SITE PRIORITIZATION OF CURRENT AND POTENTIAL RED-COCKADED WOODPECKER HABITAT IN THE ONSLOW BIGHT LANDSCAPE

By

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April 27, 2023

Masters project submitted in partial fulfillment of the requirements for the Master of Environmental Management degree in the Nicholas School of the Environment of Duke University

EXECUTIVE SUMMARY

Red-cockaded woodpeckers (RCW) are an important keystone species in southeastern pine forests. Unfortunately, however, they have been federally listed as endangered since 1970, due to habitat loss and fragmentation. They have specific habitat requirements, most often roosting in old-growth longleaf pine savannas with an open understory, a forest type that once dominated the southeastern United States. There have been reports of RCW roosting in other pine-dominant forests, such as loblolly, when the overall forest structure is similar to that of their preferred habitat – sparse trees with an open understory. Although efforts have increased in recent decades to protect this bird, populations still struggle to remain stable.

This project was completed in partnership with the North Carolina Coastal Land Trust (NCCLT), a land trust that serves 31 counties in the Coastal Plain region. Since their founding in 1992, they have protected over 85,000 acres along the coast of North Carolina. They have experience in longleaf pine restoration and have a particular interest in the recovery of RCW. They hope this study will help prioritize parcels to conserve based on the presence of or the ability to restore RCW habitat.

The overarching goal of this project was to help prioritize land for NCCLT's RCW protection efforts. This goal was broken into three achievable objectives: (1) to develop a replicable model for predicting RCW habitat presence from LiDAR-derived forest structure metrics; (2) to determine if 55 privately owned parcels within the Onslow Bight landscape have potential habitat for RCW, as determined by forest structure and soil type; (3) to prioritize those parcels based on their likelihood of having RCW habitat as well as other conservation criteria.

The area of focus for this study was within the Onslow Bight landscape of the North Carolina Coastal Plain. The Onslow Bight extends from the Cape Fear River near Wilmington north to Cape Lookout and west to New Bern. This region was chosen due to its significant population of RCW, with the largest clusters residing in Croatan National Forest, Camp Lejeune Marine Corps Base, and Holly Shelter Game Land. It was also chosen because NCCLT had already completed a prioritization of parcels within the Onslow Bight, ranking them by their calculated overall conservation value.

The 55 privately-owned parcels analyzed in this study were selected because they met two criteria: (1) were within 5 km of a current population of RCW, and (2) were given a high or very high conservation value in the previous analysis by NCCLT. Analyses for this study occurred in three main parts. First, forest structure metrics were calculated within 1-km grid cells across the 55 parcels of interest and across 14 areas of known RCW habitat from LiDAR point cloud data. Second, a binomial generalized linear model was used to estimate habitat likelihood to predict the presence of RCW habitat in parcels. Third, parcels were prioritized based on four criteria important in differentiating good habitat for RCW. These criteria included the proportion of habitat within each parcel, based on the habitat likelihood model, the distance to the nearest current population of RCW, the proportion of known longleaf pine habitat within each parcel, and the presence of a historic population of RCW.

Three variables were found to be significant predictors of the presence of RCW habitat – maximum canopy height, rumple or canopy roughness, and vertical complexity index. The logit model explained about 42.3% of the variability in habitat and had a total accuracy in predicting RCW habitat of 85.6%. Thirty-five parcels were found to contain suitable habitat for RCW, but only 10 parcels had at least 10% of their total area as habitat. Thirty parcels were within 1 km of a current RCW population,

making them the most likely candidates for future RCW to inhabit. Only two parcels contained a historic RCW population, both of which border Croatan National Forest. Five parcels had over 25% of their total area as longleaf pine, while 24 parcels had between 1 and 25%.

The final combined prioritization resulted in an RCW conservation value range from 1.8 to 9.1 out of 10 across all 55 parcels. Based on my categorization, two parcels have a high RCW conservation value, 40 parcels have a moderate RCW conservation value, and 13 parcels received a low RCW conservation value. The model was determined to not be sensitive based on the final ranking changing only slightly when the scores and weights of each layer were varied by 10% in both directions.

The habitat likelihood model and parcel prioritization will provide NCCLT with a useful estimate of current RCW habitat on their parcels of interest across the Onslow Bight landscape. These parcels have already been determined as having a high overall conservation value, and this additional data can help inform their decisions in further prioritizing parcels for purchase. However, ground truthing these parcels through site visits is a necessary next step for NCCLT to determine if they actually contain RCW habitat, as found in this project. The results from this study help conservation organizations, like NCCLT, know where potential habitat exists, and therefore where RCW could be translocated to increase population numbers or where proper management needs to take place to improve habitat and encourage RCW use. These results might also help secure funding for the purchase and management of these parcels since more funding opportunities exist for the protection of endangered species. On parcels where RCW habitat was not found to be likely, these data still provide a useful toolbox to understand each parcel's ecological structure, which can inform management decisions and help predict the presence of other important species in the future.

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1. INTRODUCTION

The red-cockaded woodpecker (RCW; *Dryobates borealis*) was once a common bird native to the pine forests of the southeastern United States. However, since 1970, it has been federally listed as endangered and today, only about 1% of its historic population remains (USFWS, 1995). Its habitat range spans from coastal North Carolina, south to Florida, and west to the eastern most portions of Texas and Oklahoma (USFWS, 2022). Historically, the species was contiguous within this range; however, today, it resides in extremely fragmented and isolated clusters (USFWS, 2020). When RCW was listed as endangered, there were an estimated 10,000 individual birds across the southeast. Today, there are an estimated 16,250 birds (Forest Service, n.d.). This increase is most notably due to the creation of artificial cavities, which can be placed in trees RCW normally would not excavate, translocation efforts to increase genetic diversity, and improved habitat management, especially on private lands (Loeb et al., 2012). Although population numbers have shown promise for the recovery of the species, RCW still lack adequate habitat and management to reach stable conditions.

RCW have very specific habitat requirements, most often roosting in old-growth longleaf pine savannas with an open understory, a forest type that once dominated the southeastern United States, including in North Carolina. It is estimated that longleaf pine ecosystems spanned 90 million acres in the southeast before Europeans colonized the area (Frost, 1993). Today, only about 3.4 million acres remain (Ross, 2010). Longleaf pine forests have historically been converted to faster growing pines used in commercial industries, such as loblolly or slash, or to agricultural land. There have been reports of RCW roosting in other pine-dominant forests, such as loblolly, when the overall forest structure is similar to that of their preferred habitat – sparse trees with an open understory (Walker & Wang, 2014). However, much of the loblolly pine presence in North Carolina is in pine plantations where trees are densely grown and eventually harvested (Fagan et al., 2018).

Another important aspect of RCW habitat is the presence of fire. Historically, longleaf pine savannas experienced natural fires ignited by lightning every few years, which were necessary to maintain the open understory and herbaceous groundcover, such as wiregrass, that RCW prefer (Lucash et al., 2022). Fire suppression over the last century is another contributor to the decline in RCW habitat. Today, wildlife managers maintain fire-dependent ecosystems with prescribed fires every few years. This can be difficult in areas of habitat close to urban zones due to city regulations. Lucash et al. (2022) also estimates that using prescribed fire as a management tool for RCW habitat will become increasingly difficult as our climate warms, due to decreases in burn windows, or the timeframe when it is safe to burn.

RCW evolved in a fire-dependent ecosystem, causing them to adapt to excavating living trees, since fire significantly reduces the number of dead trees where woodpeckers typically excavate their roosting cavities. They are the only known woodpecker to excavate living pine trees, allowing them to outcompete competitors in their preferred habitat (Conner et al., 2004). RCW are known as a keystone species because they provide critical habitat in the form of tree cavities for more than 30 other wildlife species in the fire-dependent pine forests of the southeast (Conner et al., 2004). Management efforts have shifted from being focused on preventing extinction in the late 1900s to preserving and restoring longleaf pine ecosystems, which allow for the management of habitat for a wide array of species (Weiss et al., 2019). Weiss et al. (2019) found that focusing on broader conservation strategies, rather than a single species, allowed for more sustainable long-term outcomes. The US Fish and Wildlife Service (2020) proposed downlisting RCW from endangered to

threatened in 2020. This proposal claims that the “the species' status has improved such that it is not currently in danger of extinction throughout all or a significant portion of its range.” However, many environmental organizations and local conservationists have protested the downlisting, including the Southern Environmental Law Center, which stated that the proposal was not scientifically or legally supported (Ho, 2022).

Since RCW was listed as endangered, efforts have increased to conserve remaining longleaf pine forests and restore forests to longleaf pine ecosystems; however, many RCW populations remain unstable and are under threat of further decline without increased management (NCWRC, n.d.). North Carolina Coastal Land Trust (NCCLT) has a history of conserving land across the Coastal Plain. Since their founding in 1992, they have protected over 85,000 acres along the coast of North Carolina. They have experience in longleaf pine restoration and have a particular interest in the recovery of RCW. They hope this study will help prioritize parcels to conserve based on the presence of or the ability to restore RCW habitat.

1.1 Objectives

The overarching goal of this project was to help prioritize land for NCCLT’s RCW protection efforts. This goal was broken into three achievable objectives. First, I aimed to develop a replicable model for predicting RCW habitat presence from LiDAR-derived forest structure metrics. Second, this study aimed to determine if 55 privately owned parcels within the Onslow Bight landscape have potential habitat for RCW, as determined by forest structure and soil type. Lastly, I sought to prioritize those parcels based on their likelihood of having RCW habitat, their distance from a known RCW population, the presence of a historic RCW population, and the amount of known longleaf pine present in the parcel.

2. METHODS

Analyses for this study occurred in three main parts. First, forest structure metrics were calculated across each parcel and in known habitat areas from light detection and ranging (LiDAR) point cloud data. Second, a binomial generalized linear model was used to create a habitat likelihood equation to predict the presence of RCW habitat in parcels. Third, parcels were prioritized based on four criteria important in differentiating good habitat for RCW.

2.1 Study Area

In North Carolina, the most significant remaining populations of RCW are found in the Sandhills and Coastal Plain regions (NC Wildlife Resources Commission, n.d.). The area of focus for this study was within the Onslow Bight landscape of the North Carolina Coastal Plain. The Onslow Bight extends from the Cape Fear River near Wilmington north to Cape Lookout and west to New Bern (Figure 1). It includes numerous managed lands, such as Croatan National Forest, Cedar Island Wildlife Refuge, Holly Shelter Game Land, Angola Bay Game Land, and Camp Lejeune Marine Corps Base, among many others. This region has a significant population of RCW, with the largest populations residing in Croatan National Forest, Camp Lejeune Marine Corps Base, and Holly Shelter Game Land. Smaller populations have been recorded near the Cape Fear River in Pender County and in Carteret County

near Cedar Island Wildlife Refuge and Turnagain Bay. Altogether, there are an estimated 11,858 acres of known habitat within the Onslow Bight landscape (NCNHP, 2019).

In addition to the high number of managed lands and significant population of RCW, this landscape was also chosen because of concentrated conservation efforts by the Onslow Bight Conservation Forum (OBCF). The OBCF is made up of 14 different organizations including state and federal agencies, the US military, and the client for this study, NCCLT. This forum's mission is to "provide for open discussion among the participants concerning the long-term conservation and enhancement of biological diversity and ecosystem sustainability throughout the Onslow Bight Landscape compatible with the land use, conservation, and management objectives of the participating organizations and agencies" (NC Wildlife, n.d.). The 55 parcels of interest I analyzed are all within 5 km of known RCW habitat, in close proximity to managed lands, and have a high or very high conservation value according to a previous analysis done by NCCLT.

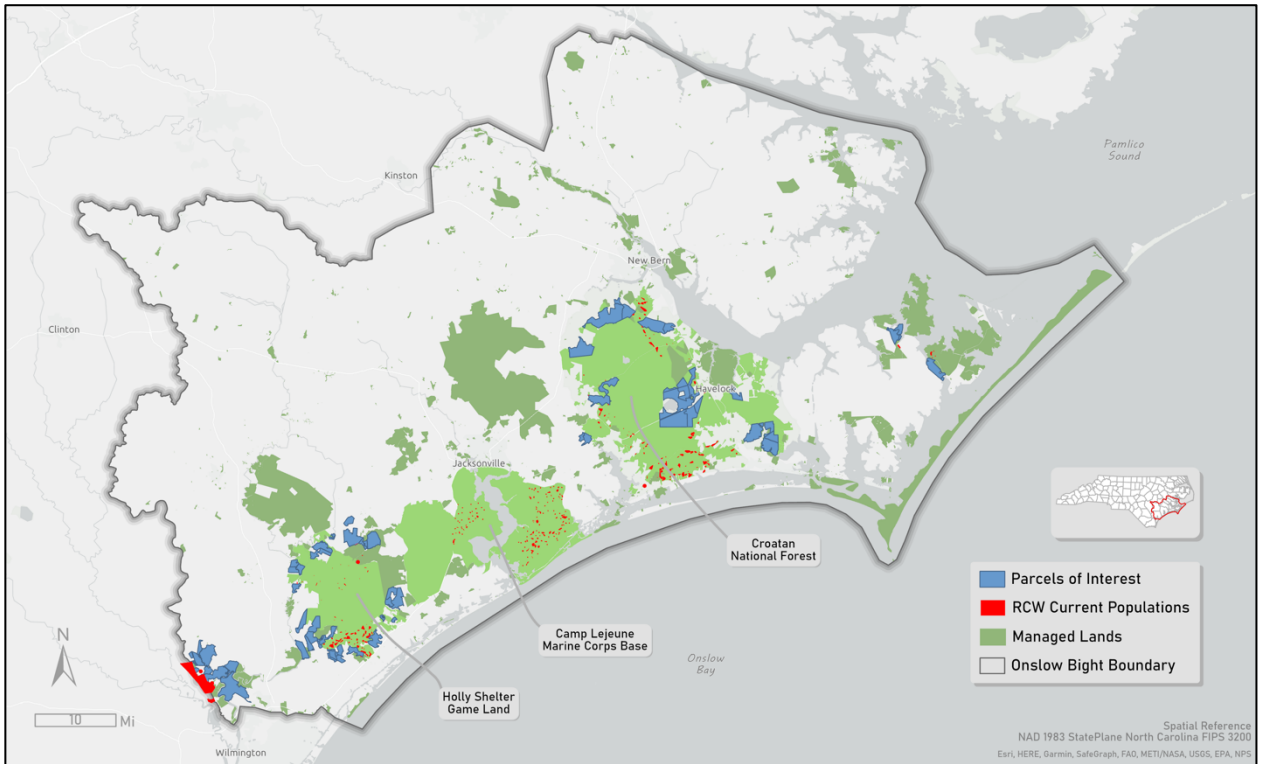

Figure 1: Study area showing areas of current RCW populations and the parcels analyzed in this study. The three highlighted managed areas have the most significant clusters of RCW in this region.

2.2 Data Collection & Preparation

Element occurrence data for red-cockaded woodpeckers across North Carolina were provided by the North Carolina Natural Heritage Program as a polygon shapefile (NCNHP, 2019). Current and historic populations of RCW were included in the layer. I used polygons of current populations in five areas of the Onslow Bight landscape for my analysis. According to the Natural Heritage Program's dataset,

current RCW clusters were last observed between 2001 and 2021, the last time a survey was conducted due to the COVID-19 pandemic (Table 1).

Table 1: Timespans and acreage of the five areas of RCW known habitat in the Onslow Bight

Location	First Observed	Last Observed	Area (Acres)
Croatan National Forest	1977	2021	3742.8
Holly Shelter Game Land	1974	2021	1795.5
Near Cape Fear River in Pender County	1976	2015	3836.2
Near Cedar Island National Wildlife Refuge	1992	2001	84.8
Near Turnagain Bay	2003	2003	61.0

I used the polygons that were nearest to the parcels of interest and larger in size within these five areas as my reference for downloading LiDAR data for areas of known habitat. I included both current and historic populations in my prioritization model since areas with historic RCW presence likely have the correct ecosystem metrics to be restored to habitat.

Parcel data were provided by NCCLT from their prioritization analysis in August 2022 across the Onslow Bight landscape, in which they ranked parcels based on a set of criteria to determine a final conservation value. These criteria included climate resilience, biodiversity, proximity to already managed/protected areas, current carbon storage, the containment of significant natural heritage areas, stream frontage, threat of urban growth (i.e., and conversion), and parcel size. Parcels smaller than 150 acres were excluded from the analysis. In this study, I included only those parcels that met two additional criteria: (1) the parcels had to be within 5 km of a current RCW population, because research has shown that is the furthest distance they will disperse (USFWS, 2022); and (2) the parcels had to have a high or very high conservation value, because this indicates that NCCLT already has some interest in the property. This narrowed the number of parcels from 580+ to 55, a much more reasonable number to analyze with the given methods.

Small-footprint LiDAR point clouds were collected from North Carolina Emergency Management's spatial data download website. Points were collected between January 30 and March 13 of 2014, during leaf-off conditions. A linear aerial sensor was used in point collection at two points per meter with full returns and with tested quality control accuracy of 6 cm (NC Emergency Management, 2014). Each of the 55 parcels and 14 known habitat areas were downloaded as separate LAS files, a file format created for the exchange of LiDAR point cloud data. Parcel boundaries were hand drawn on the website based on aerial imagery and a comparison to the parcel's location in ArcGIS Pro (Version 3.0.1; ESRI, 2022). This might have led to human error in the precise size and location of the parcel, with some LiDAR point clouds not aligning perfectly with the parcel's actual boundaries. The most significant limitation of this study is the date of collection for the LiDAR data. This analysis assumes that the landcover and forest structure of the parcels and known habitat areas have not changed since 2014, which is unlikely. I also assumed that the 14 areas of known habitat were comprehensive in their representation of good RCW habitat.

A grid of 1 km squares was created across the Onslow Bight landscape and extracted for each of the 55 parcels and 14 areas of known habitat. The number of grid cells per parcel or area ranged from two to 48. Forest structure metrics were calculated within each grid cell to have a more granular understanding of the likelihood of RCW habitat across each parcel.

The USDA gridded national soil survey geographic database (gNATSGO), which is a 10m raster, was used to determine the soil type of the parcels of interest and known habitat areas (USDA, 2021). The USGS' national land cover dataset (NLCD) from 2019, which is a 30m raster, was used to determine the distance of a parcel from urban areas, including open space, low intensity, medium intensity, and high intensity development (USGS, 2019). Longleaf element occurrence (LEO) data in polygon form was provided by The Longleaf Alliance (2019) and includes areas of current known longleaf pine presence in the southeastern US.

2.3 LiDAR-derived Forest Structure Metrics

Several studies show the benefits of using LiDAR data to estimate habitat structure. LiDAR-derived metrics have proven to be extremely accurate when compared to field-based methods, less time-consuming, and more consistent (Hyde et al., 2005; Jaime-Gonzalez et al., 2017). LiDAR has the capability of measuring horizontal and vertical metrics at the individual tree level (i.e., tree height, crown width, etc.), at the canopy level (i.e., ruggedness, leaf area, etc.), and at the landscape level (i.e., openness, etc.) (Zhao et al., 2011). Smart et al. (2012) used LiDAR to assess the relationship between forest structure and RCW habitat. They found that the inclusion of LiDAR-derived forest structure metrics improved their MaxEnt species distribution model by 8%.

Analysis of LiDAR point clouds was conducted in R (Version 4.2.2; R Core Team, 2022), using the lidR package (Roussel et al., 2022). Any points above 175 ft were excluded from the analysis, as these were assumed to be birds. LiDAR points were clipped to each grid cell for analysis. A digital terrain model (DTM) with a 3 ft resolution was then created using a TIN interpolation method by extracting only the ground points. The DTM was then used to normalize the rest of the point cloud by subtracting the elevation of points from their height. I used the normalized points to create a canopy height model (CHM), which estimates the height of the vegetative canopy across the grid cell. The CHM had a resolution of 3 ft and was created using a point-to-raster algorithm with a 0.2 sub-circle radius.

The CHMs were then used to calculate 13 forest structure metrics for each grid cell (Table 2). The methods for calculating each metric were taken from LaRue and O'Leary (2021) who conducted a similar analysis comparing the structure of two different forest types in Massachusetts and California using LiDAR data. These 13 metrics were calculated because together they provide a comprehensive (vertical and horizontal) characterization of a grid cell's forest structure.

Table 2: Descriptions of the 13 forest structure metrics used in the analysis

Metric Name	Name in Analysis	Definition
Mean outer canopy height	mean.max.canopy.ht	Mean tree height in the canopy
Maximum canopy height	max.canopy.ht	Maximum tree height in the canopy

Rumple	rumple	Ratio of outer canopy surface area to ground surface area; measure of canopy roughness
Number of deep gaps	deepgaps	Number of deep gaps, or 3 ft^2 areas of no points, which are assumed to be gaps in the canopy
Deep gap fraction	deepgap.fraction	Number of deep gaps in the canopy relative to the total number of pixels; measure of canopy openness
Cover fraction	cover.fraction	Inverse of the deep gap fraction; measure of canopy cover
Top rugosity	top.rugosity	Standard deviation of pixels in the CHM; measure of canopy roughness
Vertical standard deviation	vert.sd	Standard deviation of height values for all points in the point cloud; measure of canopy roughness
Standard deviation of the vertical standard deviation	sd.sd	Standard deviation of the vertical standard deviation; measure of both the internal and external canopy complexity
Entropy	entropy	Measure of diversity and evenness of tree heights within the plot across 1 ft tall slices
Gap fraction profile	GFP	Assesses the distribution of gaps in the canopy volume by 1 ft tall horizontal layers
Vegetation area index	VAI	Sum of leaf area density values for all 1 ft horizontal slices
Vertical complexity index	VCI	Measure of evenness of the vertical distribution of tree heights across canopy layers

2.4 Logistic Regression & Habitat Likelihood Model

One data frame was created with the forest structure metrics for all grid cells across each parcel or known habitat area, with a presence/absence column of 1 or 0 to designate areas of known habitat from parcels of interest. In addition to forest structure, I also used soil type as a variable in predicting the likelihood of RCW habitat in a parcel. To do this, I created a point layer at the center of each grid cell and sampled the soil type at each point location in ArcGIS Pro using the GNATSGO soil survey from USDA. These points were then addressed the forest structure metrics of the grid cell they fell within and inputted back into R.

Using this new point data frame, I determined which of the 14 variables (13 forest structure metrics and soil type) were highly correlated and those not as relevant in determining RCW habitat were removed (Figure A.1 in the Appendix). I used a threshold of |0.7| to reduce collinearity (Dormann et al., 2013). Correlated variables that had grid cells with missing values were removed first. The variable that had the least significance (highest p-value) and was highly correlated with another variable was then removed. I continued removing correlated variables one at a time until the model had no significant correlation between variables.

I then ran a logistic regression fitted with a binomial distribution with a logistic link on all remaining variables, which has been proven to be a successful method in modeling habitat from presence/absence data (Pearce & Ferrier, 2000). I downweighted the absence points due to a significant difference in sample size of RCW presence and absence (576 points for absence and 67 points for presence), using 67/576, or ~0.116, as the weight for absences. I then used forward and backward stepwise regression to come to a final model. The coefficients from this final model were used to predict the probability of RCW habitat presence for each grid cell. The cut-off value for predicting habitat was determined using receiver operating characteristics (ROC) curves, which is a method advocated by Pearce and Ferrier (2000) to maximize true positives while minimizing false positives when classifying habitat and not habitat. True positives occur when habitat is correctly classified as habitat, while false positives occur when non-habitat is classified incorrectly as habitat. Any grid cell with a probability above the ROC-determined threshold was classified as having habitat, and those below as not having habitat (Sing et al., 2005).

2.5 Parcel Prioritization & Model Sensitivity

Parcels were prioritized based on their RCW conservation value. This conservation value was calculated by combining four spatial layers: (1) the proportion of predicted RCW habitat to total parcel area, as calculated by the habitat likelihood model, (2) the parcel's distance to a current RCW population, (3) the proportion of known longleaf pine habitat to total parcel area, and (4) the presence of a historic population of RCW. These four layers were chosen based on available data and what factors are most important in determining good habitat for RCW. Layers were incorporated in addition to habitat likelihood to create a more robust prioritization. The distance to a current population of RCW is important in determining the likelihood of birds using the habitat. The presence of significant longleaf pine habitat aids in understanding restoration potential of parcels, as well as, habitat management techniques, such as prescribed fire. Including the presence of a historic population of RCW in the model also aids in understanding a parcels restoration potential, since previous presence of birds indicates the ability to restore habitat.

Each layer was scored and weighted based on previous studies and expert knowledge from NCCLT (J. Allen, personal communication, March 20, 2023; Table 3). The score breakdown was chosen based on the distribution of parcels within each category and by equally dividing the minimum and maximum values of each layer. The best value for RCW habitat received a 10, while the worst value received a 1 or 2. The layer of the proportion of predicted RCW habitat within each parcel ranged from 0 to 1. I created 5 categories of 0.2 because more categories allowed for smaller differences in area to be scored differently. The same logic was applied to the layer of the parcels' distance to the nearest current population of RCW, which ranked from 0 to 5 km. I created 5 categories of 1 km. The layer of the proportion of longleaf pine habitat within each parcel ranged from 0 to 1. I created 3 categories of none, less than 50%, and more than 50%, because I felt any amount of longleaf pine presence was important and therefore should receive a higher score. The layer of the presence of a historic population of RCW was binary because it was either present or not. This process was somewhat arbitrary and could be revised by NCCLT if their priorities for habitat change.

Table 3: Criteria breakdown, including weight and score, used in the prioritization model

Criteria	Weight	Score Breakdown	
Proportion of RCW habitat to total parcel area	40%	0.8 – 1 0.6 – 0.8 0.4 – 0.6 0.2 – 0.4 0 – 0.2	10 8 6 4 2
Distance to current population	40%	< 1 km 1 – 2 km 2 – 3 km 3 – 4 km 4 – 5 km	10 8 6 4 2
Proportion of longleaf pine habitat to total parcel area	10%	< 0.5 0.0001 – 0.5 0 – 0.0001	10 5 1
Presence of historic population	10%	Presence – 1 Absence – 0	10 1

These four layers were combined in a weighted overlay, which sums the scores of each parcel, considering the weight given to each layer. If the final parcel rank was above 6, it was deemed as having a high RCW conservation value. If it was between 3 and 6 it was designated as having a moderate RCW conservation value, and below a 3 was deemed as having a low RCW conservation value. The sensitivity of our prioritization model was measured by varying the costs and weights of each layer by about 10% and evaluating how the final parcel ranking changed.

3. RESULTS

3.1 Logistic Regression

RCW habitat was successfully characterized, and multiple variables were found to be statistically significant predictors of habitat, including maximum canopy height, rumple, and vertical complexity index. The final model explained an estimated 42.3% of the variability in RCW habitat (Table 4). The negative coefficient for maximum canopy height indicates that the model found RCW to prefer habitat with shorter trees compared to the pseudo absences from the model. The positive coefficient for rumple means the birds prefer habitat with more rumpled canopies or canopies with big trees separated by open spaces, while the negative coefficient for vertical complexity index indicates that RCW prefer areas with less vertical complexity or more contrast in canopy heights.

Table 4: Final logistic regression output

MODEL INFO:

Coefficients:

	Estimate	Std. Error	z val.	Pr(>|z|)	AOV Deviance	Pr(>Chi)
(Intercept)	4.440	1.347	3.296	<0.001	-	-
max.canopy.ht	-0.058	0.016	-3.563	<0.001	14.253	<0.001
rumple	1.085	0.235	4.622	<0.001	35.710	<0.001
vert.complex.index	-6.508	1.816	-3.585	<0.001	14.692	<0.001

Null deviance: 185.76 on 642 degrees of freedom
Residual deviance: 121.11 on 639 degrees of freedom
AIC: 64.587
R^2*Tjur:* 0.423

3.2 Habitat Likelihood Model

The threshold cut-off value for being classified as habitat, determined using ROC curves, was found to be 0.59. This value indicates the best performance of the model by maximizing true positives while minimizing false positives. With this threshold, the model had a total accuracy of 85.6%, a true positive rate of 73.1%, and a true negative rate of 87.2% (Table 5). The model predicted 123 grid cells from parcels of interest to have RCW habitat, with 49 actually having habitat according to my data.

Table 5: Confusion matrix for final logistic regression

Model/Data	1	0
1	49 (73.1%)	74
0	18	502 (87.2%)

Using the threshold cut-off of 0.59 and natural breaks in the data, it was considered likely that a grid cell contained habitat if the probability was between 0.59 and 0.66, very likely between 0.66 and 0.83, and extremely likely above 0.83. It was considered unlikely between 0.33 and 0.59, very unlikely between 0.17 and 0.33, and extremely unlikely if the probability was less than 0.17. From a spatial perspective, most grid cells that were found to have RCW habitat were located near the parcel's boundary, often bordering already protected land, and sometimes overlapping with a current RCW population (Figure 2).

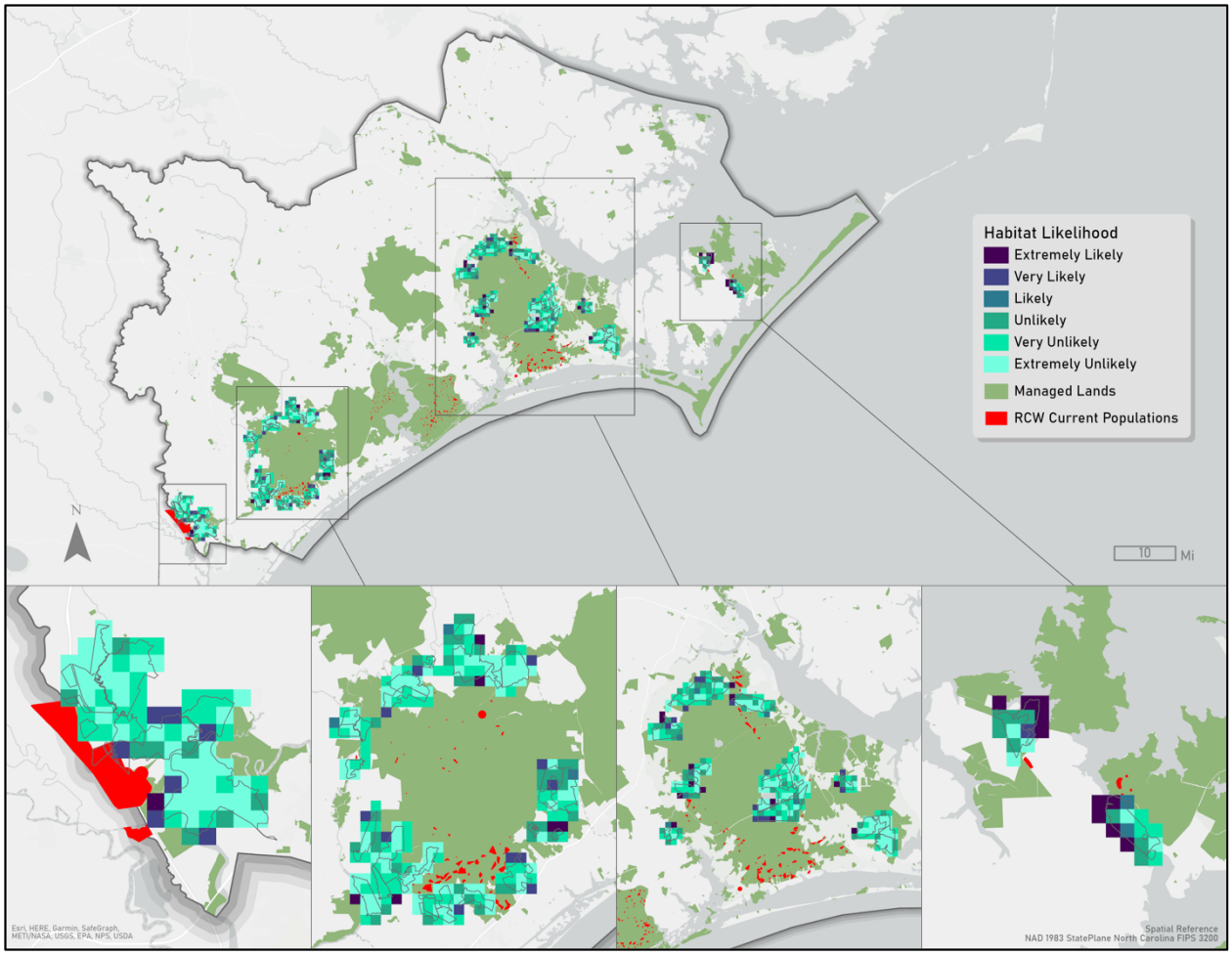

Figure 2: Distribution of grid cells across all parcels colored by likelihood of having RCW habitat

3.3 Parcel Prioritization

The 55 parcels of interest were scored for each of the four criteria in my prioritization model – the proportion of predicted habitat, the distance to a current population, the proportion of longleaf pine habitat, and the presence of a historic population (Table 3). Thirty-five parcels were found to contain suitable habitat for RCW based on our linear regression, but only 10 parcels had at least 10% of their total area as habitat (Figure 3). Thirty parcels were within 1 km of a current RCW population, making them the most likely candidates for future RCW to inhabit (Figure 4). Only two parcels contained a historic RCW population, both of which border Croatan National Forest (Figure 5). Five parcels had over 25% of their total area as longleaf pine, while 24 parcels had between 1 and 25% (Figure 6).

The final combined prioritization resulted in an RCW conservation value range from 1.8 to 9.1 across all 55 parcels. Based on my categorization, two parcels have a high RCW conservation value, 40 parcels have a moderate RCW conservation value, and 13 parcels received a low RCW conservation value (Figure 7). The model was determined to not be sensitive based on the final ranking changing

only slightly when the scores and weights of each layer were varied by 10% in both directions. The five parcels with the highest RCW conservation value are highlighted in Figure 7.

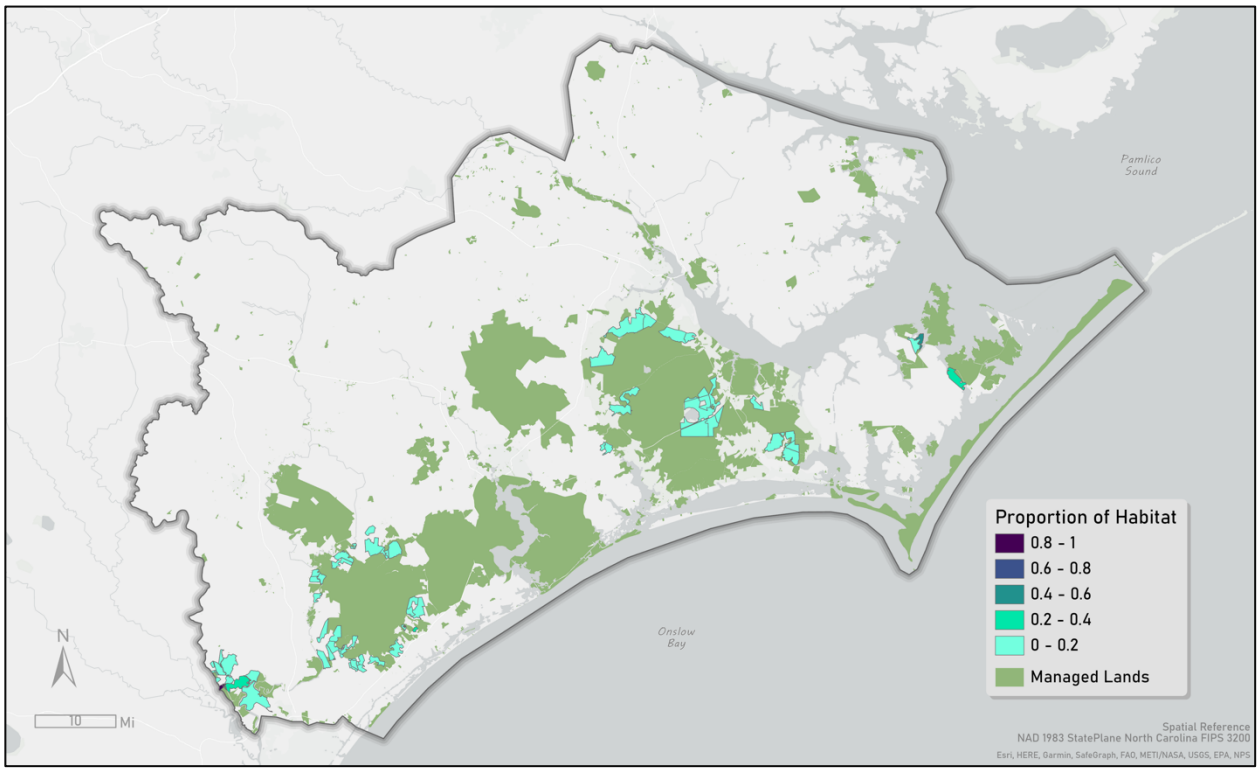

Figure 3: Proportion of RCW habitat to total parcel area, as determined by habitat likelihood linear model

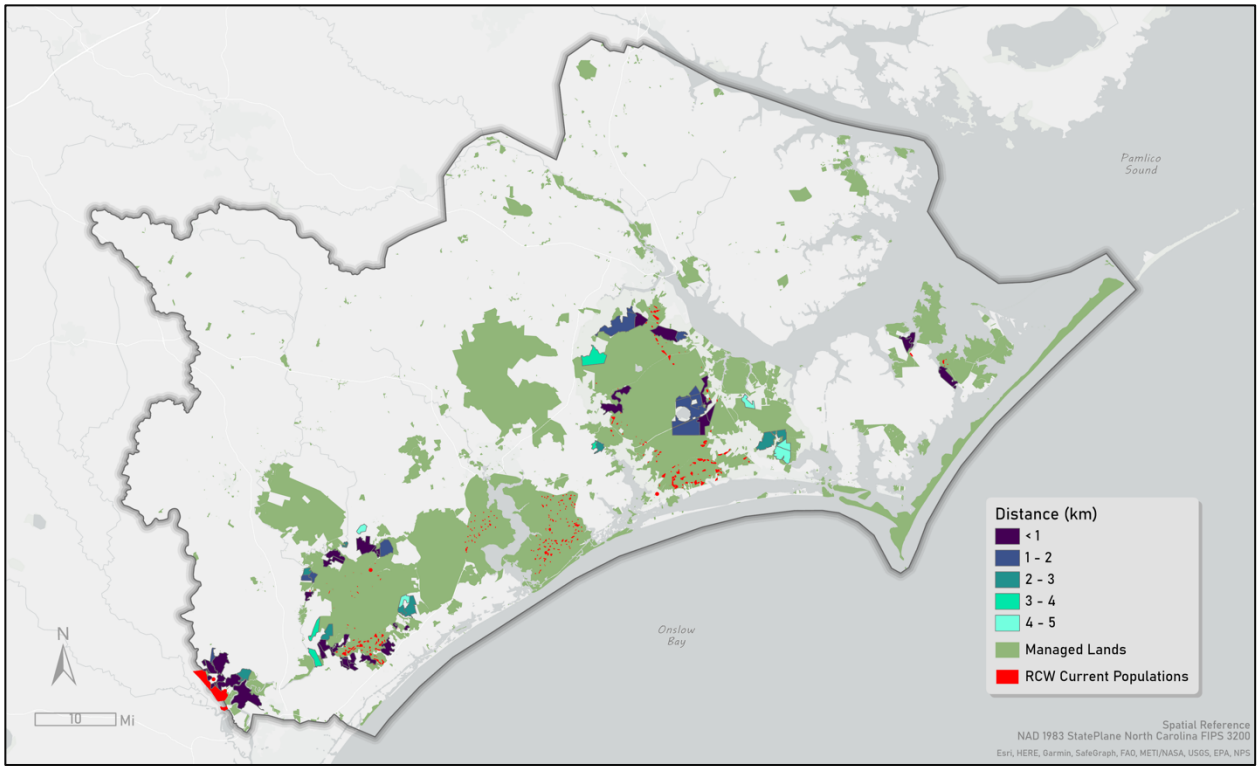

Figure 4: Distance in km to a current RCW population

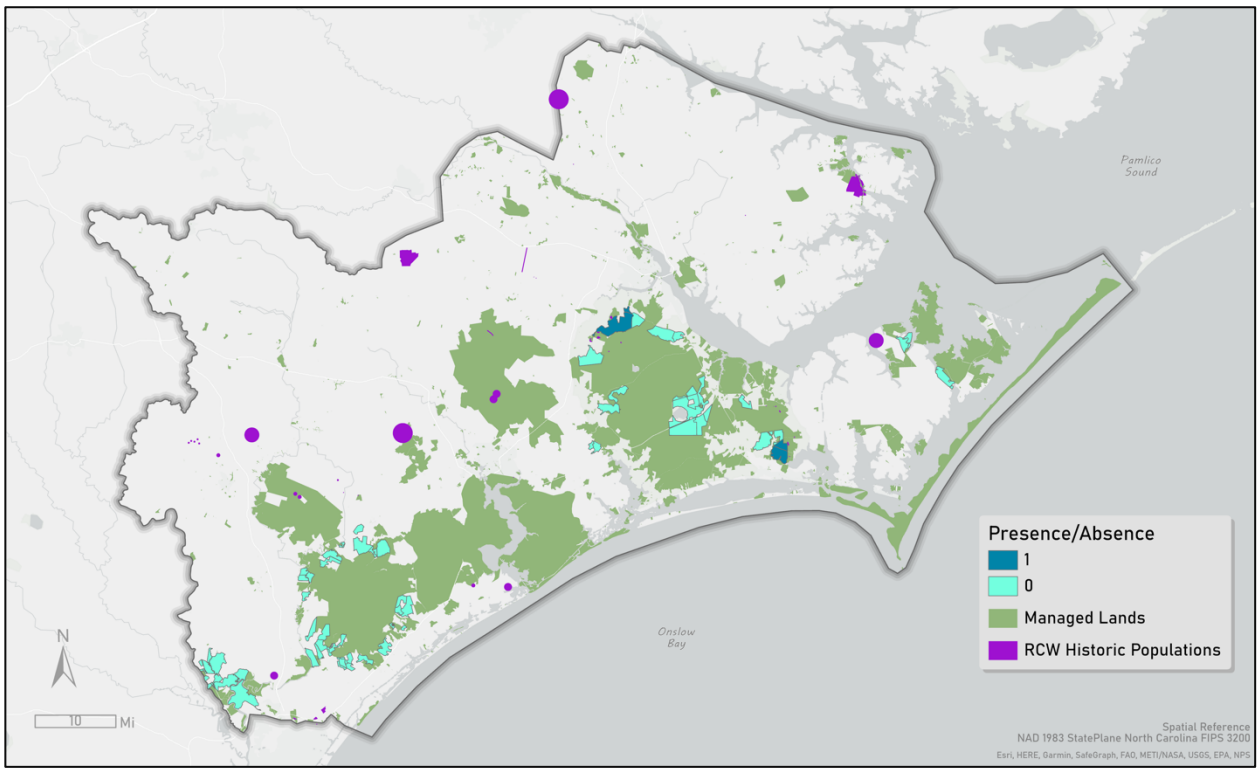

Figure 5: Presence or absence of a historic RCW population within parcel boundaries

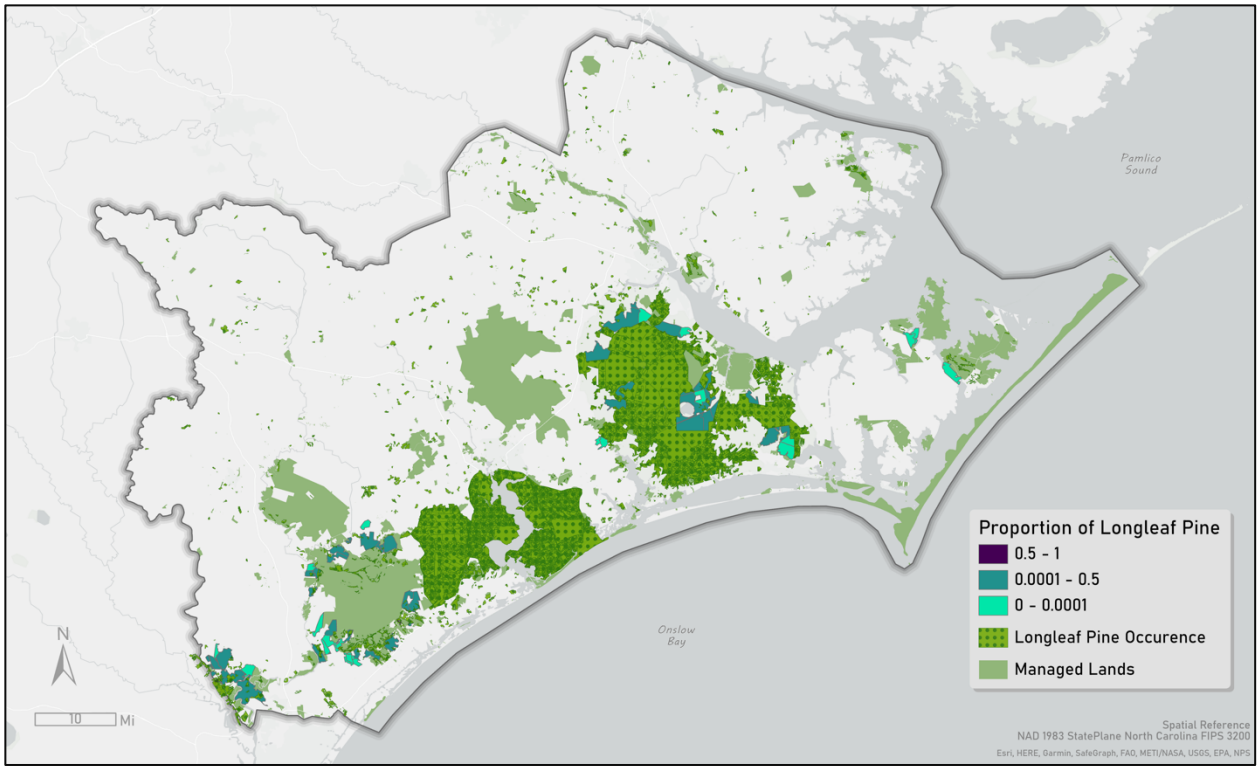

Figure 6: Proportion of longleaf pine area to total parcel area

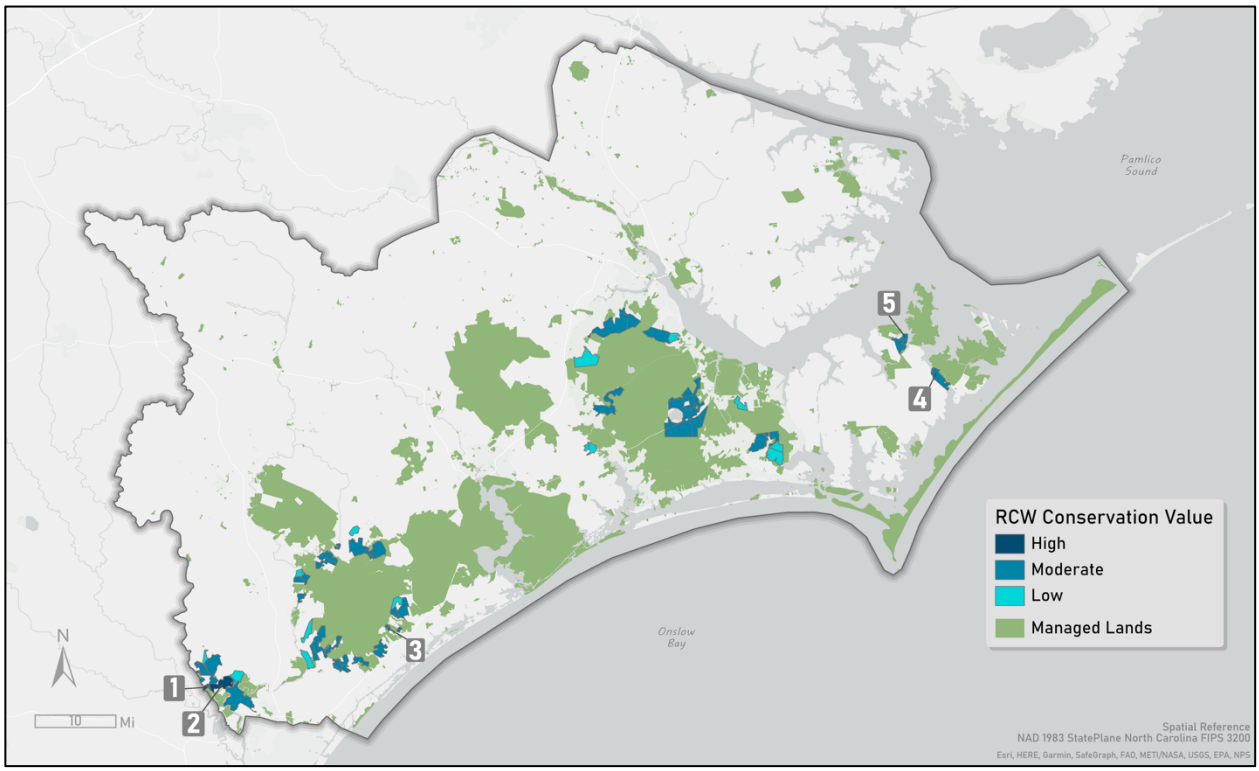

Figure 7: Final ranking of 55 parcels of interest based on their RCW conservation value, with labels for the five highest ranking parcels

4. DISCUSSION

RCW habitat was successfully characterized using LiDAR-derived forest structure metrics. The forests maximum tree height, canopy roughness, and evenness of tree heights were the most significant factors in determining the presence of habitat. My results found that RCW prefer habitat with trees about 80 ft tall, which is much shorter than the loblolly pine plantation trees common across the Onslow Bight, and consistent with the heights of mature longleaf pine trees. My results also showed that RCW like a rougher canopy, or forests with big trees separated by open spaces, as well as relatively homogenous tree heights focused in the upper canopy with little to no mid or understory (Ewijk, 2015). This is consistent with previous studies and my knowledge of RCW 's natural history.

Unsurprisingly, this study did not find a high area of suitable habitat in privately owned parcels across the Onslow Bight Landscape, with only about 8.5% of all areas analyzed predicted to be RCW habitat. Good habitat for RCW requires constant management, such as prescribed fire, which is unlikely for typical landowners unless they have a particular interest in restoring longleaf pine. Only two parcels of 55 received a high RCW conservation value. One of these parcels (ranked first in Map 7) is 100% suitable habitat and contains a current population of RCW. The other parcel (ranked second in Map 7) is 20% suitable habitat and borders a current population. The majority of the parcels of interest received a moderate RCW conservation value, with a large variance in their proportion of suitable habitat (0-55%), but all located within 3 km of a current RCW population, and most within 1 km. This means with proper management, habitat could be successfully restored, and RCW would likely inhabit many of these parcels.

The final parcel ranking changed only slightly when I adjusted the scores and weights of each layer, indicating a model with little sensitivity. This means the parcel ranking from this study truly shows that best parcels for RCW of those I analyzed. NCCLT is at liberty to tweak this model as necessary for their conservation needs, but little changes mean they should be focusing RCW conservation efforts on the five parcels highlighted in figure 7.

An important part of this work that this study did not include is ground-truthing, or traveling to these parcels and directly observing whether they actually contain RCW habitat. This is especially important in this study since the LiDAR data, which were used to calculate the probability of habitat, were collected in 2014. Site visits to these parcels will be a crucial part of any further work by NCCLT in RCW conservation in the Onslow Bight. This study could be improved by using more recent data, once it becomes available, and by including more areas of known habitat in the habitat suitability model.

5. CONCLUSION

The habitat likelihood model and parcel prioritization provide NCCLT with a useful estimate of current RCW habitat on their parcels of interest across the Onslow Bight landscape. These parcels have already been determined as having a high overall conservation value, and this additional data will help inform their decisions in further prioritizing parcels for purchase. These results also help conservation organizations, like NCCLT, know where potential habitat exists, and therefore where

RCW could be translocated to increase population numbers or where proper management needs to take place to improve habitat and encourage RCW use. They might also help secure funding for the purchase and management of these parcels since more funding opportunities exist for the protection of endangered species. On parcels where RCW habitat was not found to be likely, these data still provide a useful toolbox to understand each parcel's ecological structure, which can inform management decisions and help predict the presence of other important species in the future.

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APPENDIX A

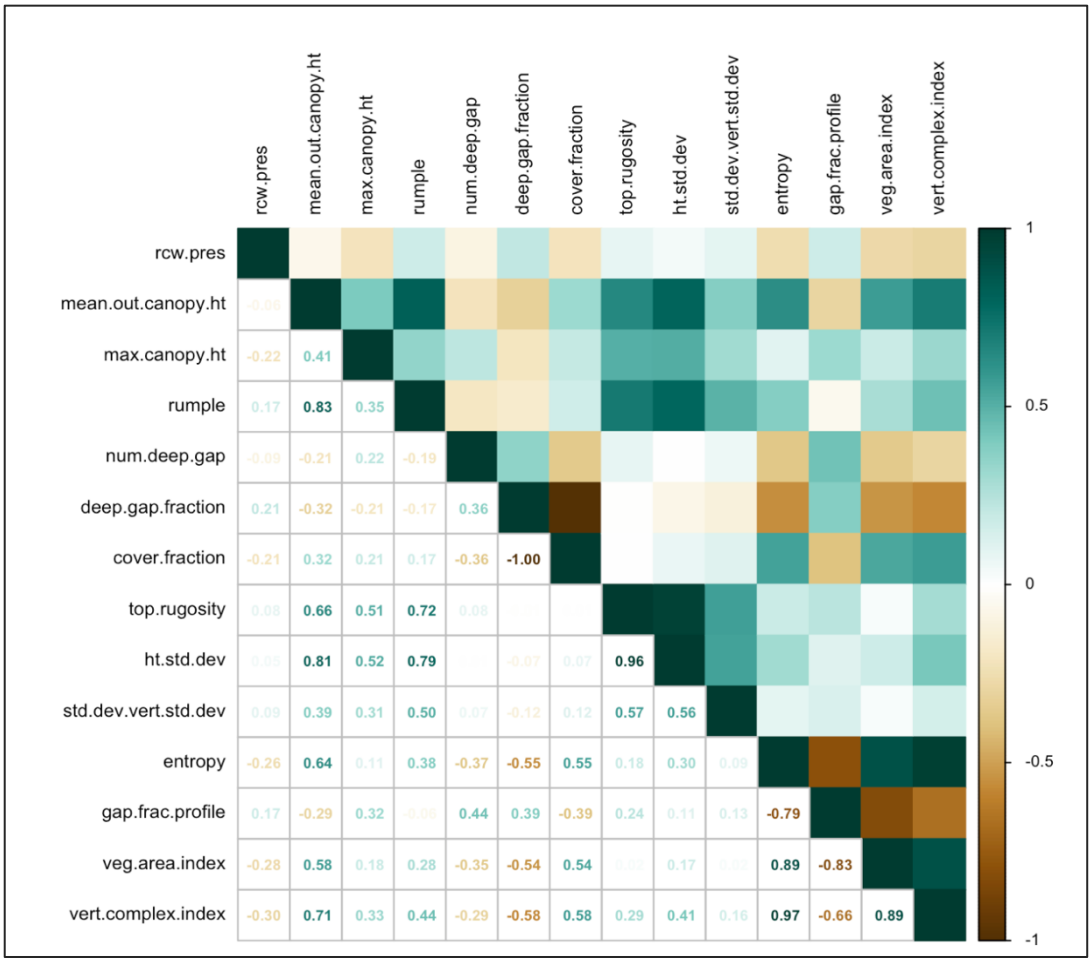

Figure A.1: Correlation plot of all 13 forest structure metrics