48 | 262.08 | 0 |
| | Private | 1377.54 | 8.28 | 3.15 | 2.97 |
| | State | 19083.96 | 380.07 | 293.58 | 258.39 |
| | Unknown | 334.89 | 0.9 | 0.45 | 0.36 |
| | total = | 186310.08 | 1079.1 | 564.84 | 267.3 |
| Fort Jackson | Local | 507.42 | 3.15 | 0 | 0 |
| | None | 86765.94 | 212.13 | 37.98 | 0 |
| | Private | 2296.08 | 5.31 | 5.31 | 5.31 |
| | State | 949.05 | 4.68 | 0 | 0 |
| | Unknown | 798.21 | 0 | 0 | 0 |
| | total = | 91316.70 | 225.27 | 43.29 | 5.31 |

## 3.3 Model application

### 3.3.1 Areas warranting additional survey effort

A total of 4719.3 $km^2$ was identified as warranting additional survey effort. These areas were variably distributed across seven states, seven ecoregions, and five consolidated types of land managers (Appendix B). North Carolina had the most area (1522 $km^2$, 33% of the total) identified for additional survey effort, which is almost entirely located on unprotected private lands within the Northeastern Piedmont ecoregion (1482 $km^2$). Alabama and Mississippi also had sizable areas identified for additional survey effort, 1119 and 1077 $km^2$, respectively. Georgia had the least amount of area (99.5 $km^2$) identified for additional survey effort and 77% of this area is on private lands. Among ecoregions, the largest areas and 93% of the total identified area warranting additional survey effort were located in the Coastal Gulf Plains (1603 $km^2$), Northeastern Piedmont (1567 $km^2$), and Gulf Plains (1237 $km^2$).

Considering DoD installations known to support *L. subcoriacea* populations and the landscapes within a 10 km buffer of the installation boundaries, Camp Shelby JFTC and Eglin AFB were found to have relatively large areas warranting additional survey effort both on the installation and within the surrounding landscape (Tables 6 and 7). In contrast, Fort Bragg and Fort Jackson had much smaller areas within the installation boundaries and the surrounding landscapes. For example, one can see widely distributed areas on Camp Shelby JFTC and within the neighboring DeSoto National Forest where additional searches for *L. subcoriacea* may be successful (Figures 3 and 4).

Figure 3. Example locations on and near Camp Shelby JFTC potently warranting additional survey effort.

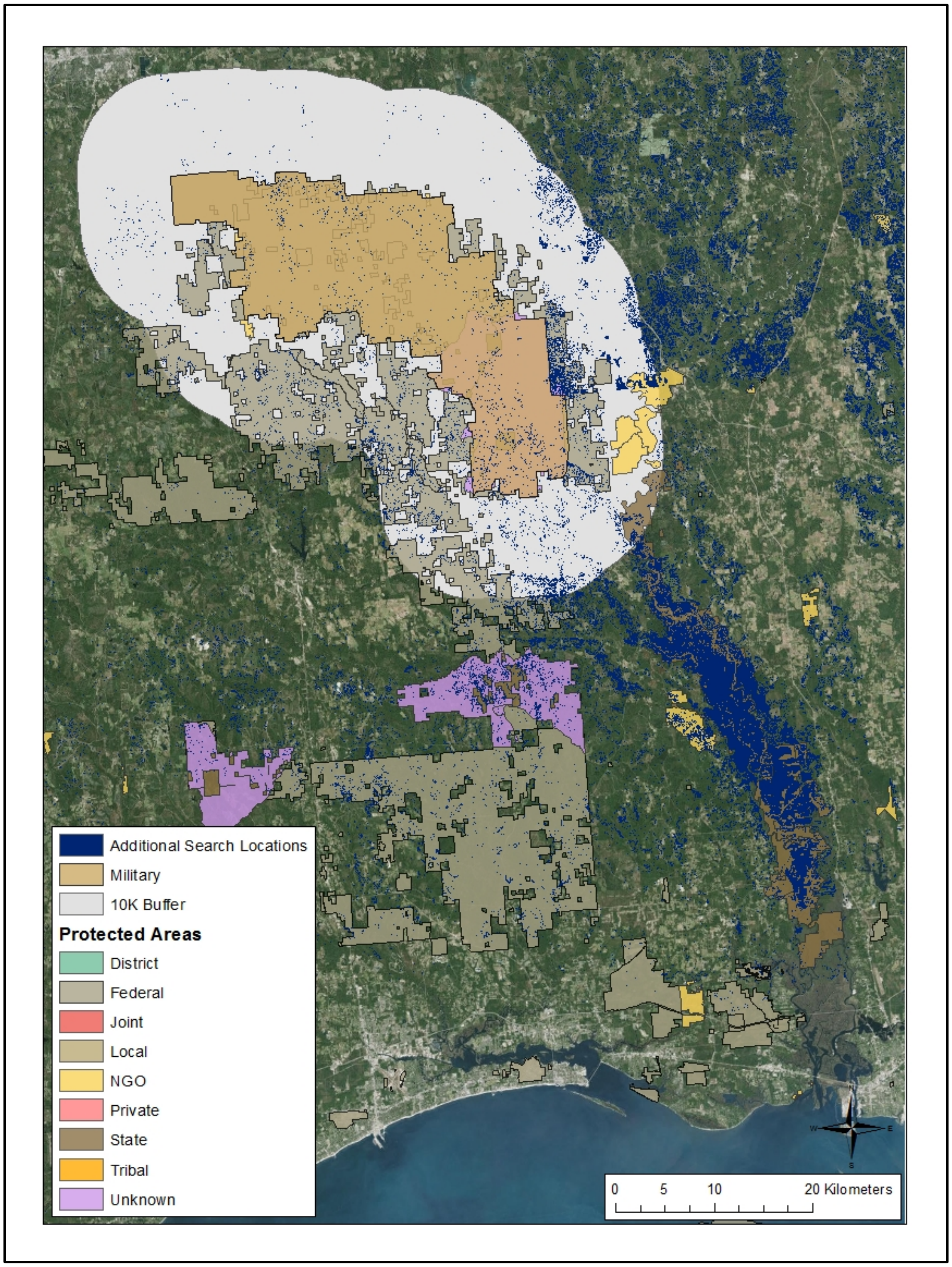
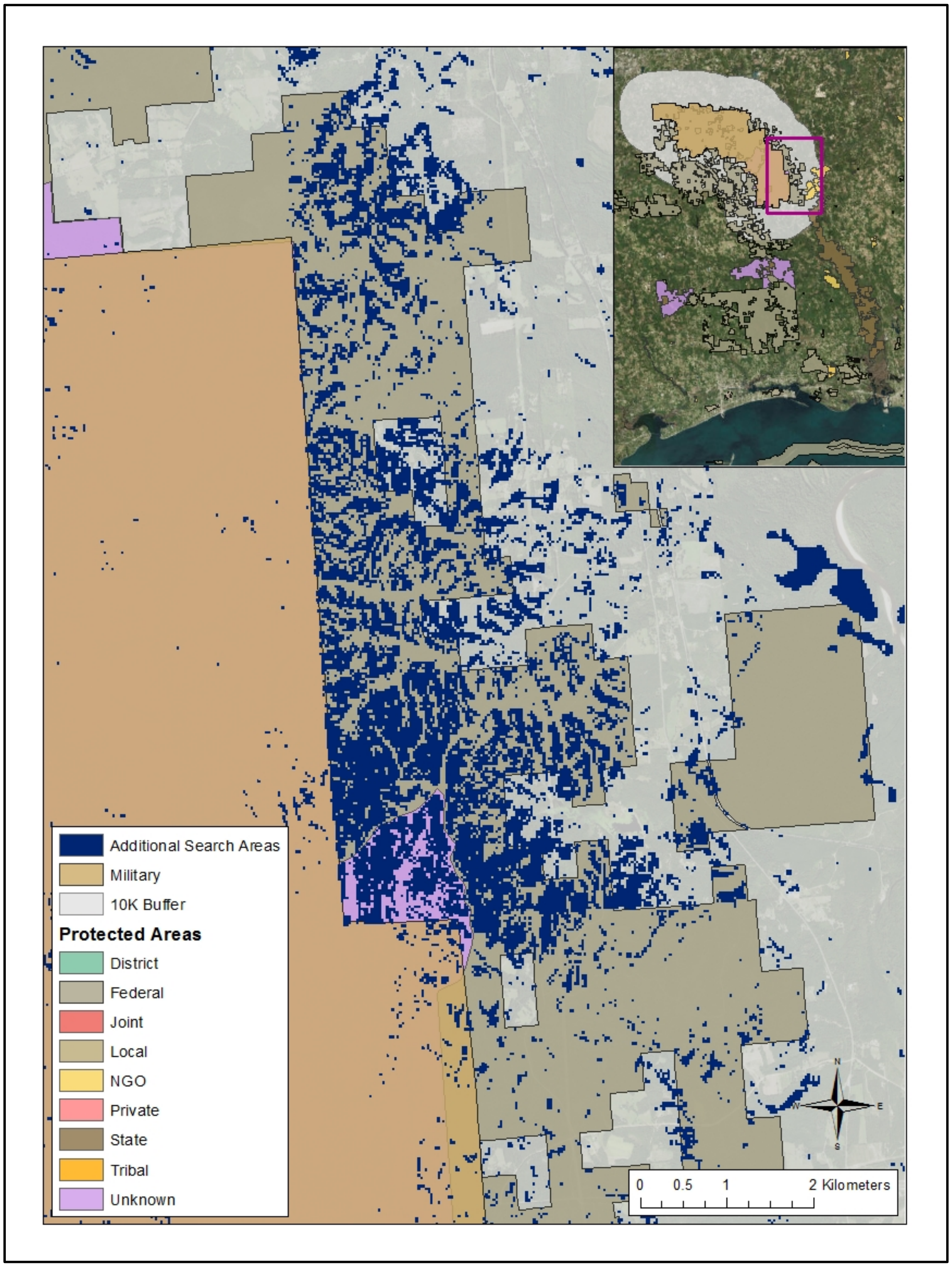


Figure 4. Close up of locations on Desoto National Forest near Camp Shelby JFTC warranting additional survey effort for *L. subcoriacea*.



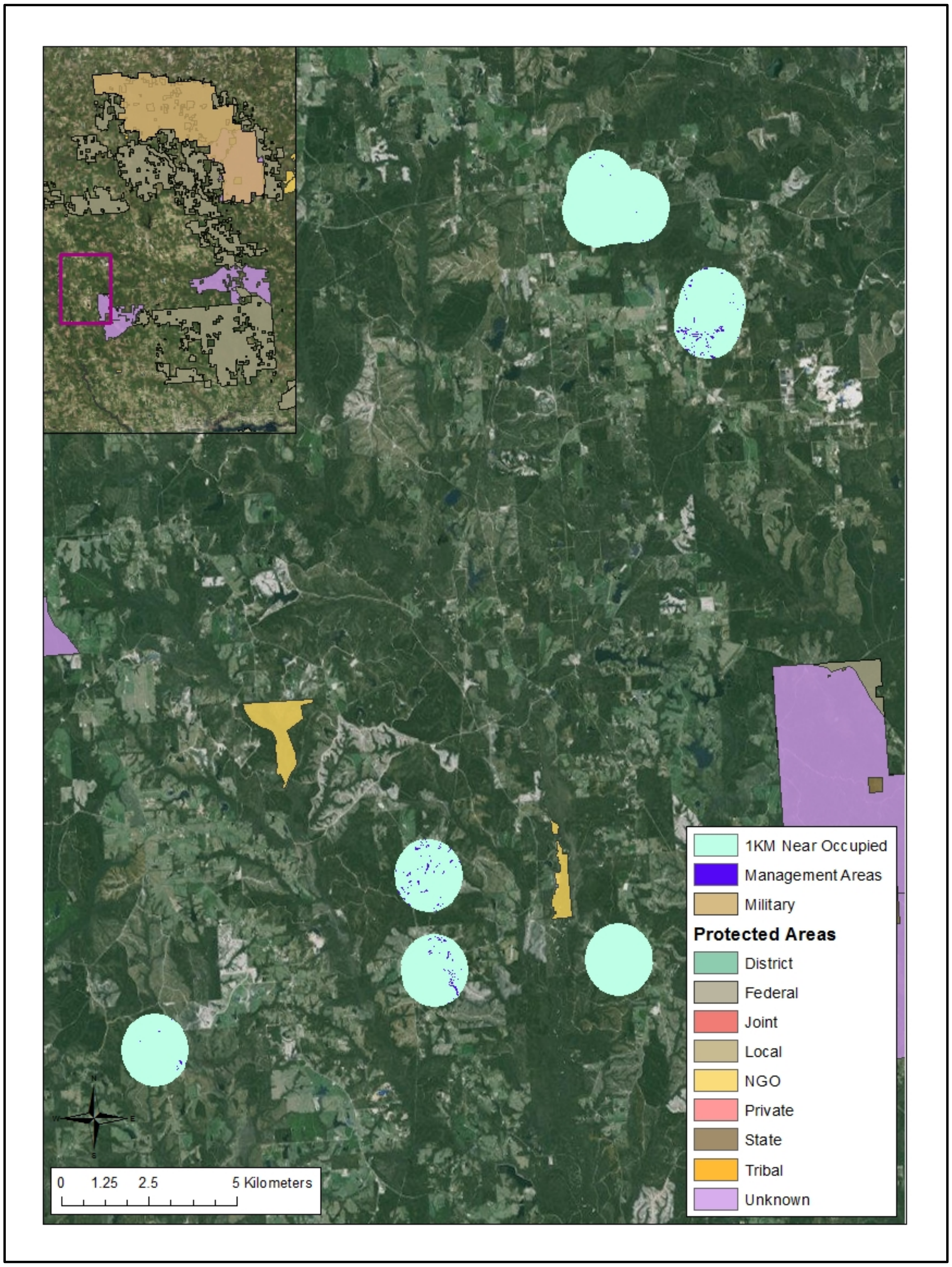
### 3.3.2 Areas for potential conservation and management

These analyses focused on identifying two types of areas of potential interest for targeted acquisition and/or development of conservation agreements. Unfortunately, no populations under private ownership within highly suitable and connected habitat were identified. There are only 32 known *L. subcoriacea* populations in private, unprotected ownership; all of these appear to be in degraded habitat, making them relatively unattractive for acquisition or inclusion within a conservation agreement without consideration of their surrounding landscapes. Consequently, the landscapes within a 1 km radius buffer of these unprotected populations were explored to identify the area of highly suitable and connected habitat that might facilitate local metapopulation dynamics. For example, lands near unprotected *L. subcoriacea* populations in Mississippi that could be targeted for acquisition or development of conservation agreements can be seen in (Figure 5). The areas within buffers varied across individual populations; Table 8 lists the number of populations and mean area by state that are potentially suitable for landscape-based conservation strategies. No privately owned, connected, high suitability habitat near known *L. subcoriacea* occurrences were identified on public lands as possible targets for extending existing conservation buffers.

Table 8. Numbers of *L. subcoriacea* populations on unprotected lands and the mean area of highly suitable and connected habitat within surrounding 1 km radius landscapes.

| State | Number of populations | Mean area (Ha) |
|---|---|---|
| AL | 3 | 4.2 |
| GA | 3 | 5.0 |
| MS | 9 | 5.1 |
| NC | 13 | 6.0 |
| SC | 4 | 2.7 |

Figure 5. Example of locations within 1 km buffers of unprotected *L. subcoriacea* populations in Mississippi that may be suitable for acquisition or development of conservation agreements as part of landscape-based conservation strategies.



This work also sought to identify *L. subcoriacea* populations on protected lands potentially needing habitat restoration or population monitoring. Results of these analyses suggest that 46 of 88 (52%) populations on protected lands occur in locations having low to moderate habitat suitability, but high connectedness (Table 9). An example of populations on Federal lands potentially needing habitat restoration or population monitoring are those on the U.S. Department of Energy (DOE) Savannah River Site. The percent of known *L. subcoriacea* occurrences identified as potentially needing restoration, was roughly equal among Federal- and state-managed land, which are responsible for the vast majority of populations. Although, one can alternately interpret these findings as poor model performance, it is generally known that the condition of *L. subcoriacea* habitats and populations can wax and wane in response to fire, flooding, and other environmental variables. Consequently, land managers should consider evaluating the condition of populations in the field and investing effort in restoring them as necessary (e.g., via prescribed fire or thinning the canopy).

Table 9. Number and percent of *L. subcoriacea* populations identified as potentially needing restoration or population monitoring.

| Land manager | Number of populations | Percent of populations |
|---|---|---|
| Federal | 73 | 52 |
| State | 12 | 50 |
| NGO | 2 | 100 |
| Local | 1 | 0 |

These results suggest that modeling habitat suitability can provide insight into the appropriateness of different conservation and management strategies for *L. subcoriacea* populations on protected lands versus those on unprotected lands.

### 3.3.3 Areas suitable for potential (re)introduction

A total of 906.9 km$^2$ was identified as potentially suitable for (re)introduction efforts. These areas were variably distributed across seven states, seven ecoregions, and five consolidated types of protected lands (Appendix B). Among types of protected lands, the largest area suitable for potential (re)introduction is located on Federal properties (477.7 km$^2$). Mississippi had the most area (344.7 km$^2$) identified for potential (re)introduction, with a large region of state-owned land (Pascagoula State Fish and Wildlife Area) concentrated in the Coastal Gulf Plains ecoregion (Figure 6). Among ecoregions, the Coastal Gulf Plains had the largest (371 $km^2$) and the Mississippi Delta had the smallest (0.0 $km^2$) areas potentially suitable for (re)introduction.

Considering DoD installations known to support *L. subcoriacea* populations (Table 6), both Camp Shelby JFTC and Eglin AFB were identified to have sizable areas suitable for (re)introduction. In contrast, Fort Bragg and Fort Jackson had relatively little area suitable for (re)introduction. Considering 10 km buffers of these installations, only Camp Shelby JFTC was identified to have a sizeable area potentially suitable for (re)introduction (Table 7), and these areas were largely under Federal ownership. Although the available areas are much smaller, there were also some sites on state game lands near Fort Bragg/Camp Mackall that could contribute to local metapopulation dynamics if (re)introductions were implemented (Figure 5).

The success rates of rare plant (re)introductions are often low due to difficulty identifying suitable habitat for restoration (Godefroid et al. 2011, Drayton and Primack 2012, Questad et al. 2014). Consequently, SDM can play an important role in guiding listed and at-risk plant (re)introductions. Still, there are relatively few examples of published studies where MaxEnt has been used to identify potential (re)introduction sites for listed and at-risk plants (e.g., Adhikari, Barik, and Upadhaya 2012). These results suggest there are many locations potentially suitable for (re)introducing *L. subcoriacea* across its range. However, in states (e.g., Georgia) and ecoregions where suitable (re)introduction sites are less available, management options may be limited to restoration of existing occupied sites.

Two hundred *L. subcoriacea* seedlings were successfully outplanted into eight (re)introduction sites on Fort Bragg. Germination rates were high (~85%) and 1-year (2016) survival rates were approximately 65% across the sites (unpublished data). The relatively high, albeit short-term, survivorship of these outplants suggests that (re)introduction could prove successful for either augmenting small populations, or establishing new populations to increase the metapopulation structure within clusters of populations. These outplanting data also speak to the potential influence of seed, dispersal, and recruitment limitation on the realized distribution of the species. Experiments were initiated to robustly test the differential effects of these limitations on the species' population dynamics.

Figure 6. Large area potentially suitable for *L. subcoriacea* (re)introduction efforts within the Coastal Gulf Plains ecoregion.

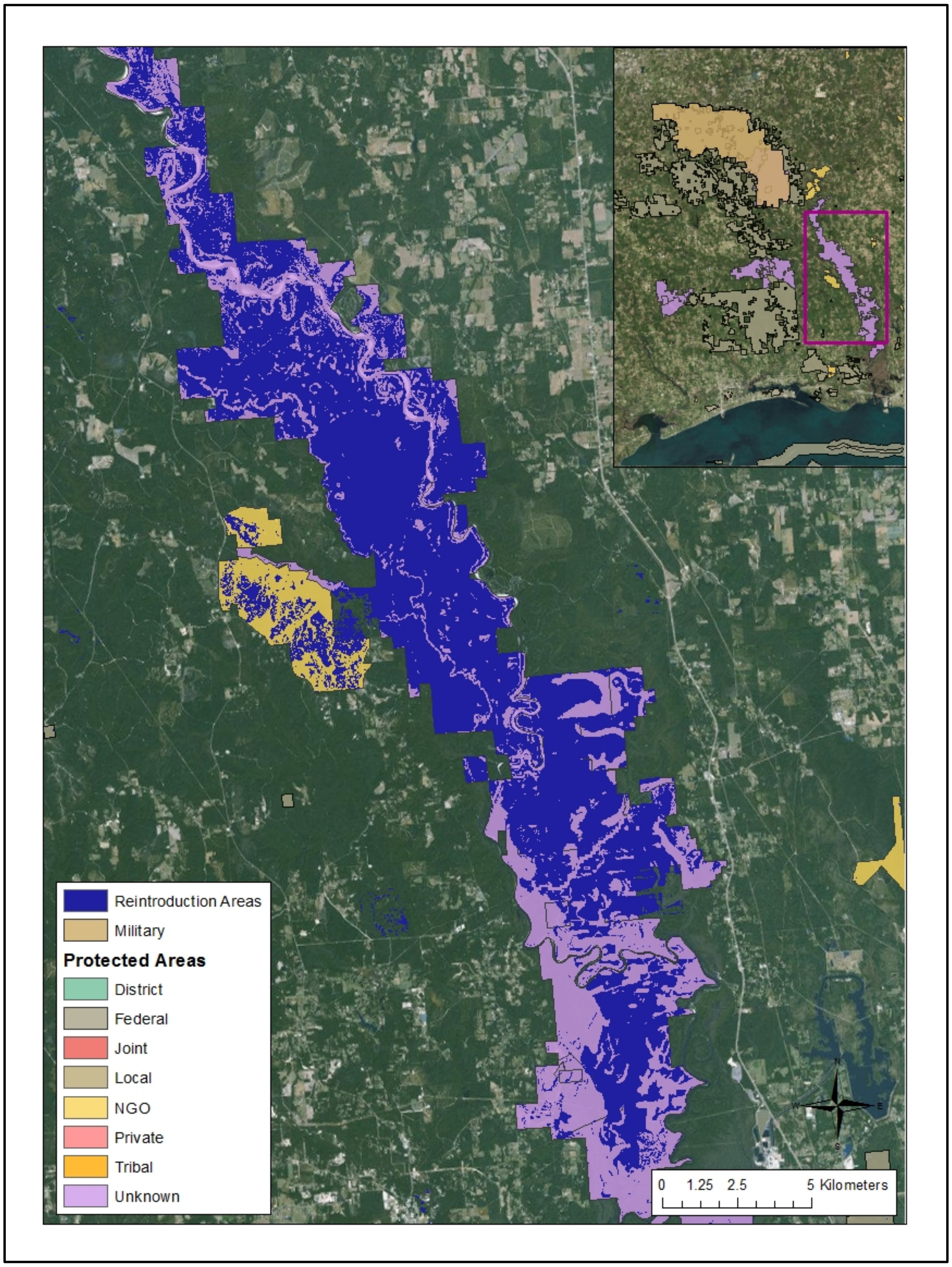
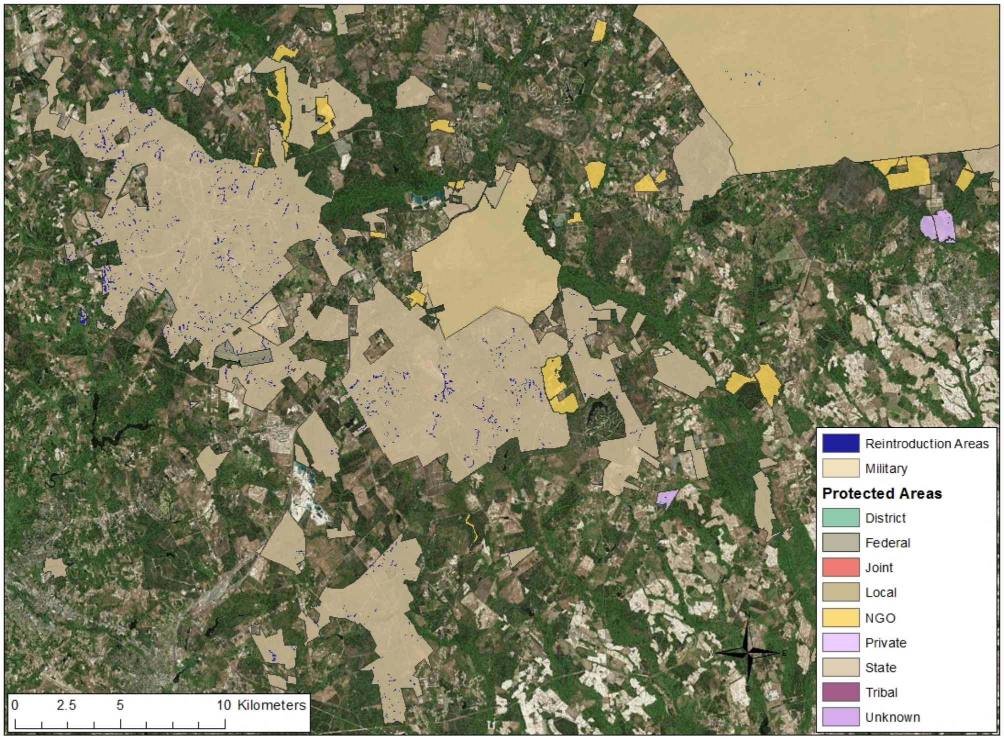


Figure 7. Locations on state game lands near Fort Bragg and Camp Mackall identified as being potentially suitable for *L. subcoriacea* (re)introduction efforts.



# 4 Conclusions and Recommendations

## 4.1 Conclusions

Species distribution modeling can be a valuable tool for rare plant conservation assessment and planning. This application of SDM to *L. subcoriacea* identified abundant high suitability habitat across the species' range, numerous locations warranting additional survey effort, specific conservation assessment and management needs for occupied sites and their surrounding landscapes, and sites potentially suitable for population (re)introduction.

Although it is anticipated that these results will benefit multiple facets of *L. subcoriacea* conservation, it is also recognized that species distributions are affected by historical processes, dispersal limitation, and the dynamics of natural systems. Collectively these factors preclude species from occupying their whole potential distribution (Marcer et al. 2013). This can generate mismatches between predicted habitat suitability and current site occupation. Therefore, the absence of *L. subcoriacea* from areas identified as highly suitable, or presences in areas identified as unsuitable cannot be simply interpreted as a model failure.

## 4.2 Recommendations

### 4.2.1 Potential opportunities for model improvement

As is often the case, several opportunities for potential model improvement came to light after completing the analyses. First, any assessment of habitat suitability should be considered a temporary estimate given the dynamic nature of the vegetation communities occupied by *L. subcoriacea*. The species occupies habitats that are in constant flux due to the influence of fire, fire suppression, and flooding (e.g., due to beaver activity) on vegetation composition and structure. This effort used vegetation and disturbance data provided within the most recent version of LANDFIRE (version 1.3), which represents the conditions in 2012 and the landscape disturbances that occurred in 2011 and 2012. An updated version (1.4) of LANDFIRE is scheduled to be completed in March 2017 and a remapping effort designed to produce new base maps of the LANDFIRE product suite (version 2.0) will likely be completed by 2020. It is advised that the model be revised when these newer data become available as they will better represent actual conditions in the field.

Second, it is also possible that some of the locations within the present dataset used for model development are no longer occupied. Wall et al. (2013) combined multi-year field inventories with modeling, and estimated that only 72% of known *L. subcoriacea* populations have persisted in North Carolina over the past 30 years. Fortunately many of the sites in North Carolina and all known sites in Georgia were recently revisited (Wall et al. 2013; pers. com, Tom Patrick). However, last observation dates from other states occasionally went as far back as 1985 and may be a source of modeling error. Therefore a separate model of habitat suitability generated using only recent presence data may be worth pursuing.

### 4.2.2 Implementing SDM-informed conservation

Public and private entities concerned about *L. subcoriacea* conservation should use the information generated by this effort to enhance conservation assessment and planning efforts. The USFWS should consider this estimate of available suitable habitat near extant *L. subcoriacea* populations and throughout the species' modeled distribution during its listing review. However, further examination of the strength of existing local protections, the ability to carry out management activities, and potential future threats to this suitable habitat are all necessary.

Survey efforts informed by this SDM can be used to improve sampling efficiency and population discovery rates for *L. subcoriacea*. However, implementation of field surveys for *L. subcoriacea* based on these results will likely benefit from knowledge about distance from roads, as well as property ownership, as extensive areas within multiple jurisdictions were identified. Estimates of areas warranting additional survey effort on installations and within their surrounding landscapes can also be used to estimate costs for planning targeted searches.

The numerous management needs and opportunities identified here should be pursued to the extent feasible. Conservation partnerships may be helpful in magnifying the beneficial impact of these efforts. Implementation will likely require additional localized analyses based on criteria identified by conservation practitioners (e.g., property costs and acquisition budgets). Additionally, one could consider other variables likely to be important to long term *L. subcoriacea* population success, including the number of individuals in populations, metapopulation criteria (e.g., size and distance of neighbor populations), and ability to implement such management actions as prescribed fires. Consequently, these results should be viewed as an initial screening to identify potential management options.

The results of this work indicate that the prospects for augmenting or (re)introducing *L. subcoriacea* populations are good. However, before implementing any (re)introductions it will be important to give consideration to additional factors that can influence population success, such as the size of the specific patches of suitable habitat and their distance from neighboring patches. Field validation of site suitability and ability to implement management actions are also critical (Guerrant and Kaye 2007, Godefroid et al. 2011).

## 4.3 Military Benefits

Installation training ranges are essential for preparing DoD forces for combat and complex missions across the globe. To ensure the long-term sustainability of its training ranges, DoD recognizes that it is necessary to “sustain excellence in environmental stewardship” and “mitigate encroachment pressures on training activities” (USDOD 2015). Threatened and endangered species are consistently reported as the primary encroachment threat to range accessibility and capability across DoD, while at-risk species are identified as a key evolving challenge to sustainability. The results of this effort support DoD’s environmental stewardship and encroachment mitigation requirements in multiple ways.

Stewardship of listed and at-risk species is dependent on knowing about species’ biology, locations where they occur, the distribution of suitable habitat, and the viability of different conservation strategies. This effort generated information related to the latter three for DoD installations, regions, and across the range of *L. subcoriacea*. For DoD installations, this information will improve survey efficiency, aid development of management plans, expand available management strategies, and help identify conservation partnering opportunities.

The numerous widely distributed *L. subcoriacea* populations found across installation landscapes would not only present a management burden, but also a significant encroachment constraint on DoD land use if the species were to be listed. Options for mitigating listed and at-risk species encroachment on training activities are dependent on species’ listing status, knowledge about the availability and distribution of suitable habitat, and the viability of different conservation strategies. This effort generated information related to all of these needs. Increased efficiency and efficacy of new population discovery will improve the accuracy of range-wide estimates of *L. subcoriacea* distribution, population numbers, and total number of individuals. Novel range-wide estimates of available suitable habitat will help identify the degree to which *L. subcoriacea* habitats are threatened by damage or destruction. Both of these are critical for determining the risk of extinction and listing status under ESA. This effort also generated information about landscape-level conservation partnering opportunities and areas potentially suitable for population (re)introduction, which are invaluable strategies that DoD installations might wish to employ to mitigate encroachment on training activities.

The results of this effort provide DoD natural resource managers with important information needed to adopt proactive approaches to *L. subcoriacea* management, which generally provide the greatest payoff on investment. Collectively, the stewardship and encroachment mitigation benefits generated will contribute towards improving the species' conservation status, and will help ensure that DoD maintains the flexibility needed for unencumbered, mission-directed land use.

# Appendix A: Climate, Topographic, Soil, Fire and Vegetation Variables Evaluated

Of the 52 climate, topographic, soil, fire, and vegetation variables evaluated during development of the *Lindera suboriacea* habitat suitability map, only 20 variables contributing > 1% and having a Pearson's r <|0.9| were retained for use in the final model. Sources for the environmental predictors are: climate (www.worldclim.org), fire regime, topographic, and vegetation (www.landfire.gov), soils (www.nrcs.usda.gov).

Table A-1. Fifty-two climate, topographic, soil, fire and vegetation variables evaluated during development of the *Lindera suboriacea* habitat suitability map.

| Type | Code | Name | Description | % |
|---|---|---|---|---|
| Climate | BIO1 | bioclimatic indicator 1 | annual mean temperature (°C) | NA |
| Climate | BIO10 | bioclimatic indicator 10 | mean temperature of warmest quarter (°C) | NA |
| Climate | BIO11 | bioclimatic indicator 11 | mean temperature of coldest quarter (°C) | NA |
| Climate | BIO12 | bioclimatic indicator 12 | annual precipitation (mm) | 0.15 |
| Climate | BIO13 | bioclimatic indicator 13 | precipitation of wettest month (mm) | NA |
| Climate | BIO14 | bioclimatic indicator 14 | precipitation of driest month (mm) | NA |
| Climate | BIO15 | bioclimatic indicator 15 | precipitation seasonality | 3.64 |
| Climate | BIO16 | bioclimatic indicator 16 | precipitation of wettest quarter (mm) | NA |
| Climate | BIO17 | bioclimatic indicator 17 | precipitation of driest quarter (mm) | 6.84 |
| Climate | BIO18 | bioclimatic indicator 18 | precipitation of warmest quarter (mm) | NA |
| Climate | BIO19 | bioclimatic indicator 19 | precipitation of coldest quarter (mm) | NA |
| Climate | BIO2 | bioclimatic indicator 2 | mean monthly diurnal temperature range (°C) | NA |
| Climate | BIO3 | bioclimatic indicator 3 | Isothermality [(BIO2/BIO7) * 100] (%) | 0.82 |
| Climate | BIO4 | bioclimatic indicator 4 | temperature seasonality | NA |
| Climate | BIO5 | bioclimatic indicator 5 | maximum temperature of warmest month (°C) | NA |
| Climate | BIO6 | bioclimatic indicator 6 | minimum temperature of coldest month (°C) | NA |
| Climate | BIO7 | bioclimatic indicator 7 | temperature annual range [BIO5 - BIO6] (°C) | NA |
| Climate | BIO8 | bioclimatic indicator 8 | mean temperature of wettest quarter (°C) | NA |
| Climate | BIO9 | bioclimatic indicator 9 | mean temperature of driest quarter (°C) | 2.51 |
| fire regime | FRG | fire regime group | classification of presumed historical fire regime | 7.32 |
| fire regime | FRI | mean fire return interval | mean fire return interval | NA |
| fire regime | PLS | percentage of low severity fire | percentage of low severity fire (%) | NA |
| fire regime | PMS | percentage of mixed severity fires | percentage of mixed severity fires (%) | NA |
| fire regime | PRS | percentage of replacement severity fires | percentage of replacement severity fires (%) | 1.77 |
| fire regime | VCC | vegetation condition class | classification of vegetation departure (VDEP) | 12.53 |

| Type | Code | Name | Description | % |
|---|---|---|---|---|
| fire regime | VDEP | vegetation departure | percentage estimation of vegetation departure from historical reference conditions (%) | 1.70 |
| Soils | AWC | available water capacity | amount of water than an increment of soil depth can store that is available to plants | NA |
| Soils | AWS0150WTA | available water storage | available water storage to a depth of 150 cm | NA |
| Soils | CEC7 | cation exchange capacity | amount of readily exchangeable cations that can be electrically adsorbed to negative charges in the soil, soil constituent, or other material, at pH 7.0, as estimated by the ammonium acetate method. | NA |
| Soils | CLAY | percentage clay | total clay (%) | NA |
| Soils | DRAINAGECL | drainage class | natural drainage conditions of the soil, refers to frequency and duration of wet periods | NA |
| Soils | HYDRICON | hydric condition | natural condition of the soil component | NA |
| Soils | HYDRICRATI | hydric soil | classification as hydric soil or not | NA |
| Soils | KSAT | soil permeability | amount of water that would move vertically through a unit area of saturated soil | 3.68 |
| Soils | OM | organic matter | amount by weight of decomposed plant and animal residue | NA |
| Soils | PH01MCACL2 | hydrogen ion activity of soil | The negative logarithm to base of 10 or the hydrogen ion activity in the soil, using the 0.01M CaCl2 method, in a 1:2 soil:solution ratio. A numerical expression of the relative acidity or alkalinity of a soil sample. | NA |
| Soils | PH1TO1H2O | hydrogen ion activity of soil | The negative logarithm to the base 10, of the hydrogen ion activity in the soil using the 1:1 soil-water ratio method. A numerical expression of the relative acidity or alkalinity of a soil sample. | 7.58 |
| Soils | PTOTAL | phosphorous | estimate of total phosphorous content of soil | NA |
| Soils | SAND | percentage sand | total sand (%) | NA |
| Soils | SILT | percentage silt | total silt (%) | |
| Soils | WTDEPANNMIN | depth to wet soil layer | shallowest depth to a wet soil layer (water table) at any time during the year | 2.17 |
| Soils | WTENTHBAR | field capacity | volumetric content of a soil water retained at a tension of 1/10 bars (field capacity) | 1.42 |
| topographic | ASPECT | Aspect | aspect at 30 meter resolution | 1.92 |
| topographic | SLOPE | slope of terrain | represents the percentage change in elevation | 0.52 |
| topographic | TPI | topographic position index | classified topographic position (e.g. hilltop, slope, valley) | 3.12 |
| Vegetation | BPS | biophysical setting | vegetation that may have been dominant before Euro-American settlement | 31.48 |
| Vegetation | CC | canopy cover | canopy cover (%) | 2.13 |
| Vegetation | CH | canopy height | canopy height (m) | 7.42 |
| Vegetation | ESP | environmental site potential | vegetation that could be potentially supported at a site | 1.26 |
| Vegetation | EVC | existing vegetative cover | vegetation currently at the site | NA |
| Vegetation | EVH | existing vegetative height | mean, species-over weighted existing vegetation height | NA |
| Vegetation | EVT | existing vegetation type | plant community classification | NA |

# Appendix B: Area of L. subcoriacea Habitat Summarized by State, Ecoregion, and Ownership for Different Management Strategies

Table B-1. Total (km²) and percent (in parentheses) area of highly suitable habitat, locations warranting additional survey effort, and locations potentially suitable for *L. subcoriacea* population (re)introductions across seven states and associated ecoregions.

| State, Ecoregion, Ownership | Total | Suitable | Additional Survey | Reintroduction |
|---|---|---|---|---|
| Alabama | 94219.4 (14.7) | 1870.7 (16.1) | 1118.7 (23.7) | 250.2 (27.6) |
| *Coastal Gulf Plains* | 35878.5 (5.6) | 432.6 (3.7) | 157.2 (3.3) | 5.3 (0.6) |
| Federal | 498.9 (0.1) | 1.4 (0) | 1.3 (0) | 1.3 (0.1) |
| NGO | 6.2 (0) | 0.3 (0) | 0.3 (0) | 0.3 (0) |
| Other | 582.6 (0.1) | 16.3 (0.1) | 0.9 (0) | 0.9 (0.1) |
| Private | 34129.8 (5.3) | 407.1 (3.5) | 151.4 (3.2) | 0 (0) |
| State | 661 (0.1) | 7.6 (0.1) | 3.3 (0.1) | 2.9 (0.3) |
| *Gulf Plains* | 45630.6 (7.1) | 1363.2 (11.7) | 928.3 (19.7) | 240.1 (26.5) |
| Federal | 713.6 (0.1) | 229.4 (2) | 221.7 (4.7) | 220.8 (24.3) |
| NGO | 1.9 (0) | 0 (0) | 0 (0) | 0 (0) |
| Other | 591.9 (0.1) | 17.9 (0.2) | 14.4 (0.3) | 14.1 (1.6) |
| Private | 43745.3 (6.8) | 1109.6 (9.5) | 686.7 (14.6) | 0 (0) |
| State | 577.9 (0.1) | 6.4 (0.1) | 5.5 (0.1) | 5.2 (0.6) |
| *Southeastern Coastal Plain* | 226.3 (0) | 0.4 (0) | 0.1 (0) | 0.1 (0) |
| NGO | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Other | 93.9 (0) | 0.1 (0) | 0.1 (0) | 0.1 (0) |
| Private | 131.9 (0) | 0.2 (0) | 0 (0) | 0 (0) |
| State | 0.5 (0) | 0 (0) | 0 (0) | 0 (0) |
| *Southern Piedmont* | 12484.1 (2) | 74.6 (0.6) | 33.1 (0.7) | 4.6 (0.5) |
| Federal | 776.5 (0.1) | 0.4 (0) | 0.3 (0) | 0.3 (0) |
| NGO | 1.9 (0) | 0 (0) | 0 (0) | 0 (0) |
| Other | 201 (0) | 4.5 (0) | 2.3 (0) | 2.3 (0.2) |
| Private | 11320 (1.8) | 65.6 (0.6) | 28.3 (0.6) | 0 (0) |
| State | 184.7 (0) | 4.2 (0) | 2.2 (0) | 2.1 (0.2) |
| Florida | 71575.4 (11.2) | 720.6 (6.2) | 147.3 (3.1) | 56.1 (6.2) |
| *Coastal Gulf Plains* | 20600.4 (3.2) | 710.3 (6.1) | 145 (3.1) | 55.8 (6.2) |
| Federal | 129.4 (0) | 0 (0) | 0 (0) | 0 (0) |
| NGO | 26.7 (0) | 1.3 (0) | 1.2 (0) | 1.2 (0.1) |
| Other | 3082.3 (0.5) | 56.7 (0.5) | 37.6 (0.8) | 37.3 (4.1) |

| State, Ecoregion, Ownership | Total | Suitable | Additional Survey | Reintroduction |
|---|---|---|---|---|
| Private | 16160.3 (2.5) | 629.7 (5.4) | 88.8 (1.9) | 0 (0) |
| State | 1201.8 (0.2) | 22.6 (0.2) | 17.5 (0.4) | 17.4 (1.9) |
| *Southeastern Coastal Plain* | 50975 (8) | 10.3 (0.1) | 2.2 (0) | 0.3 (0) |
| Federal | 4896.6 (0.8) | 0 (0) | 0 (0) | 0 (0) |
| NGO | 89.8 (0) | 0.1 (0) | 0 (0) | 0 (0) |
| Other | 4615 (0.7) | 0.2 (0) | 0.1 (0) | 0.1 (0) |
| Private | 36928 (5.8) | 9.3 (0.1) | 1.9 (0) | 0 (0) |
| State | 4445.5 (0.7) | 0.7 (0) | 0.2 (0) | 0.2 (0) |
| Georgia | 137737.7 (21.5) | 238.5 (2.1) | 99.5 (2.1) | 23 (2.5) |
| *Gulf Plains* | 3.9 (0) | 0 (0) | 0 (0) | 0 (0) |
| Other | 0.8 (0) | 0 (0) | 0 (0) | 0 (0) |
| Private | 3.1 (0) | 0 (0) | 0 (0) | 0 (0) |
| *Southeastern Coastal Plain* | 93155 (14.6) | 151.6 (1.3) | 70.8 (1.5) | 6.7 (0.7) |
| Federal | 2097.7 (0.3) | 0.1 (0) | 0.1 (0) | 0.1 (0) |
| NGO | 636 (0.1) | 0.9 (0) | 0.4 (0) | 0.4 (0) |
| Other | 4019.1 (0.6) | 6.4 (0.1) | 3.2 (0.1) | 3.2 (0.4) |
| Private | 84750 (13.3) | 140.7 (1.2) | 64 (1.4) | 0 (0) |
| State | 1652.2 (0.3) | 3.5 (0) | 3.1 (0.1) | 3.1 (0.3) |
| *Southern Piedmont* | 44578.9 (7) | 86.9 (0.7) | 28.7 (0.6) | 16.2 (1.8) |
| Federal | 834.7 (0.1) | 6.5 (0.1) | 4.7 (0.1) | 4.7 (0.5) |
| NGO | 52.2 (0) | 0 (0) | 0 (0) | 0 (0) |
| Other | 1920 (0.3) | 13.6 (0.1) | 7.7 (0.2) | 7.6 (0.8) |
| Private | 41277.6 (6.5) | 61.4 (0.5) | 12.4 (0.3) | 0 (0) |
| State | 494.3 (0.1) | 5.4 (0) | 3.9 (0.1) | 3.9 (0.4) |
| Louisiana | 53731.5 (8.4) | 1794.6 (15.4) | 634.6 (13.4) | 37.8 (4.2) |
| *Coastal Gulf Plains* | 11298 (1.8) | 1657.4 (14.3) | 532.8 (11.3) | 25.3 (2.8) |
| Federal | 145.8 (0) | 1.8 (0) | 1.8 (0) | 1.8 (0.2) |
| NGO | 16.8 (0) | 0.1 (0) | 0.1 (0) | 0.1 (0) |
| Other | 82.6 (0) | 34.2 (0.3) | 1.6 (0) | 1.5 (0.2) |
| Private | 10796.1 (1.7) | 1588.8 (13.7) | 507.1 (10.7) | 0 (0) |
| State | 256.7 (0) | 32.4 (0.3) | 22.2 (0.5) | 21.8 (2.4) |
| *Mississippi Delta* | 42433.4 (6.6) | 137.2 (1.2) | 101.7 (2.2) | 12.5 (1.4) |
| Federal | 792.2 (0.1) | 0.1 (0) | 0.1 (0) | 0.1 (0) |
| NGO | 0.7 (0) | 0 (0) | 0 (0) | 0 (0) |
| Other | 610.3 (0.1) | 1.3 (0) | 1.2 (0) | 1.2 (0.1) |
| Private | 38027.5 (5.9) | 122.5 (1.1) | 89.1 (1.9) | 0 (0) |
| State | 3002.8 (0.5) | 13.3 (0.1) | 11.3 (0.2) | 11.2 (1.2) |

| State, Ecoregion, Ownership | Total | Suitable | Additional Survey | Reintroduction |
|---|---|---|---|---|
| Mississippi | 103844 (16.2) | 1598.8 (13.7) | 1076.9 (22.8) | 344.7 (38) |
| *Coastal Gulf Plains* | 33416.6 (5.2) | 1042.4 (9) | 767.9 (16.3) | 287.9 (31.8) |
| Federal | 2597.9 (0.4) | 138.7 (1.2) | 132.8 (2.8) | 131.9 (14.5) |
| NGO | 50 (0) | 7.4 (0.1) | 7.1 (0.1) | 7 (0.8) |
| Other | 858.6 (0.1) | 29.3 (0.3) | 25.1 (0.5) | 24 (2.6) |
| Private | 28479.5 (4.5) | 732 (6.3) | 477.4 (10.1) | 0 (0) |
| State | 1430.7 (0.2) | 134.9 (1.2) | 125.6 (2.7) | 125 (13.8) |
| *Gulf Plains* | 69928.3 (10.9) | 556.2 (4.8) | 308.9 (6.5) | 56.7 (6.3) |
| Federal | 2174.5 (0.3) | 42.1 (0.4) | 35.8 (0.8) | 35.5 (3.9) |
| NGO | 0.3 (0) | 0 (0) | 0 (0) | 0 (0) |
| Other | 936.5 (0.1) | 17.3 (0.1) | 13.5 (0.3) | 13.4 (1.5) |
| Private | 65331.6 (10.2) | 482.3 (4.1) | 251.8 (5.3) | 0 (0) |
| State | 1485.3 (0.2) | 14.5 (0.1) | 7.9 (0.2) | 7.8 (0.9) |
| *Mississippi Delta* | 499.1 (0.1) | 0.2 (0) | 0.1 (0) | 0 (0) |
| Federal | 69 (0) | 0 (0) | 0 (0) | 0 (0) |
| Other | 78.7 (0) | 0 (0) | 0 (0) | 0 (0) |
| Private | 336.8 (0.1) | 0.1 (0) | 0.1 (0) | 0 (0) |
| State | 14.6 (0) | 0 (0) | 0 (0) | 0 (0) |
| North Carolina | 99034.6 (15.5) | 4977.1 (42.8) | 1522.4 (32.3) | 167.5 (18.5) |
| *Eastern Coastal Plain* | 51528.2 (8.1) | 120.4 (1) | 39.2 (0.8) | 6.6 (0.7) |
| Federal | 2134.7 (0.3) | 2.2 (0) | 1.1 (0) | 1.1 (0.1) |
| NGO | 57.4 (0) | 0 (0) | 0 (0) | 0 (0) |
| Other | 1822.7 (0.3) | 1.7 (0) | 0.5 (0) | 0.4 (0) |
| Private | 44259 (6.9) | 108.4 (0.9) | 31.8 (0.7) | 0 (0) |
| State | 3254.4 (0.5) | 7.9 (0.1) | 5.8 (0.1) | 5.1 (0.6) |
| *Northeastern Piedmont* | 46049.1 (7.2) | 4850.2 (41.7) | 1482.2 (31.4) | 160.5 (17.7) |
| Federal | 226.5 (0) | 76.8 (0.7) | 73.2 (1.6) | 72.5 (8) |
| NGO | 50.7 (0) | 8.8 (0.1) | 6.4 (0.1) | 6.1 (0.7) |
| Other | 695.4 (0.1) | 48.7 (0.4) | 9.4 (0.2) | 8.9 (1) |
| Private | 44569.4 (7) | 4616.3 (39.7) | 1319 (27.9) | 0 (0) |
| State | 507.2 (0.1) | 99.6 (0.9) | 74.2 (1.6) | 73.1 (8.1) |
| *Southern Piedmont* | 1457.2 (0.2) | 6.5 (0.1) | 1.1 (0) | 0.4 (0) |
| NGO | 1.1 (0) | 0 (0) | 0 (0) | 0 (0) |
| Other | 14 (0) | 0.1 (0) | 0 (0) | 0 (0) |
| Private | 1432.7 (0.2) | 6 (0.1) | 0.7 (0) | 0 (0) |
| State | 9.4 (0) | 0.4 (0) | 0.4 (0) | 0.4 (0) |

| State, Ecoregion, Ownership | Total | Suitable | Additional Survey | Reintroduction |
|---|---|---|---|---|
| South Carolina | 79402.4 (12.4) | 428.3 (3.7) | 119.9 (2.5) | 27.6 (3) |
| *Eastern Coastal Plain* | 50635.2 (7.9) | 65.5 (0.6) | 23.1 (0.5) | 5.1 (0.6) |
| Federal | 1555.6 (0.2) | 0.8 (0) | 0.7 (0) | 0.7 (0.1) |
| NGO | 64.9 (0) | 0 (0) | 0 (0) | 0 (0) |
| Other | 2717.6 (0.4) | 4.8 (0) | 3 (0.1) | 2.7 (0.3) |
| Private | 44788.2 (7) | 57.7 (0.5) | 17.7 (0.4) | 0 (0) |
| State | 1508.8 (0.2) | 2.2 (0) | 1.6 (0) | 1.6 (0.2) |
| *Northeastern Piedmont* | 4696.7 (0.7) | 288.9 (2.5) | 85 (1.8) | 19.3 (2.1) |
| Federal | 16.6 (0) | 5.5 (0) | 5.5 (0.1) | 5.5 (0.6) |
| NGO | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Other | 20.5 (0) | 4.4 (0) | 0.7 (0) | 0.7 (0.1) |
| Private | 4605.5 (0.7) | 264.7 (2.3) | 65.7 (1.4) | 0 (0) |
| State | 54.1 (0) | 14.3 (0.1) | 13.1 (0.3) | 13.1 (1.4) |
| *Southeastern Coastal Plain* | 847.7 (0.1) | 0.1 (0) | 0 (0) | 0 (0) |
| Federal | 63.5 (0) | 0 (0) | 0 (0) | 0 (0) |
| NGO | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Other | 144 (0) | 0 (0) | 0 (0) | 0 (0) |
| Private | 543.2 (0.1) | 0 (0) | 0 (0) | 0 (0) |
| State | 97 (0) | 0 (0) | 0 (0) | 0 (0) |
| *Southern Piedmont* | 23222.8 (3.6) | 73.9 (0.6) | 11.8 (0.2) | 3.3 (0.4) |
| Federal | 1191.8 (0.2) | 6.6 (0.1) | 1.4 (0) | 1.4 (0.2) |
| NGO | 2.9 (0) | 0 (0) | 0 (0) | 0 (0) |
| Other | 595.2 (0.1) | 2.9 (0) | 1.2 (0) | 1.2 (0.1) |
| Private | 21245.8 (3.3) | 63.5 (0.5) | 8.5 (0.2) | 0 (0) |
| State | 187 (0) | 1 (0) | 0.7 (0) | 0.7 (0.1) |
| **Grand Total** | **639545.1 (100)** | **11628.6 (100)** | **4719.3 (100)** | **906.9 (100)** |

# References


Adhikari, D., S. K. Barik, K. Upadhaya. 2012. Habitat distribution modelling for reintroduction of *Ilex khasiana* Purk., a critically endangered tree species of northeastern India. *Ecological Engineering* 40:37-43.

Aiello-Lammens, M. E., R. A. Boria, A. Radosavljevic, B. Vilela, and R. P. Anderson. 2015. spThin: An R package for spatial thinning of species occurrence records for use in ecological niche models. *Ecography* 38:541-545.

Anderson, M. G., A. Barnett, M. Clark, C. Ferree, A. Olivero Sheldon, and J. Prince. 2016. *Resilient Sites for Terrestrial Conservation in Eastern North America*. Boston, MA: The Nature Conservancy, Eastern Conservation Science, http://climatechange.lta.org/wp-content/uploads/cct/2016/07/Resilient_Sites_for_Terrestrial_Conservation.pdf

Araújo, M. B., and A. Guisan. 2006. Five (or so) challenges for species distribution modelling. *Journal of Biogeography* 33:1677-1688.

Barbet-Massin, M., F. Jiguet, C. H. Albert, and W. Thuiller. 2012. Selecting pseudoabsences for species distribution models: How, where and how many? *Methods in Ecology and Evolution* 3:327-338.

Cipollini, M. L., D. A. Wallace-Senft, and D. F. Whigham. 1994. A model of patch dynamics, seed dispersal and sex ratio in the dioecious shrub *Lindera benzoin* (Lauraceae). *Journal of Ecology* 82:621-633.

Compton, B. W., K. McGarigal, S. A. Cushman, and L. G. Gamble. 2007. A resistant-kernel model of connectivity for amphibians that breed in vernal pools. *Conservation Biology* 21: 78-799.

Crall, A. W., C. S. Jarnevich, B. Panke, N. Young, M. Renz, and J. Morisette. 2013. Using habitat suitability models to target invasive plant species surveys. *Ecological Applications* 23:60-72.

Drayton, B., and R. B. Primack. 2012. Success rates for reintroductions of eight perennial plant species after 15 years. *Restoration Ecology* 20:299-303.

Elith J., and M. Burgman. 2002. Predictions and their validation: Rare plants in the central highlands, Victoria, Australia. pp 303-314 in J.M. Scott, et al (eds.). *Predicting Species Occurrences: Issues of Accuracy and Scale.* Washington DC: Island Press.

Elith, J., C. H. Graham, R. P. Anderson, M. Dudik, S. Ferrier, A. Guisan, R. J. Hijmans, F. Huettmann, J. R. Leathwick, A. Lehmann, J. Li, L. G. Lohmann, B. A. Loiselle, G. Manion, C. Moritz, M. Nakamura, Y. Nakazawa, J. M. Overton, A. T. Peterson, S. J. Phillips, K. Richardson, R. Scachetti-Pereira, R. E. Schapire, J. Soberon, S. Williams, M. S. Wisz, and N. E. Zimmermann. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29:129-151.

Frost, C. 1998. Presettlement fire frequency regimes of the United States: A first approximation. In: T. Pruden and L. Brennan (eds.). *Fire in Ecosystem Management: Shifting the Paradigm from Suppression to Prescription*. Tall Timbers Research Station, Tallahassee, FL, pp 70–81.

Godefroid, S., C. Piazza, G. Rossi, S. Buord, A. D. Stevens, R. Aguraiuja, C. Cowell, C. W. Weekley, G. Vogg, J. M. Iriondo, and I. Johnson. 2011. How successful are plant species reintroductions? *Biological Conservation* 144(2):672-682.

Gogol-Prokurat, M. 2011. Predicting habitat suitability for rare plants at local spatial scales using a species distribution model. *Ecological Applications* 21:33-47.

Gordon, K. L., R. L. Jones, J. B. Wiseman, Jr, and B. E. Wofford. 1986. Status report, *Lindera subcoriacea*. Jackson, MS: U.S. Fish and Wildlife Service, Endangered Species Office.

Gridded Soil Survey Geographic Database (gSSURGO). 2014. *Gridded Soil Survey Geographic Database for the Conterminous United States*. Washington, DC: USDA, Natural Resources Conservation Service. Accessed 15 January 2015, https://gdg.sc.egov.usda.gov/

Guerrant, E. O., and T. N. Kaye. 2007. Reintroduction of rare and endangered plants: common factors, questions and approaches. Australian Journal of Botany 55:632-370.

Halsey, S. J., T. J. Bell, K. McEachern, and N. B. Pavlovic. 2015. Comparison of reintroduction and enhancement on metapopulation viability. *Restoration Ecology* 23:375-384.

Hijmans, R. J. 2012. Cross-validation of species distribution models: Removing spatial sorting bias and calibration with a null model. *Ecology* 93:679-688.

Hijmans, R. J., S. E. Cameron, J. L. Parra, P. G. Jones, and A. Jarvis. 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25:1965-1978.

Homer, C. G., J. A. Dewitz, L. Yang, S. Jin, P. Danielson, G. Xian, J. Coulston, N. D. Herold, J. D. Wickham, and K., Megown. 2015. Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. *Photogrammetric Engineering & Remote Sensing 81*:345-354.

Iturbide, M., J. Bedia, S. Herrera, O. del Hierro, M. Pinto, and J.M. Gutiérrez. 2015. A framework for species distribution modelling with improved pseudo-absence generation. *Ecological Modelling* 312:166-174.

Jueterbock, A. 2015. *R package MaxentVariableSelection: Selecting the Best Set of Relevant Environmental Variables along with the Optimal Regularization Multiplier for Maxent Niche Modeling*, https://cran.r-project.org/web/packages/MaxentVariableSelection/index.html

Just, M. G., M. G. Hohmann, and W. A. Hoffmann. 2016. Where fire stops: Vegetation structure and microclimate influence fire spread along an ecotonal gradient. *Plant Ecology* 217:631-644.

Luken, J. O., L. M. Kuddes, T. C. Tholemeier, and D. M. Haller. 1997. Comparative responses of L*onicera maackii* (amur honeysuckle) and *Lindera benzoin* (spicebush) to increased light. *American Midland Naturalist* 138:331-343.

Marcer, A., L. Saez, R. Molowny-Horas, X. Pons, and J. Pino. 2013. Using species distribution modelling to disentangle realized versus potential distributions for rare species conservation. *Biological Conservation* 166:221-230.

Martens, S. N., D. D. Breshears, and C. W. Meyer. 2000. Spatial distributions of understory light along the grassland/forest continuum: Effects of cover, height, and spatial pattern of tree canopies. *Ecological Modeling* 126:79–93.

Mateo, R. G., T. B. Croat, A. M. Felicísimo, and J. Muñoz. 2010. Profile or group discriminative techniques? Generating reliable species distribution models using pseudo-absences and target-group absences from natural history collections. *Diversity and Distributions* 16:84-94.

McEuen A. B., and L. M. Curran. 2006. Plant recruitment bottlenecks in temperate forest fragments: Seed limitation and insect herbivory. *Plant Ecology* 184:297-309.

McPherson, J. M., W. Jetz, and D. J. Rogers, 2004. The effects of species' range sizes on the accuracy of distribution models: ecological phenomenon or statistical artefact? *Journal of Applied Ecology* 41:811–823.

Menges, E. S., and S. Kennedy. 2007. A successful introduction of the rare endemic *Dicerandra thinicola* to a protected site (Florida). *Ecological Restoration* 25:222–223.

Muscarella, R., P. J. Galante, M. Soley-Guardia, R. A. Boria, J. M. Kass, M. Uriarte, and R. P. Anderson. 2014. ENMeval: An R package for conducting spatially independent evaluations and estimating optimal model complexity for Maxent ecological niche models. *Methods in Ecology and Evolution* 5:1198-1205.

Muth, N. Z., E. C. Kluger, J. H. Levy, M. J. Edwards, and R. A. Niesenbaum. 2008. Increased per capita herbivory in the shade: Necessity, feedback, or luxury consumption. *Ecoscience* 15:182-188.

NatureServe. 2011. Species at Risk on Department of Defense Lands: Updated Analysis, Report and Maps. DoD Legacy Project 10-247. Washington, DC: U.S. Department of Defense (DoD), http://www.dodnaturalresources.net/10-247_FS_SAR_on_DoD_Lands_Update.pdf

NatureServe. 2013. *NatureServe Explorer: An Online Encyclopedia of Life* (web application). Version 7.1. Arlington, VA: NatureServe. Accessed 12 June 2013, http://www.natureserve.org/explorer

NatureServe. 2014. *Species at Risk on Department of Defense Lands: Updated Analysis, Report and Maps*. DoD Legacy Project 14-722. Washington, DC: DoD.

Niesenbaum, R. A. 1992. The effects of light environment on herbivory and growth in the dioecious shrub *Lindera benzoin* (Lauraceae). *American Midland Naturalist* 128:270-273.

Niesenbaum, R. A. 1993. Light or pollen – Seasonal limitations on female reproductive success in the understory shrub *Lindera benzoin*. *Journal of Ecology* 81:315-322.

Open Space Institute (OSI). 2009. *Industrial Forest Classification Dataset*.

Openstreet Map. 2015. OpenStreetMap contributors. https://www.openstreetmap.org/

Parcel Point. 2013. Parcel Boundary Map Data. Irvine, CA: Corelogic®, http://www.corelogic.com/products/parcelpoint.aspx

Phillips, S. J., and M. Dudík. 2008. Modeling of species distributions with MaxEnt: New extensions and a comprehensive evaluation. *Ecography* 31:161-175.

Phillips, S. J., R. P. Anderson, and R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190: 231-259.

Questad, E. J., J. R. Kellner, K. Kinney, S. Cordell, G. P. Asner, J. Thaxton, J. Diep, A. Uowolo, S. Brooks, N. Inman-Narahari, and S. A. Evans. 2014. Mapping habitat suitability for at-risk plant species and its implications for restoration and reintroduction. *Ecological Applications* 24(2):385-395.

R Core Team. 2013. *R: A language and environment for statistical computing. R Foundation for Statistical Computing*. Vienna, Austria: The R foundation, http://www.R-project.org/

Sorrie, B. A., J. B. Gray, and P. J. Crutchfield. 2006. The vascular flora of the longleaf pine ecosystem of Fort Bragg and Weymouth Woods, North Carolina. *Castanea* 71:129-161.

Stambaugh, M. C., R. P. Guyette, and J. M. Marschall. 2011. Longleaf pine (*Pinus palustris* Mill.) fire scars reveal new details of a frequent fire regime. *Journal of Vegetation Science* 22:1094–1104.

Swets, J. A. 1988. Measuring the accuracy of diagnostic system. *Science* 248:1285-1293.

Syfert, M. M., M. J. Smith, and D. A. Coomes. 2013. The effects of sampling bias and model complexity on the predictive performance of MaxEnt species distribution models. *PLoS One* 8:e55158.

Thorpe, A. S., and T. Kaye. 2011. Conservation and reintroduction of the endangered Willamette daisy. *Native Plants Journal* 12:289-298.

U.S. Census. 2014. 2014 TIGER/Line Shapefiles (machine-readable data files). Prepared by the U.S. Census Bureau, 2014 http://www.census.gov/geo/maps-data/data/tiger-line.html

U.S. Department of Agriculture (USDA). 2015. *The Gridded Soil Survey Geographic (gSSURGO) Database for [State Name]* (FY2016 official release). USDA Natural Resources Conservation Service, https://gdg.sc.egov.usda.gov/

U.S. Department of the Defense (USDOD). 2015. *Report to Congress on Sustainable Ranges*. Washington, DC

U.S. Department of the Interior (USDOI), Geological Survey. 2012. *LANDFIRE: LANDFIRE Existing Vegetation Type Layer*. Version 1.3. Accessed 18 November 2015, http://landfire.cr.usgs.gov/viewer/

U.S. Geological Survey (USGS). 2010. *Southeast GAP Land Cover Dataset*. Biodiversity and Spatial Information Center. Raleigh, NC: USGS North Carolina Cooperative Fish and Wildlife Research Unit, North Carolina State University, http://www.basic.ncsu.edu/segap/DataServer.html

VanDerWal, J., L. P. Shoo, C. Graham, and S. E. Williams. 2009. Selecting pseudo-absence data for presence-only distribution modeling: How far should you stray from what you know? *Ecological Modelling* 220:589-594.

Veloz, S. D. 2009. Spatially autocorrelated sampling falsely inflates measures of accuracy for presence only niche models. *Journal of Biogeography* 36:290-2299.

Ventyx Corp. 2014. *Velocity Suite: Transmission Lines Constrained or Congested, Transmission Lines (in Service by Voltage Class), and Natural Gas Pipelines (in Service).* Accessed October 2014.

Wall W. A., M. G. Hohmann, A. S. Walker, and J. B. Gray. 2013. Sex ratios and population persistence in the rare shrub *Lindera subcoriacea* Wofford. *Plant Ecology* 214:1105-1114.

Wall W. A., M. G. Hohmann. 2016. Unpublished data. Champaign, IL: Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL).

Wang, O., L. J. Zachmann, S. E. Sensnie, A. D. Olsson, and B. G. Dickson. 2014. An iterative targeted sampling design informed by habitat suitability models for detecting focal plant species over extensive areas. *PLoS ONE* 9(7):e101196. doi:10.1371/journal.pone.0101196

Warren, D. L., and S. N. Seifert. 2011. Ecological niche modeling in Maxent: The importance of model complexity and the performance of model selection criteria. *Ecological Applications* 21:335-342.

Williams J. N., C. Seo, J. Thorne, J. K. Nelson, S. Erwin, J. M. O'Brien, and M. W. Schwartz 2009. Using species distribution models to predict new occurrences for rare plants. *Diversity and Distributions* 15:565-576.

Wintle, B. A. and D. C. Bardos. 2006. Modeling species-habitat relationships with spatially autocorrelated observation data. *Ecological Applications* 16:1945-1958.

Wofford, B.E. 1983. A new *Lindera* (Lauraceae) from North America. *Journal of the Arnold Arboretum* 64:325–331.

# Acronyms and Abbreviations

| Term | Definition |
|---|---|
| AFB | Air Force Base |
| ASA(ALT) | Assistant Secretary of the Army for Acquisition, Logistics, and Technology |
| AUC | Under the Curve |
| BPS | Biophysical Settings |
| CART | Classification and Regression Tree |
| CC | Canopy Cover |
| CEERD | U.S. Army Corps of Engineers, Engineer Research and Development Center |
| CERL | Construction Engineering Research Laboratory |
| CH | Canopy Height |
| DoD | U.S. Department of Defense |
| DOE | U.S. Department of Energy |
| DOI | U.S. Department of Interior |
| ERDC | U.S. Army Engineer Research and Development Center |
| ERDC-CERL | Engineer Research and Development Center, Construction Engineering Research Laboratory |
| ESA | U.S. Endangered Species Act |
| ESP | Environmental Site Potential |
| ESRI | Environmental Systems Research Institute, Inc. |
| FRG | Fire Regime Group |
| GAP | USGS Gap Analysis Program |
| JFTC | Joint Forces Training Center |
| LANDFIRE | Landscape Fire and Resource Management Planning Tools |
| NGO | Nongovernmental Organization |
| NLCD | National Land Cover Data |
| NRCS | Natural Resources Conservation Service |
| OSI | Open Systems Interconnection |
| PRS | Percentage of Replacement Severity (fires) |
| ROC | Receiver Operating Curve |
| SAR | Species at Risk |
| SDM | Species Distribution Modeling |
| SF | Standard Form |
| SSURGO | Soil Survey Geographic |
| TM | Thematic Mapper |
| TNC | The Nature Conservancy |
| TPI | Topographic Position Index |
| TR | Technical Report |
| URL | Universal Resource Locator |

| Term | Definition |
|---|---|
| U.S. | United States |
| USA | United States of America |
| USFWS | U.S. Fish and Wildlife Service |
| USGS | U.S. Geological Survey |
| VCC | Vegetation Condition Class |
| VDEP | Vegetation Departure |
| WTDEPANMIN | Lower Depth to the Water Table |
| WTDEPANNMIN | Depth to Wet Soil Layer |
| WTENTHBAR | Field Capacity |

| REPORT DOCUMENTATION PAGE | | | *Form Approved* *OMB No. 0704-0188* |
|---|---|---|---|



| 1. REPORT DATE (DD-MM-YYYY) | 2. REPORT TYPE | 3. DATES COVERED (From - To) |
|---|---|---|
| 14-09-2016 | Final | |

**4. TITLE AND SUBTITLE**
A Species Distribution Modeling Informed Conservation Assessment of Bog Spicebush

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT**

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**5d. PROJECT NUMBER**
332112

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**
C6JB27

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
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PO Box 9005,
Champaign, IL 61826-9005

**8. PERFORMING ORGANIZATION REPORT NUMBER**
ERDC/CERL TR-16-31

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology, ASA(ALT)
U.S. Army Acquisition Support Center
9900 Belvoir Road, Bldg. 201
Fort Belvoir, VA 22060

**10. SPONSOR/MONITOR'S ACRONYM(S)**
ODUSD(I&E)

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

**12. DISTRIBUTION / AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**
Bog Spicebush (*Lindera subcoriacea*) is a U.S. Department of Defense (DoD) Species at Risk (SAR) that has recently been proposed for listing under the Endangered Species Act. Roughly 60% of all known Bog Spicebush populations are found on five DoD installations: Fort Bragg, Camp Mackall, Fort Jackson, Eglin Air Force Base (AFB) and Camp Shelby Joint Forces Training Center (JFTC). This recently described species has been reported to occupy a variety of plant communities that have varying disturbance dependence, suggesting the habitat suitability of occupied sites is spatially and temporally dynamic. Additional information about Bog Spicebush habitat requirements and potential distribution is needed to inform assessments of the species' conservation status and management needs. This project used MaxEnt, a widely applied species distribution modeling approach to generate a range-wide habitat suitability map. This map was also used to identify: (1) sites warranting targeted surveys for novel populations, (2) suitable habitat for conservation and management, and (3) sites suitable for population (re)introduction.

**15. SUBJECT TERMS**
Endangered plants, Plant conservation, Shrubs, Phytogeography, Habitat suitability index models, Restoration ecology, Military bases

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | 19b. TELEPHONE NUMBER (include area code) |
| Unclassified | Unclassified | Unclassified | SAR | 51 | |