GEOSPATIAL ANALYSIS OF VEGETATIVE CHARACTERISTICS ASSOCIATED WITH RED-COCKADED WOODPECKER HABITAT IN A PINE FLATWOODS ECOSYSTEM

By

DOUGLAS O. SHIPLEY

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2003

Research presented in this document is dedicated to the School of Forest Resources and Conservation at the University of Florida.

ACKNOWLEDGMENTS

I am especially grateful to Loukas G. Arvanitis, my major advisor, who has provided knowledge, opportunity, and support throughout my graduate studies. I would also like to thank my other committee members, Alan Long and Leonard Pearlstine, for providing useful comments on earlier versions of this document and input to improve my public presentation of thesis material. I would also like to thank the members of the Forest Information Systems Lab of the School of Forest Resources, University of Florida, for assistance with computer software and data analysis.

The efforts of those who assisted in collection of field data for my research are greatly appreciated, especially those of Jonathan Huels and Brian Holmes. Their diligence in the field and reliability were integral to the completion of this work.

Special thanks are due to Charles Marcus of the Florida Division of Forestry and the Goethe State Forest staff of Herb Heesch, Robert Cahal III, and Robin Boughton who have provided equipment and expertise throughout my research. My parents, Donna and Dennis Shipley, have given me opportunities and confidence throughout my graduate career, which I am most thankful for. My experience is not complete without the close relationship that I have with my family.

TABLE OF CONTENTS

page

LIST OF TABLES

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science

GEOSPATIAL ANALYSIS OF VEGETATIVE CHARACTERISTICS ASSOCIATED WITH RED-COCKADED WOODPECKER HABITAT IN A PINE FLATWOODS ECOSYSTEM

By

Douglas O. Shipley

May 2003

Chair: Loukas G. Arvanitis
Major Department: Forest Resources and Conservation

A geographic information system was used to characterize and model pine species composition, basal area, and diameter at breast height (DBH) of forest habitat occupied by the endangered red-cockaded woodpecker (*Picoides borealis*) in the Goethe State Forest, Florida. Samples were collected in three habitat zones: a) a 75 ac buffer zone surrounding 19 nest cavities; b) a 320 ac zone of active habitat (zone A); and c) 500 ac zones which constitute active and inactive management units (clusters). Samples collected beyond a 320 ac zone within the cluster boundary were designated as non-selected habitat (zone B). Basal area in nesting habitat averaged 35 ft^2/ac of longleaf pine (*Pinus palustris*) and 22 ft^2/ac of slash pine (*Pinus elliottii*). Longleaf-dominated habitat was significantly greater ($p < 0.000$) in active clusters (60 ft^2/ha) compared to inactive clusters (49 ft^2/ac). Estimated DBH did not differ significantly between longleaf and

slash pine dominated habitat in active ($p = 0.073$) and inactive ($p = 0.200$) clusters, respectively.

Binary logistic regression models were developed to analyze preference of forest characteristics within nesting habitat. Our forest-wide population model suggests that the probability of longleaf pine association with nest cavity habitat is 0.60. Two alternative models were developed to evaluate habitat associations across the population and within two subpopulations. The probability of association with active habitat for areas that are dominated by longleaf pine is 0.76, where the average DBH of longleaf pines is $\geq$ 13 in *and* wiregrass (*Aristida beyrichiana*) is present throughout the population. For north and south subpopulations, the same model yielded less significant results, most likely due to far fewer sample observations where both wiregrass and large longleaf were present.

Findings of this study suggest that cluster recruitment and artificial cavity construction efforts must be focused on habitats dominated by contiguous longleaf pine with several large pine trees, and understory conditions associated with frequent burning. Potential cavity sites may be limited as the average age of site index trees is 55 years, which is not conducive to cavity excavation. The density of pines at the Goethe State Forest are within the guidelines of the U. S. Fish and Wildlife Service for red-cockaded woodpecker habitat restoration. The iterative system used to model habitat associations in this forest was very effective in characterizing forest data. However, given the variability of sample data, a relative large number of samples are needed for effective hypotheses testing. The modeling process used in this study may be considered as a template to identify habitat variables associated with other red-cockaded woodpecker populations in Florida.

CHAPTER 1
INTRODUCTION

The red-cockaded woodpecker (*Picoides borealis*) and the associated old-growth longleaf pine (*Pinus palustris*) ecosystem once dominated the pine forests in the southeastern United States. Currently, less than five percent of the original 50 to 60 million acres of longleaf pine forest remains due to timber harvesting, fire suppression, and conversion to agricultural land or other uses (Dennington and Farrar 1983, Outcalt and Sheffield 1996). In response to habitat loss and subsequent population decline, the red-cockaded woodpecker is listed as an endangered species, protected by the U.S. Endangered Species Act of 1973. The bird serves as an "umbrella species" for protection and restoration of longleaf pine habitat (U.S. Fish and Wildlife Service 2000). Management for this species, mainly on federal and state holdings, involves restoring its native pine ecosystem, thus enhancing populations through construction of artificial cavities and woodpecker translocation.

Data for this project were collected at Florida's Goethe State Forest, which contains two geographically isolated sub-populations of the red-cockaded woodpecker, which has adapted to habitat of marginal quality. Sampling was conducted in order to characterize current habitat conditions around 19 known red-cockaded woodpecker nesting sites. Results suggest preference for large longleaf pines in foraging areas. However, most of the Goethe State Forest is dominated by slash pine (*Pinus elliottii*). Biologists and land managers may use data from this study to understand forest conditions which are preferred by the woodpecker and identify areas that are suitable for artificial cavity construction and translocation of birds. Forest inventory data suggest that ground cover composition and basal area per acre of all pines > 4 in diameter at breast height (DBH) are within the ranges outlined by the Recovery Standard for Good Quality Foraging Habitat (U.S. Fish and Wildlife Service 2000). However, the mosaic of cypress domes, found in the swamps of the Goethe State Forest, cover the largest percentage of habitat within clusters when compared to other red-cockaded woodpecker habitats in central Florida. This factor may increase the amount of quality foraging habitat needed as compared to sites with similar pine tree characteristics and species composition.

The goal of the project was to establish baseline data for forest overstory and understory components found within known red-cockaded woodpecker habitat at the Goethe State Forest. This information was used to identify vegetative characteristics associated with existing red-cockaded woodpecker nesting sites and active habitat to support decision making and management for population expansion.

Population Characteristics

As territorial cooperative breeders, red-cockaded woodpecker groups usually consist of a breeding pair and one to several helper males, organized in clans, also referred to as groups (Carter et al. 1995, Conner et al. 2001). Each group occupies an active cluster, defined as the defended habitat surrounding an aggregate of roost and surplus cavity trees (Engstrom and Mikusinski 1998, Hovis and Labisky 1996). Groups of two to three woodpeckers are most common within clusters. Males that do not remain in their natal territory as helpers disperse in search of a new place to breed (Conner et al. 2001). Isolation of these territories or breeding units may limit the ability of dispersing young females to find mates. As a non-migratory species, red-cockaded woodpecker populations are particularly susceptible to the confounding effects of forest fragmentation

(Conner and Rudolph 1991, Rudolph and Conner 1994). The limited number of potential cavity sites and the investment required for cavity construction limits development of functional metapopulations (Rudolph and Conner 1994, U.S. Fish and Wildlife Service 2000).

Habitat Use and Forest Structure

The red-cockaded woodpecker's use of living pine trees for cavity construction is unusual. Most woodpeckers in North America prefer dead trees. Cavities can take from one to three years to complete. They are the most important resource for populations of red-cockaded woodpeckers as they compete for existing tree cavities rather than construct new ones (Gaines et al. 1995, Walters et al. 1995). The birds create and maintain resin wells about one inch deep around the perimeter of the cavity opening to encourage resin flow which is effective in deterring predators, particularly rat snakes (*Elaphe spp.*) (Ross et al. 1997). Mature pines are chosen for cavity construction because of their large diameter and likelihood of red heart fungus (*Phellinus pini*) (Affeltranger 1971, Ligon 1971). Pines larger than 12 in DBH and 60 years of age are most often selected for cavity excavation. This may be attributed to a positive relationship between arthropod biomass and increased pine tree age (Hooper 1996). Various studies indicate that when available, the red-cockaded woodpecker prefers older, larger trees for foraging (Hopkins and Lynn 1971). The use of younger trees, less than 60 years old, is generally dependent on the availability of older ones (Conner et al. 2001). Use of trees less than 60 years of age is often necessary as most of the habitat within the red-cockaded woodpeckers' range has been harvested within the last 100 years, or disturbed mechanically, and is not typical of historic stand age classes and size.

Red-cockaded woodpeckers cannot tolerate pine forests with a well developed midstory (Conner et al. 2001). Increases in overstory of pine and hardwoods have been associated with colony abandonment (Loeb et al. 1992). Management treatments should be applied to reduce midstory basal area below 25 ft^2/ac in colonies as cluster abandonment drastically increases above this level. Successional advancement in hardwoods is primarily due to fire suppression in recent decades, which has also impacted pine reproduction rates. Dying pines are an important foraging substrate as woodpeckers consume many species of beetles and arthropods which are abundant in infested pines (Conner et al. 2001).

The red-cockaded woodpecker is an insectivorous species, primarily feeding on a variety of arthropods usually foraged from the bark of living pine trees (Hanula and Franzreb 1998, Ligon 1971). The quality of the available forage may affect both the nesting success and density of woodpeckers (Conner et al. 1999). The area required for foraging varies depending on the quality of the habitat. In north Florida's Apalachicola National Forest, Porter and Labisky (1986) reported a foraging preference for pines with a DBH >7.8 in within old-age stands ranging in age from 57 to 87 years. In addition to tree diameter and age, the suitability of foraging habitat is strongly correlated with stand density. Basal area of pines four inches or greater in diameter for longleaf systems should be between 40 and 60 ft^2/ac (U.S. Fish and Wildlife Service 2000). However, basal area of pine habitat in north Florida has been as dense as 70 ft^2/ac in Florida's Apalachicola National Forest (Hovis and Labisky 1996). Red-cockaded woodpeckers appear to be flexible in their ability to successfully forage in pines of various ages (Azevedo et al. 2000, Hooper 1996).

Foraging and Territory Range in Florida

In central and southern Florida, pine forest habitat is relatively poor. Home range sizes vary depending on the amount and quality of available forage (Hovis and Labisky 1996). At central Florida's Curtis H. Stanton Energy Center, DeLotelle et al. (1987) observed a mean home range and defended territory size of 361 ac and 287 ac respectively, over a two-year period. Cypress domes and bay heads accounted for approximately 8.6 percent of habitat within territories. In a study using radio telemetry, Nesbitt et al. (1978) determined an average foraging range of 172 ac for three red-cockaded woodpecker clans in central Florida's Marion County. Foraging habits of four clans (social groups) at the Apalachicola National Forest in north Florida averaged 319 ac (Porter and Labisky 1986). The study was conducted over a period of one year. The study results are summarized in Table 1-1.

Table 1-1. Home range sizes for red-cockaded woodpecker colonies in north and central Florida (NA = not available).

Author	Year	Duration of Study	Study Location	Foraging Range	Longleaf Pine	Pond-slash Pine	Cypress/bay-heads
Nesbitt et al.	1978	128 hrs.	Central Florida, Marion County	172 ac	38.2%	43.8%	6.5%
DeLotelle et al.	1987	2 yrs.	Curtis H. Stanton Energy Center	361 +/- 81 ac	NA	NA	8.6%
Porter and Labisky	1986	1 yr.	Apalachicola National Forest	319 +/- 31 ha	31%	35%	7% 23% (titi)

In Florida, red-cockaded woodpecker habitat ranges differ greatly and are substantially larger than ranges found in other states. Average year-round home ranges were estimates as 205 ac in North Carolina (Walters et al. 2000), 215 ac in South Carolina (Hooper et al. 1982), and 198 ac in coastal Georgia (Epting et al. 1995).

Vegetative Associations with Red-cockaded Woodpeckers in Florida

Overstory and understory vegetative associations specific to habitat selection have been explored for the species in central and north Florida habitats (DeLotelle et al. 1987, Hovis and Labisky 1996, Hovis and Labisky 1985, Nesbitt et al. 1978, U.S. Fish and Wildlife Service 2000). In the Apalachicola National Forest, located in the Florida panhandle, Hovis and Labisky (1985) quantitatively evaluated habitat conditions found within two peripheral "zones" surrounding nest cavities. Basal area was found to be 46 ft^2/ac in the "selected habitat" zone, and 65 ft^2/ac in a zone, representative of outer foraging limits. The mean DBH in these zones was 8.2 in and 6.8 in respectively. Within in selected habitat, the overstory was characterized by 70 percent longleaf/slash pine flatwoods and baldcypress (*Taxodium distichum*) swamps/titi thickets (6 percent of the habitat). Habitat in the outer foraging limits was composed of 65 percent longleaf/slash pine flatwoods and 15 percent baldcypress swamps/titi thickets (Hovis and Labisky 1985). Midstory plants consisted mainly of gallberry (*Ilex glabra*), St. Johnswort (*Hypericum* spp), longleaf pine, and saw palmetto (*Serenoa repens*).

In central Florida, DeLotelle et al. (1987) sampled red-cockaded woodpecker territory and reported that 88.1 percent of the home range was pine flatwoods and 8.6 percent consisted of cypress domes and bay heads. The remaining 3.3 percent was wet prairie and open area. Qualitative estimates of habitat in the species' southernmost range reveal a similar composition of pines and understory species. In Marion County Florida, Nesbitt et al. (1978) reported longleaf pine on the higher sites, with slash and pond pine (*Pinus serotina*) in lower, wetter sites with intermittent flatwood ponds bordered by bay and pondcypress (*Taxodium ascendens*).

Goethe State Forest Population Characteristics

The State of Florida purchased the Goethe Tract in 1992 as part of its Conservation and Recreation Lands (CARL) program. Management authority was given to the Florida Department of Agriculture and Consumer Services, Division of Forestry. Although red-cockaded woodpeckers were known to exist prior to state acquisition, the status of the population at the Goethe State Forest was unknown. A cooperative agreement with the Florida Fish and Wildlife Conservation Commission conducted a survey of the forest to determine the status of the resident red-cockaded woodpecker population. In 1994, the geographic location and characteristics of red-cockaded woodpecker cavities at the Goethe State Forest were identified, and cluster boundaries were developed using the circular scale technique (Hovis 1996). Nesting data were used to determine cluster status. Active status was assigned to areas with a single active tree or a group of active cavity trees, some of which included an active tree occupied by a nesting pair. Areas with groups of cavity trees that were not used by the red-cockaded woodpecker were deemed inactive. In 1995, 26 clusters were active in the Goethe State Forest. They were divided geographically into north and south regions of the forest. Monitoring of cluster status was conducted on an annual basis by the Goethe State Forest staff, during spring and summer months. In 2000, 30 clusters were active (23 were nesting), 16 of which were located in the northern part of the forest. The remaining 14 clusters were in the southern region of the main tract. Figure 1-1 includes the distribution of the 30 clusters that were uninhabited, or inactive, in 2000. The distribution of nesting clusters in 2001 is included in Figure 1-2. In this study, the geographic location of these nineteen nesting cavities were used to identify selected habitat for various analyses.

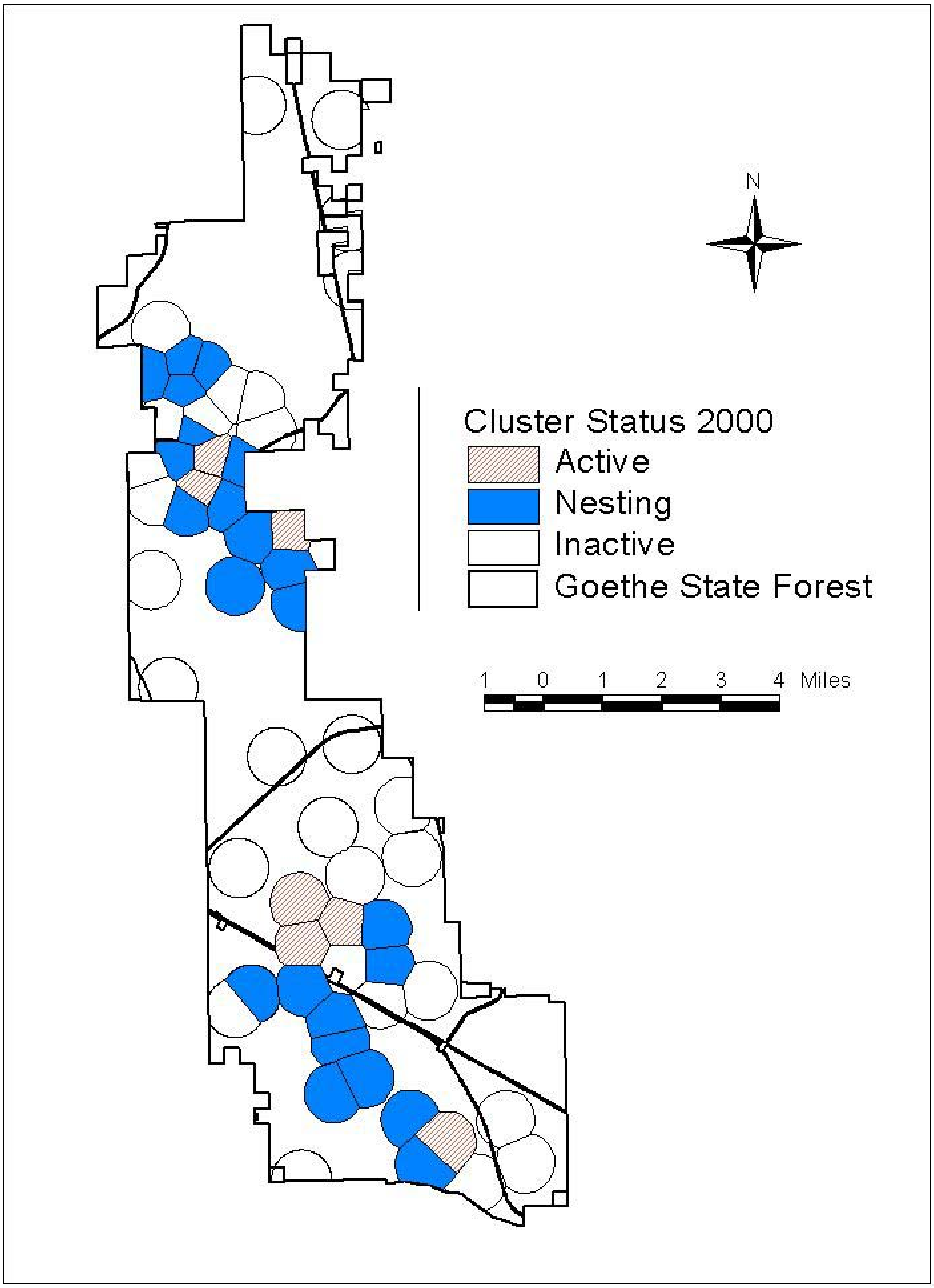

Figure 1-1. Red-cockaded woodpecker cluster status in 2000, Goethe State Forest, Florida.

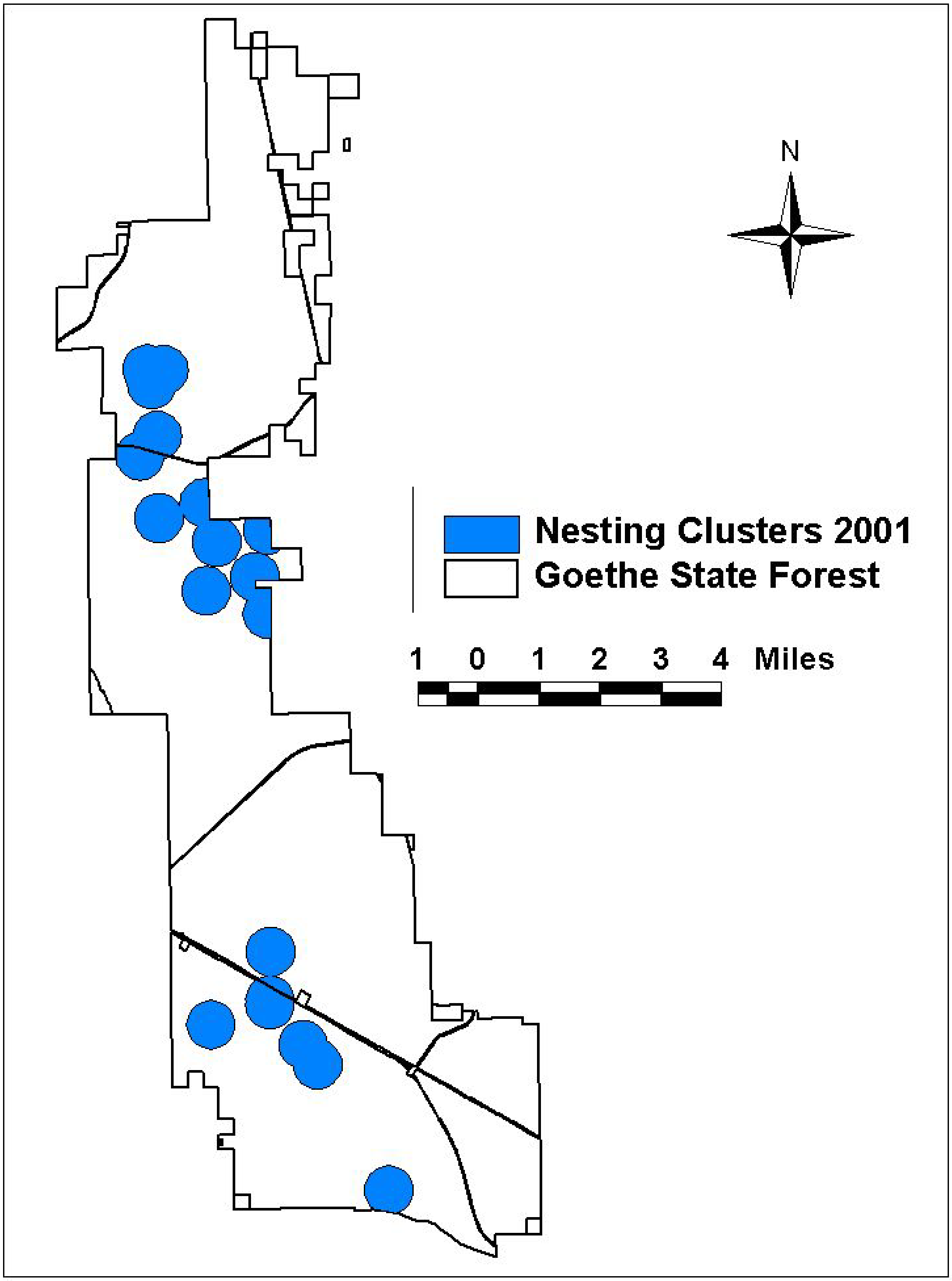

Figure 1-2. Map of 19 red-cockaded woodpecker nesting sites during 2001. A 320 acre buffer surrounds each site.

Staff biologists at the Goethe State Forest monitor red-cockaded woodpecker cavities on an annual basis, usually during breeding season (May through June). A portable "peeper" camera unit or ladder assembly are used to observe fledgling status or other species within nesting cavities. The spatial location of all active and inactive cavity trees is recorded using the Global Positioning System (GPS). Cavity trees are marked with a single white band (approximately 8 in wide) around the stem at eye level.

Within active clusters, a minimum of four viable cavities must be maintained at the Goethe State Forest. Artificial cavities are installed in living pine trees, if needed, as cavity trees may die or become occupied by other species such as red-bellied woodpeckers (*Melanerpes carolinus*), or pileated woodpeckers (*Dryocopus pileatus*). Inserts are only installed if site and pine tree characteristics are suitable. The minimum diameter at breast height of the selected pine trees must be 17 in to accommodate the size of the cavity insert. The diameter at the point of insertion is generally larger than 15 in This diameter permits the excavation of a hole 4 in wide, 10 in tall, 6 in deep to hold the cavity insert (Allen 1991). The minimum installation height is 20 ft and the opening of the insert box generally faces a southwest direction or is pointed to active cavity trees within the cluster. If the crown of a potential cavity tree touches the crown of others, it is generally not considered ideal. Longleaf pines which are "flat-topped" are avoided to leave potential nest sites for natural excavation. The species of pines is not often considered by biologists at the Goethe State Forest, as it is common for the larger pines that grow near cypress ponds to be chosen for cavity construction. Cavity inserts may be installed near the border of cypress forests, if suitable pine tree selection is limited. In this situation, cavities are installed in a fashion so that openings do not face the cypress ponds. Cavity installation and cosmetic preparation is completed. The newly added cavity closely resembles a natural active cavity. Recruitment clusters consist of cavity inserts, usually a pair, installed within a half mile range of an existing nesting cluster. Site conditions are generally similar to those found in the neighboring active cluster.

Study Objectives

To support habitat restoration and provide current baseline data for management decisions, this research focuses on the following:

a) Develop a geo-referenced forest and understory vegetative cover inventory ArcView® database of active and inactive cluster sites.

b) Test for differences in pine tree species and vegetative cover characteristics between selected and non-selected habitat.

c) Evaluate the effectiveness of logistic regression as a tool for identifying forest variables that have a significant association with selected versus non-selected habitats.

CHAPTER 2
METHODOLOGY

Study Area

Field data were collected within the main tract of the Goethe State Forest, located in the southeastern portion of Levy County, Florida (29°22’ N, 82°37’ W and 29°6’ N 82°32’ W). The main Goethe tract is comprised of 49,295 ac and is managed by the Florida Division of Forestry for multiple-use purposes throughout scrub, sandhill, pine flatwoods, and dome swamp ecosystems. Activities offered to the public include: hunting and camping by permit, wildlife viewing, bicycling, hiking, and horseback riding.

At the time of this study there were 60 known red-cockaded woodpecker clusters throughout the tract (Figure 1-1). The forest landscape is primarily pine flatwoods with a high proportion of intermixed baldcypress swamps and hardwoods. The latter are considered unsuitable for foraging. Hardwood features influence the area of good quality foraging habitat that can be used throughout the red-cockaded woodpecker’s home range. This is apparent by the variation in estimates of foraging ranges in forests that contain hardwood substrate (U.S. Fish and Wildlife Service 2000). The active red-cockaded woodpecker population is split into two isolated groups: the north and south regions of the forest (Figure 1-2). This separation is most likely related of a lack of suitable cavity trees and dense midstory vegetation which follows drain flats in the central part of the main tract. Unfortunately, the historical distribution of clusters at the Goethe State Forest is not known.

Within the sampled clusters, pine overstory consists of slash pine, longleaf pine, and scarce loblolly pine (*Pinus taeda*). Understory vegetation is dominated by saw palmetto, gallberry (*Ilex glabra*), fetter-bush (*Lyonia lucida*), grasses, and forbs.

Data Collection

Field data were collected in 60 clusters, as identified by the Florida Division of Forestry to be sampled for standing tree data and understory vegetation composition. In this study, potential foraging habitat is defined as contiguous pine forest within each cluster. Active clusters are management units defined by the presence of cavity trees with flowing sap from resin-wells or the presence of a breeding pair. Inactive clusters are abandoned red-cockaded woodpecker cavities at the time of study. Cypress and hardwood areas were excluded from sampling.

A combination of compass bearings and pacing was used to navigate between pre-determined sample points, each representative of ten acres of foraging habitat. Sample points were located systematically within each cluster on a 10-chain (660 ft) square grid. At each sample location, geographic coordinates were recorded with a handheld global positioning system (GPS) unit, used for a 20 second duration. Data were post processed with an accuracy of one to three meters. A forest inventory was conducted at each sample location and data were recorded with a ruggedized handheld computer (CMT PC5-L, Corvallis, OR) operating on Field Dog software (Two Dog Inc., Blacksburg, VA). Vegetative ground cover attributes were recorded in a field book. Data collection began in May 2000 and completed in August 2001.

Forest Inventory

Management officials at the Goethe State Forest identified 52 clusters that were considered priority for forest inventory. At each sample location within these clusters, a

10-factor prism was used to select pine trees with probability proportional to tree DBH. Limiting-distance calculations were used for borderline trees. For each sampled pine tree, the species and DBH were recorded. Pines with a DBH < 4 in were not recorded. At each sample point, the nearest dominant or co-dominant of the most common pine species from the plot center was selected as the site index tree. Tree age, bark thickness, and total tree height were measured. Stem cores were extracted at breast-height to determine the age of the site index tree, and its five-year radial growth. A bark gauge was used to measure bark thickness at breast height. The height of each site index tree was measured with a precise vertex hypsometer.

Understory Vegetation Sampling

At each sample point, a square meter quadrat was used to assess ground cover composition. Palmetto, forbs, and woody-stem categories were each estimated as percent cover within the sample quadrat. Average height was estimated for each category in 3 ft intervals. Dominant species for forbs and woody stem categories were recorded in the field. Total percent cover for leaf litter, exposed mineral soil, and grasses (noting wiregrass (*Aristida beyrichiana*) if dominant) were estimated and recorded.

Data Analysis Procedures

Baseline Statistics

An initial quantified summary of vegetative characteristics associated with red-cockaded woodpecker habitat as well as abandoned forage was developed to support habitat restoration and to provide current baseline statistics and data for management decisions. This process was carried out using traditional t-tests for differences in measurement averages for dominant pine basal area and DBH between active and inactive clusters. The classification of samples used in testing was based on the zone or cluster status in the analysis, as described below.

Tests for differences in means were performed at two foraging zone scales. The 320 ac area (zone A) surrounding nesting cavities was used to represent preferred habitat, i.e. the expected area used by the red-cockaded woodpecker at the Goethe State Forest (Figure 2-1). Samples collected within a larger zone of 500 ac, represent the potential foraging area within each active and inactive cluster. The 500 ac foraging areas were classified as active if either nesting cavities or a single active cavity tree (trees with resin wells) was present within a cluster. All clusters that contain previously used red-cockaded woodpecker cavities but are not currently in use were considered inactive. Samples used to represent non-selected habitat were selected from zone B which is formed by a "ring" between the 320 ac zone (zone A) and the outer margin of the 500 ac zone (Figure 2-1).

A geographic information system was used to classify samples as either preferred or non-selected habitat. Classified samples within the buffers as described above, were exported as a *.dbf* file for testing in Minitab and SPSS statistical analysis software packages.

In addition, the center of inactive clusters was buffered by a 2110 ft radius. Samples located within this buffer may be representative of selected habitat, if cluster abandonment was recent. Therefore, samples beyond the 2110 ft buffer and within the 500 ac inactive cluster boundary were classified as non-selected habitat. A third zone was used to compare immediate nesting habitat characteristics to non-selected habitat.

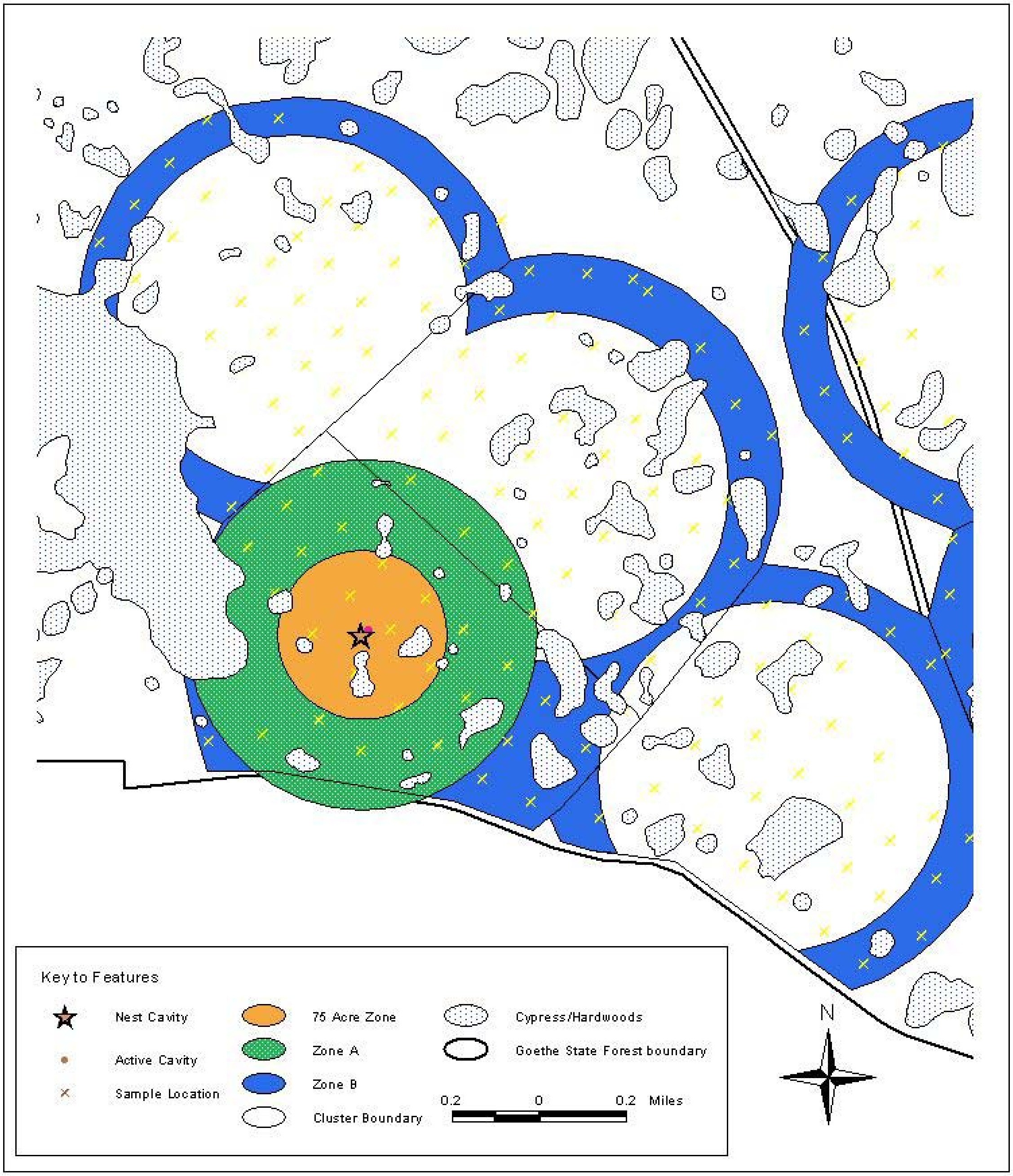

Figure 2-1. Location of a red-cockaded woodpecker nest cavity, and zones used to identify habitat characteristics within the maximum sampled foraging area.

A 75 ac buffer was created around 19 nesting cavity locations. The size of this buffer includes 86 percent of active cavity trees associated with the nesting cavities.

Data were managed using Microsoft Excel® and tested for differences between measurement means using SPSS® and MINITAB® software packages. Interpretation of these results provided a basis for selecting variables to be used in logistic regression models.

Binary Logistic Regression

Cluster recruitment requires an in-depth knowledge of forest conditions that are suitable for artificial cavity construction within potential forest habitats. Identifying which resources are selected most often by the red-cockaded woodpecker provide important information about the nature of the species' habitat preference at the Goethe State Forest. In previous studies, longleaf pine trees were used by red-cockaded woodpeckers disproportionately to their availability among other pine species (Hovis and Labisky 1985, Nesbitt et al. 1978). The binary logistic regression procedure was used to explore the relationship between existing habitat and used habitat at the Goethe State Forest. Based on the abundance of slash pine at the Goethe State Forest, it is possible that the population of red-cockaded woodpeckers may be selective. However, this assumption does not hold true for all populations, as foraging preference was positively correlated with individual tree and stand age, independent of species availability (Engstrom and Sanders 1997, Rudolph and Conner 1994, Zwicker and Walters 1999). In this study, binary logistic regression was used to estimate the probability and odds of habitat selection based on measured forest characteristics.

The availability of forest resources is not generally uniform, and use may change as availability changes. Therefore, used resources should be compared with available (or unused) resources to reach a valid conclusion concerning resource selection (Manly et al. 1993). In this study, sample points are classified according to the type of habitat they represent. These classifications represent the dependent, or use variable (*Y*). A resource probability function estimates the probability that a measured resource (*X*) in a particular binary category (*Y*) is used by the red-cockaded woodpecker.

Binary logistic regression was chosen for several reasons. Data collected in this study do not include a quantifiable estimate of habitat use by the woodpecker. A general linear model is not suitable because the outcome variable (habitat use) was not measured on a continuous scale. The outcome variable is binary, as determined by the classification of samples based on the zone they are collected in from the cluster center or nesting cavity. Samples collected within the 75 ac zone, or zone A are used as indicators of 'selected resources'. Information obtained outside of these zones, where the woodpecker is not known to forage, are used to define resources that are not preferred. Criteria that are related to resource selection vary depending on forest resource condition. However, factors such as pine species, age, midstory height, and understory species composition are generally associated with red-cockaded woodpecker habitat (Hardesty et al. 1997, Loeb et al. 1992, Rudolph and Conner 1994, U.S. Fish and Wildlife Service 2000). Because of the dichotomous nature of the dependent variable and the combination of discrete and continuous predictors, the binomial distribution was used for regression analysis. For this type of analysis, the 'logit transformation' of variables is often used because it is very flexible and an easily used function which lends itself to a biologically meaningful interpretation (Hosmer and Lemeshow 1989). The logistic model produces an output in terms of probability, which is bounded by 0 and 1. The interpretation of the logistic regression coefficients incorporates the calculation of odds, or the likelihood of association, with an outcome. This is accomplished by transforming the probability to an odds to remove the upper bound. The lower bound is removed by using the logarithm of the odds. The result is set to a linear function of the explanatory variables. The probability (p_i) of $\hat{g}$ is calculated using the 'logit' model:

$$\hat{g} = \alpha + \beta_1 x_{1i} + \beta_2 x_{i2} + \ldots + \beta_k x_{ik}$$

where $p_i = \dfrac{e^g}{1 + e^g}$

$\alpha =$ the outcome variable, and $\beta_k =$ predictor(s)

for k explanatory variables, and $i = 1,\ldots n$ individuals.

This equation has the desired property that p_i will always be between 0 and 1 for any number that is substituted for the $\beta's$ and the $x's$ (Allison 1999). This probability is sometimes excluded from interpretation in favor of an odds ratio or the likelihood of a predictor being a member of an event. The odds ratio for each predictor can be solved by using the regression coefficient (β_k) of the predictor variable as the exponent of e, or the base of the natural logarithms (Grimm and Yarnold 1995).

Tests for Habitat Association

Tests were used to determine if the values of predicted coefficients of habitat variables were different from zero. The null hypothesis assumes that the predictor is zero in the population, and if rejected, the alternative hypothesis that the coefficient differs from zero, is accepted. For models containing n predictors, a chi-square distribution with *n* degrees of freedom is used to obtain the probability for the likelihood statistic, *G*. Coefficient parameter(s) differ from zero if the probability of calculated *G*-statistic is less than .05 (the cutoff probability for the hypothesis test, $\alpha = .05$). The *z* test is another approach to determine if an estimated value of a coefficient is different from zero. The predictor coefficient is divided by its standard error to compute *z*, which is a measure of expected variability in the coefficient among samples. The cutoff probability for *z* tests in this study is .05. Confidence intervals for odd ratios were computed to estimate the range of likelihood of association for a predictor with 95 percent confidence. Interpretation of this interval provides a reliable estimate of increase in the odds of association with foraging habitat from one pine species (or other habitat component) to another.

Foraging Preference Analysis: Multivariable Models

Data used to indicate the outcome variable (*Y*) were selected from two categories: a) Samples within the 320 ac foraging area (zone A) represent 'preferred' habitat (coded as 1) b) Samples collected in zone B were considered 'non-selected' habitat (coded as 0). An initial screening of habitat components was conducted by fitting each potential variable to a resource probability function to eliminate habitat characteristics with a low probability of association with preferred habitat. This was done in order to develop a model with a minimum number of variables for field application. Four variables tested for significant association with selected habitat (above 95 percent probability) during initial testing across all nesting clusters: a) longleaf dominance, b) slash pine basal area, c) longleaf diameter at breast height, and d) longleaf basal area (Table 4-8). Based on the statistical significance of these results, the outcomes from previous studies, and their role in supporting the woodpeckers' ecological niche, select predictors that suggested a strong association with habitat selection were then tested interactively.

Two models, consisting of 612 samples each, were tested to explore associations of multiple habitat characteristics with habitat preference across the entire forest population (Models 1_p and 2_p). Model 1_p includes one predictor (b_1), which involves the interaction between: a) sample points with an average diameter of pines $\geq$ 33 cm (coded 1, if true) and b) samples dominated by longleaf pine (coded 1, if true). A minimum diameter of 13 in was chosen because of cited preferences of the red-cockaded woodpeckers to forage on trees larger than 12 in when available (Engstrom and Sanders 1997), and because samples which contain trees of this average DBH are less prevalent throughout the Goethe State Forest.

The second test for habitat preference include two predictors. The first coefficient (b_1) in Model 2_p is the interaction of samples where a) the average DBH of longleaf pine samples was $\geq$ 33 cm (coded 1, if true) and b) samples where wiregrass was present in the understory (coded 1, if true). The interaction of these factors is expressed as a binary variable. The second coefficient of Model 2_p is longleaf dominance, coded 1, if present at a sample and coded 0, if longleaf pine was not dominant. Tests for multicollinearity, using a correlation matrix, were performed for all interactive coefficients. The two models used in the population analysis were also used to test for differences in habitat preference between the geographically separated north and south cluster groups. The models in the north are termed Model 1_N and Model 2_N, and in models which tested variables in the south are termed Model 1_S and Model 2_S.

Nesting Habitat Model

A third model was employed to estimate the probability of resource selection for specific pine species within the foraging area that surrounds the immediate area of nesting sites. Model 3 involves 150 random samples taken from two regions of the forest. Samples within the 75 ac buffer zone surrounding 19 nesting sites, were used to represent preferred habitat and samples. Data collected within zone B (Figure 2-1) were representative of unused habitat. Seventy-five random samples were used from each zone in the logistic regression analysis to determine if the longleaf pine dominance, (b_1=1 if the sample was dominated by longleaf pine, and 0 if not) could be used to predict selection of nesting sites. Output statistics for Model 3 denote the probability and likelihood of selection between longleaf pine dominance and a binary variable Y, where Y= 1 for samples collected within the 75 ac zone, and Y = 0 for samples collected in zone B. The Minitab® procedure BINARY LOGISTIC REGRESSION was used to fit each model to its respective data.

CHAPTER 3
RESULTS: COMPARISON OF HABITAT COMPONENTS

Pine Characteristics Throughout Foraging Zones

Within nesting habitats (75 ac zone), 60 percent of sampled trees were longleaf pine, while slash pine comprised the remaining 40 percent (Figure 3-1). Proportions of longleaf and slash pine within zone A were similar, but less pronounced. Slightly more than half (53 percent) of the sample trees in zone A were composed of longleaf pine. In zone B, representative of unused habitat, almost two-thirds (61 percent) of the tree samples were slash pine.

Across all 52 clusters, slash pine represented 54 percent of the sampled trees in the potential red-cockaded woodpecker habitat (500 ac/cluster). Within these 500 ac clusters, the remainder of sampled trees were longleaf (approximately 46 percent) and loblolly pine (< .6 percent). However, pine species abundance differed based on cluster status. Active units were 51 percent longleaf pine while 62 percent of the trees in inactive units were slash pine (Figure 3-1). In active clusters, 29 of 572 samples were recorded as having no dominant (>50 percent of total samples) species. Of 679 samples in inactive clusters, 39 contained equal numbers of slash and longleaf pines.

Nesting habitat within the 75 ac zone (n = 94), averaged 36 ft^2/ac of longleaf pine basal area, substantially more than the average slash pine basal area (22 ft^2/ha) (Table 4-1). Compared to the concentration of pines in zone B, the immediate area surrounding nesting sites averaged approximately 11 ft^2/ac more longleaf basal area and 11 ft^2/ac less slash pine basal area (Table 4-1).

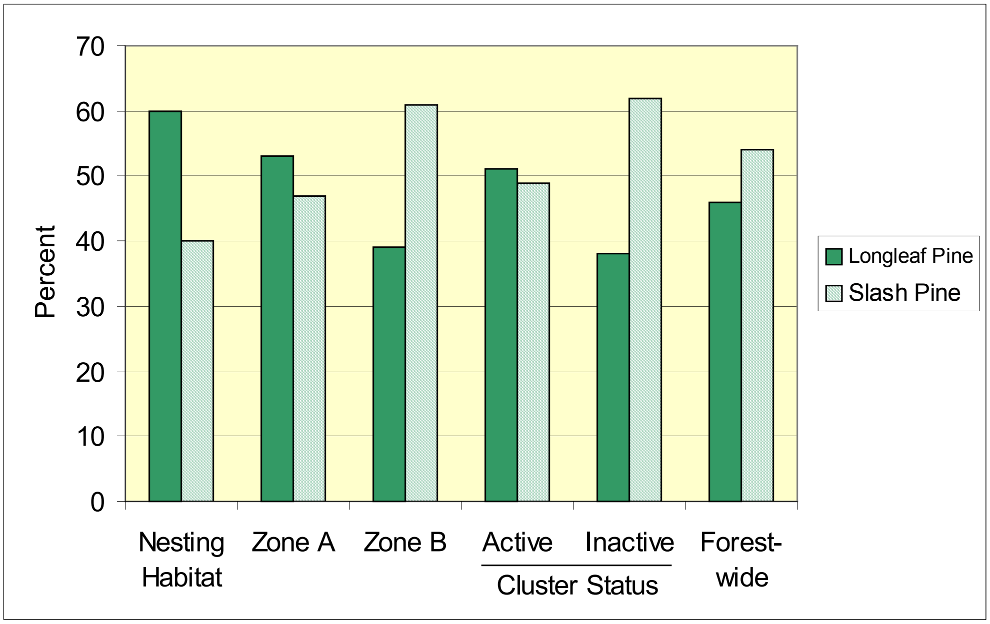

Figure 3-1. Percentage of sampled longleaf and slash pine trees at various habitat scales.

The DBH of longleaf and slash pines within nesting habitat was similar to averages found in other habitat zones. The range of average longleaf and slash pine DBH estimates was 1.7 in and 5.3 in, respectively, across all foraging zones.

The DBH of pines was not significantly different in zones A (n = 338) and B (n = 301) (Table 4-6). Zone A averaged 31 ft^2/ac basal area of longleaf pine, which exceeds longleaf basal area in zone B by 6.9 ft^2/ac. Slash pine basal area in zone B is greater than in zone A, by an average of 6.0 ft^2/ac (Table 4-1).

Pine tree DBH is similar for active (n = 572) and inactive (n = 679) clusters with a difference of 1.7 in for longleaf and 2.0 in for slash pines, respectively (Table 4-3). Longleaf pine basal area is 9.5 ft^2/ac greater in active versus inactive clusters, on average. Between pine species in active clusters, longleaf is most prolific, averaging 5.6 ft^2/ac more than slash pine, while slash pine basal area is higher on average in inactive clusters by 12.6 ft^2/ac (Table 4-1).

Active and Inactive Cluster Habitat Composition Analysis

Comparisons of Pine Basal Area

Basal area within active and inactive clusters averaged 62.7 ft^2/ac and 59.8 ft^2/ac, respectively (Table 4-2). Although there is no statistical difference between these overall basal area estimates, basal area is greater by 10.6 ft^2/ac, ($p = 0.0000$) when longleaf is dominant in active versus inactive clusters (Table 4-2). Samples taken in habitat dominated by slash pine averaged a significantly higher basal area than longleaf pine in both active and inactive clusters. Active clusters are characterized by a mean basal area of 67.4 ft^2/ac when slash pine is dominant compared to 59.6 ft^2/ac when longleaf dominates the sample ($p < 0.006$). Inactive clusters are characterized by samples where slash pine was most often dominant. When compared to areas dominated by longleaf pine, inactive clusters contained 21 ft^2/ac more basal area in areas dominated by slash pine. This difference was tested significant ($p = 0.0000$). Basal area of sample points dominated by slash pine was not significantly different ($p = 0.39$) between active (67.4 ft^2/ac) and inactive (70 ft^2/ac) clusters. The estimates for total basal area of longleaf dominated pine habitat in active and inactive clusters are within the United States Fish and Wildlife Service guidelines, but given the small average DBH (<13 in) of pines, habitat in these clusters is of marginal quality.

Differences in Pine DBH

Within active clusters, the average DBH per sample point is 11.9 in. This is significantly larger ($p = 0.061, \alpha = 0.10$) than the average DBH of samples in inactive clusters, which averaged 11.7 in (Table 4-3). When longleaf pines dominate the sample location, the average DBH is 11.7 in within inactive clusters and 12.1 in within active clusters.

Table 4-1. Pine characteristics in nest habitat and foraging zones at the Goethe State Forest.

Pine Species		75 acre Zone ($\bar{x}$)	320 acre Zones ($\bar{x}$)		500 acre Clusters ($\bar{x}$) Cluster Status	
			Zone A	Zone B	Active	Inactive
Longleaf	Basal Area (ft^2/ac)	36 (10–100)[a]	31.35 (10–130)	24.3 (10–130)	31.3 (10–150)	21.7 (10–120)
	DBH (in)	11.8 ± .2[b]	11.9 ± .09	12.0 ± .1	11.8 ± .07	12 ± ..09
Slash	Basal Area (ft^2/ac)	22.0 (10–120)	27.0 (10–170)	33.14 (10–170)	25.7 (10–170)	34.4 (10–200)
	DBH (in)	12.3 ± .3	11.9 ± .1	11.7 ± .11	11.8 ± .07	11.49 ± .07

[a] denotes sample range
[b] denotes ± 1 standard error

Table 4-2. The average basal area of pines relative to longleaf or slash pine dominance within active and inactive clusters.

	Mean (ft^2/ac)		
Dominant Pine Species	Active Clusters	Inactive Clusters	P Value
Longleaf Basal Area	59.6 ± 1.7[a]	49 ± .36	0.000
Slash Pine Basal Area	67.4 ± 2.7	70 ± .41	0.390
P Value	0.006	0.000	
Basal Area	62.7 ± 1.3	59.8 ± 1.2	0.098

[a] denotes ± 1 standard error

Table 4-3. The average Diameter at Breast Height (DBH) of pines relative to longleaf or slash pine dominance within active and inactive clusters.

	Mean (in)		
Dominant Pine Species	Active Clusters	Inactive Clusters	P Value
Longleaf DBH	12.1 ± .12[a]	11.7 ± .15	0.073
Slash DBH	11.8 ± .19	11.6 ± .13	0.200
P Value	0.350	0.480	
DBH	11.9 ± .10	11.7 ± .10	0.061

[a] denotes ± 1 standard error

These estimates are not significantly different at the 95 percent confidence level, but they are significantly different when tested at $\alpha = .10$ (p = 0.073). The average DBH for samples dominated by slash pine is 11.8 in, and 11.6 in within active and inactive clusters, respectively. Similarly, these estimates are not different at the .95 confidence level (p = 0.20). Within active and inactive clusters, tests do not provide sufficient evidence for differences in mean DBH between samples where longleaf and slash pine are dominant (p = 0.350 and p = 0.480, respectively). It is clear that trees sampled within clusters, regardless of species, are very nearly the same DBH.

Differences in Basal Area of Large Pines

For samples where longleaf pine is dominant and the average DBH is greater than or equal to 12 in, the average basal area in active clusters is 4.3 ft^2/ac greater than in inactive clusters (Table 4-4). Basal area for sample points dominated by slash pine averaging 12 in DBH or greater is 70.7 ft^2/ac and 67.7 ft^2/ac in active and inactive clusters, respectively. Differences between basal areas of sample points dominated by either large longleaf or slash pine in both active (p = 0.0000) and inactive (p = 0.0000) clusters were highly significant (Table 4-4). The apparent association between increased levels of basal area of larger pines in active clusters was tested further in this study through the use of logistic regression models.

Wiregrass Observations

In active clusters, wiregrass was the dominant grass in 60 percent of samples that contained coverage ($\geq$ 5 percent) of any grass within the square meter sampling quadrat. For inactive clusters, wiregrass was observed as the dominant grass in 25.2 percent of grass samples. The groups of red-cockaded woodpeckers that live in active clusters may

Table 4-4. The average basal area of pines ≥ 12 in for samples dominated by either longleaf or slash pine within active and inactive clusters.

	Mean (ft^2/ac)		
Dominant Pine Species	Active Clusters	Inactive Clusters	P Value
Longleaf Basal Area	54.4 ± .2.1[a]	49.7 ± 2.0	0.110
Slash Pine Basal Area	70.7 ± .2.9	67.7 ± 2.6	0.570
P Value	0.000	0.000	

[a] denotes ± 1 standard error

be remnant of a population that was sustained by fire and where wiregrass was prolific throughout their territory. Today's inactive cluster status may be the result of fire exclusion, which, among other factors, could cause wiregrass presence to dwindle as new understory species colonized unburned red-cockaded woodpecker territories.

Habitat Characteristics Within Zone A and Zone B

Comparisons of Pine Basal Area

The mean basal area per sample point in zone A was 60.2 ft^2/ac. Samples in zone B averaged 59.6 ft^2/ac basal area, which does not differ significantly from zone A. Samples located in 'selected habitat' of zone A and dominated by longleaf pine had a basal area that was significantly less than samples dominated by slash pine ($p < 0.000$) (Table 4-5). Similarly, within 'non-selected' habitat in zone B, the basal area of longleaf-dominated habitat is significantly less than the basal area in samples dominated by slash pine ($p<0.000$). When samples dominated by longleaf pine were compared between foraging zones, samples in zone A contained a significantly higher basal area ($p = 0.046$) than in zone B. The significantly greater levels of basal area in longleaf pine dominated habitat is similar in both zones and the larger, active clusters. Much like the cluster level analysis, a test for differences between slash pine basal area between habitat zones A and B did not provide evidence for statistical difference ($p = 0.660$) (Table 4-5).

Differences in Pine DBH

The average diameter for all pine samples within zone A was 12.0 in, which is significantly larger ($p = 0.014$) from the average diameter of 11.6 in within zone B. This significant difference was not found in a comparison of the average DBH of all pines sampled within active and inactive clusters (Table 4-3).

Table 4-5. Test results for differences in mean basal area between zones A and B. T-tests were conducted at $\alpha = 0.05$.

	Mean (ft^2/ac)		
Dominant Pine Species	Zone A	Zone B	P Value
Longleaf Basal Area	55.6 ± 1.9[a]	49.0 ± 2.1	0.046
Slash Pine Basal Area	66.9 ± 2.6	70 ± 2.2	0.660
P Value	0.000	0.000	
Basal Area	60.2 ± 1.3	59.6 ± 1.2	0.810

[a] denotes ± 1 standard error

Table 4-6. Test results for differences in mean DBH between samples collected within zones A and B. T-tests were conducted at $\alpha = 0.05$.

	Mean (in)		
Dominant Pine Species	Zone A	Zone B	P Value
Longleaf DBH	12.2 ± .14[a]	11.5 ± .20	0.006
Slash DBH	11.8 ± .23	11.5 ± .18	0.330
P Value	0.130	0.950	
DBH	12.0 ± .13	11.6 ± .13	0.014

[a] denotes ± 1 standard error

Possible reasons for this characteristic change could be the removal of large, harvestable timber in densely stocked nesting habitat of inactive clusters. Perhaps overstocking close to roosting cavities was a contributing factor to cluster abandonment. Tests for differences in mean pine tree DBH between samples dominated by slash and longleaf pines did not differ significantly from each other in either habitat zone (Table 4-6). Samples dominated by longleaf pine had a significantly larger ($p = 0.006$) DBH in preferred habitat in zone A (12.2 in) versus zone B (11.5 in). The average DBH for samples dominated by slash pine within zone A was not dissimilar from the average pine tree DBH for samples dominated by slash pine in zone B (Table 4-6).

Differences in Basal Area of Large Trees

Samples dominated by longleaf pine with a minimum average diameter of 12 in contained significantly less basal area (49.7 ft^2/ac, $p < 0.000$) than samples dominated by slash pine with a minimum diameter of 12 in (68.1 ft^2/ac) in zone A. Similarly, the basal area of large slash pine was statistically higher ($p < 0.000$) than samples dominated by large longleaf pines within zone B. The increased levels of basal area associated with slash pine dominated samples is most likely due to the substantial area of pines which border cypress ponds. These areas are almost exclusively slash pine, and because of the moist soil conditions, these pines are often of large size given a young age. The skewing effect of the large slash pines on estimates of basal area and quality of habitat should be studied further through field observation of foraging habits and buffer analysis using a geographic information system. The basal area of samples dominated by large longleaf pine trees (≥ 12 in) within zone A did not significantly differ ($p = 0.250$) from trees of the same condition found within zone B. Statistical tests revealed no evidence that large slash pine basal area differs between zones A (selected) and B (non-selected forage) (Table 4-7).

Observed Wiregrass

Within the preferred habitat of zone A, understory vegetation samples suggest that wiregrass dominated 60.7 percent of samples (n = 84) when grass was present. Non-selected habitat in zone B included proportionally fewer wiregrass observations, as wiregrass was dominant in only 23.6 percent of samples which contained some type of grass (n = 110).

Logistic Regression Model Estimates

Variable Screening Results

During the development of habitat association models, an interactive process was used to find a good subset of variables, i.e. a subset that includes only significant predictors that result in strong negative and positive predictive values. Table 4-8 shows the predictive coefficient value (b_i) and results for probability of habitat association for each of 16 variables. The iterative process eliminated certain variables, such as percent leaf litter cover. Although the probability of association with habitat for this variable is statistically significant (p = 0.0000), its predictive value is low as it is at or near zero. Other variables that were not significantly associated with active habitat were retained for model development. In this mode of variable testing, active habitat and large longleaf pines were not significantly associated (p = 0.9499). However, the t-test results on cluster data indicate that large longleaf pines were significantly larger in active clusters (Table 4-3). This factor was considered in conjunction with wiregrass presence as an interactive variable in Model 1, based on the assumption that the two variables are indicative of historic habitat conditions.

Table 4-7. Test results for differences in basal area of pines ≥ 12 in within zones A and B. T-tests were conducted at $\alpha = 0.05$.

	Mean (ft^2/ac)		
Dominant Pine Species	Zone A	Zone B	P Value
Longleaf Basal Area	49.7 ± 2.4[a]	45.9 ± .2.5	0.250
Slash Pine Basal Area	68.1 ± 3.2	70.0 ± 3.4	0.750
P Value	0.000	0.000	

[a] denotes ± 1 standard error

Table 4-8. Results from fitting the logistic regression equation separately to the data on habitat selection by red-cockaded woodpeckers at the Goethe State Forest in 2001.

Predictor Variable (X) (*=binary)	Significance p	**Constant Term b_x**
Leaf Litter Cover %	*.0000*	-.0286
Longleaf Dominance*	*.0037*	.4744
Slash Pine Basal Area	*.0069*	-.0065
Longleaf DBH	*.0136*	.0352
Longleaf Basal Area	*.0124*	.0074
Palmetto % Cover	*.0524*	.0054
Slash Pine DBH	*.0910*	-.0226
Forb % Cover	.1932	-.0161
Exposed Ground %	.2734	.0031
Wiregrass Presence*	.2958	.2470
Average DBH	.3006	.0330
Basal Area	.4399	-.0021
Av. DBH ≥ 13” *	.7371	.0575
Slash Pine DBH ≥ 13”*	.7984	-.0475
Wood Stem % Cover	.8190	-.0009
Longleaf DBH ≥ 13”*	.9499	-.0112

Following the initial screening, two models were finalized, and were tested using field data. The potential for field application was a major consideration in the formulation of the models.

Forest-Wide Model Diagnostics

Data from 612 sample points were used in Models 1_p and 2_p to evaluate habitat characteristics for significant association with red-cockaded woodpecker habitat within all nesting clusters at the Goethe State Forest. For Model 1_p, a correlation coefficient (CC) of 0.02 suggests no sign of multicollinearity between samples with an average DBH of all pines $\geq$ 13 in, and samples that were dominated by longleaf pine (Table 4-9). The evaluation of the z-score of b_1 in Model 1_p ($z = 1.76$, $p = 0.078$) suggests that it does not yield significant results at the 95 percent confidence level. The Model’s test statistic does not exceed the critical value of 3.841. Therefore, the null hypothesis, which states that the model variables are not associated with nesting habitat ($b_1 = 0$), cannot be rejected.

Even if this test level is relaxed, this model does not yield significant results at the 90 percent significance level.

Model 2_p includes two variables that contribute to the overall understanding of habitat selection. The predicted probability of habitat selection was solved by the following equation and subsequent transformation:

$$\hat{g} = -.0806 + .8091\ (1) + .4330\ (1) \quad = 1.161$$

The predicted probability is $e^{1.161}/(1+e^{1.161})$, or 76 percent. Thus the probability that areas dominated by large longleaf pines which contain wiregrass are associated with nesting habitat is 76 percent. Alternatively, the odds of association with nesting habitat is 1.16 times greater if those variables are present. Coefficients and related statistics are shown in Table 4-9. The "G-statistic" was used to test for at least one of the variables as statistically significant contributing factor in understanding habitat selection. The computed value of G is 12.5 with two degrees of freedom. The probability associated with this statistic is less than 0.002. This indicates that the alternative distribution is accepted and at least one of the coefficients $\{b_1, b_2\}$ is not equal to zero. The z-score for longleaf dominance (b_2) is positive and has a probability less than .05. This means that habitats dominated by longleaf pine tend to be selected as opposed to habitats where it is not dominant, when taking into account habitats where there is a combination of large longleaf pine (≥ 13 in) and wiregrass presence. Raising e to the power of b_2 gives the odds ratio of 1.54. Model 2_p suggests that when controlling b_1 the odds of habitat association increase by 1.54 if longleaf is dominant. At the .10 level of confidence this coefficient does appear to have a significant association with habitat selection.

Table 4-9. Results from fitting the logistic regression model to habitat data collected throughout 19 nesting clusters of the Goethe State Forest, Florida.

Forest-Wide Models	Coefficient	SE	G	p	Z	p	CC	Odds Ratio (e^b)	(e^b) 95 % CI Lower	Upper
1_P. Constant (b_0)	.0987		3.15	.076			.02			
Av. DBH $\geq$ 13 * LL DOM (b_1)	.3868	.22			1.76	.078		1.47	.956	2.26
2_P. Constant (b_0)	-.0806									
LL DBH $\geq$ 13" * WP (b_1)	.8091	.42	12.5	.002	1.91	.056	.06	2.25	.98	5.14
LL DOM (b_2)	.4330	.16			2.62	.009		1.54	1.12	2.13

It can be said with greater than 90 percent certainty that the variables in Model 2 are strongly associated with nesting habitat.

North and South Regions

Within the northern part of the Goethe State Forest, 274 samples taken near nesting cavities were used to characterize the association between habitat selection and vegetative characteristics. Preferred and non-selected habitat were analyzed in the southern population with data collected at 338 sample locations.

Table 4-10. Results from fitting the logistic regression model to habitat data collected in the northern region of the Goethe State Forest, Florida.

Model Variable (North)	Coefficient	SE	G	p	Z	p	CC	Odds Ratio (e^b)	(e^b) 95 % CI Lower	Upper
1_N. Constant (b_0)	.7329		0.07	.788						
Av. DBH ≥ 13 * LL DOM (b_1)	.0938	.35			.27	.789	.12	1.10	.55	2.18
2_N. Constant (b_0)	.6039									
LL DBH ≥ 13" * WP (b_1)	21	*	5.29	.071	0.00	.998	.03	*	0	*
LL DOM (b_2)	.1999	.26			.76	.009		1.22	0.73	2.04

Model 1_n tested samples where the average diameter of all pines was at least 13 in and longleaf pine was dominant. The correlation coefficient for b_1 in Model 1_n was 0.12, which indicates no strong relationship exists between the average diameter of pines ≥ 13 in and longleaf pine dominance. These variables, when tested interactively, were not significantly associated with habitat selection in the north (p = 0.788) (Table 4-10). In this case, as with the results from the population Model 1_p, the null hypothesis is not rejected. By comparison, in the southern cluster group, the coefficient b_1 in Model 1_s was significantly associated (p = 0.027) with selected habitat (Table 4-11). In addition, there is no indication of autocorrelation between the factors in b_1 observed in Model 1_s (CC= 0.02). Data from this sample suggest that the odds of habitat association, given the presence of dominant longleaf pine *and* pines averaging ≥ 13 in, is estimated to be between 1.07 and 3.34 higher for the southern population at the 95 percent level of certainty. The likelihood ratio statistic for Model 1_S (4.91) has a probability of 0.027, which suggests a positive association between the variables used in Model 1_S and the preferred habitat.

The probability of association for variables in Model 2_s is:

$$\hat{g} = -.4844 + 1.02\ (1) + .2981\ (1)$$

$$= .8337$$

$$and\ e^{.8337}/(1+e^{.8337}) = .69$$

Within the Goethe State Forest, if habitat contains large longleaf with wiregrass, and is dominated by longleaf pine, the likelihood of habitat association is 69 percent greater than if these variables are not present. This assumes that other environmental factors such as pine density and understory height are within acceptable limits.

On the basis of the z-score in Table 4-10 for Model 2N, this particular sample generated a b1 coefficient that does not differ from zero ($p = 0.998$). However, longleaf dominance (b2), is most likely different from zero since its associated z-score of 1.22 with a probability of 0.009 may suggest otherwise. An overall likelihood ratio test (G) was used to determine if either predictor is different from zero. For Model 2N, the G statistic is 5.29 with a probability of 0.071, suggesting that with almost 93 percent certainty that one of the model predictors differs from zero. There is no correlation of interactively tested variables in Model 2N (Table 4-10). This models poor performance was mostly due to highly variable data and smaller sample size when compared to the southern population.

Table 4-11. Results from fitting the logistic regression model to habitat data collected in the southern region of the Goethe State Forest, Florida.

Model Variable (South)	Coefficient	SE	G	p	Z	p	CC	Odds Ratio (e^b)	(e^b) 95 % CI Lower	Upper
1_S. Constant (b_0)	-.3995		4.91	.027			.02			
Av. DBH ≥ 13 * LL DOM (b_1)	.6379	.29			2.21	.027		1.89	1.07	3.34
2_S. Constant (b_0)	-.4844									
LL DBH ≥ 13" * WP (b_1)	1.02	.45	8.61	.014	2.28	.023	.06	2.79	1.16	6.75
LL DOM (b_2)	.2981	.23			1.30	.192		1.35	0.86	2.11

Measurements for b_1 in Model 2_S (the interaction between large longleaf and wiregrass presence), were not correlated (CC = 0.06). The associated *z*-score for b_1 is 2.28 with a probability of 0.023, indicating that in the southern region, b_1 denotes a significant relationship with habitat selection when considering b_2, longleaf pine dominance (Table 4-11). A 95 percent confidence interval, placed on the odds ratio (2.79), suggests that if the variable $b_2 = 1$ in the southern region, the level of habitat association with the red-cockaded woodpecker is between 1.16 and 6.75 times greater compared to habitat that does not include both large longleaf pines and wiregrass. The probability of habitat association, assuming habitat with all factors present as stated in the model is:

$$\hat{g} = -.4844 + 1.02(1) + .2981(1)$$

$$\hat{g} = .834$$

$$e^{.834} / (1 + e^{.834}) = .70$$

In this situation, the complete model was used to predict probability of association even though b_2 was not statistically significant (p = 0.192). This is justified by the significant G statistic (8.61 with 2 degrees of freedom) (p = 0.014) obtained by evaluating the overall model.

Nesting Habitat

The computed odds ratio ($e^{.8115}$) for Model 3 was 2.25 (Table 4-12). The predicted probability ($\hat{g}$) of longleaf pine preference (b_1 = 1) surrounding nesting habitat is:

$\hat{g}$ =-0.3947 + .8115*(1)

$\hat{g}$ = .4168

$e^{.4168}/(1+e^{.4168})$ =.60. The lower and upper confidence limits of the odds ratio are 1.17 and 4.33. One may argue with 95 percent confidence that the odds of habitat use for nest sites at the Goethe State Forest is between 1.17 and 4.33 times greater if longleaf pine is dominant rather than if longleaf pine is not the dominant species, assuming other environmental factors are held constant. The likelihood ratio statistic (*G*) was used to test whether the predictor variable is zero. The computed value for *G* = 6.045, which is considered large (p = 0.014), indicated that the variable is not equal to zero. The null hypothesis, which assumes the predictor coefficient is zero, was rejected. The probability of obtaining a *z*-score higher than 2.43 is less than 0.015. Thus, as with the likelihood ratio test, the result of the *z*-test indicates that a positive association exists between longleaf dominance and nest cavity habitat. Because the predicted probability is greater than 0.50, one may argue that maintenance of longleaf dominated habitat near nesting cavities is a priority at the Goethe State Forest. The iterative model building process used in this study considered several habitat components, but used a minimum number of variables for simplified field application. Most models performed well when applied to data for the forest population but did not when applied to the north and south sub-populations. This is an indication that for hypothesis tests to be accurate, logistic regression requires large samples.

Table 4-12. Computed coefficients and scores for longleaf pine as a predictor of nesting habitat selection.

Model 3: Variable	Coefficient	SE	G	p	Z	p	Odds Ratio (e^b)	(e^b) 95 % CI Lower	Upper
3. Constant (b_0)	-.3947		6.04	0.014					
LL DOM (b_1)	.8115	..333			2.43	0.015	2.25	1.17	4.33

CHAPTER 4
DISCUSSION OF FORAGING ZONE ANALYSES

Habitat Characteristics at the Goethe State Forest

In this study, a geographic information system was used to examine pine forest conditions within various spatial scales of active and inactive red-cockaded woodpecker habitat. A high proportion of longleaf pine samples (60 percent) was located within 1020 ft radius of nest cavities. By comparison, inactive clusters (half mile radius) contained approximately 45 percent longleaf pine. The indication that most longleaf-dominated habitat used for foraging is preferred over available slash pine-dominated habitat is consistent with previous studies that show a preference for, or selection of available longleaf pine over slash pine habitat in Florida (DeLotelle et al. 1987, Nesbitt et al. 1978, Porter and Labisky 1986).

The extent of red-cockaded woodpecker foraging zones varies between forests (Nesbitt et al. 1978, Porter and Labisky 1986, Zwicker and Walters 1999). Results of this study indicate that habitat dominated by larger longleaf pines, compared to other available pines, is associated with habitat at both spatial scales used for analyses in this study (zones A and B, and active and inactive clusters). Samples in areas dominated by longleaf trees in foraging zone A average significantly greater DBH ($P = 0.006$) and basal area ($P = 0.046$) compared to samples in zone B. The difference in average DBH and basal area between zones, is .68 in and 5.7 ft^2/ac, respectively. Longleaf pine basal area in zone A is 7.0 ft^2/ac greater than in zone B. Compared to inactive clusters, longleaf basal area is 9.6 ft^2/ac greater in active clusters. This indicates a positive trend towards longleaf preference given its availability. Although data on actual use or selection in longleaf dominated habitats was not collected, dominant pine overstory preference is apparent. The similarity of large longleaf pine trees in both active and inactive foraging zones and clusters suggest that although used habitat is dominated by longleaf overstory, preference may be influenced by factors other than DBH. Selection for cavity construction and foraging preference of longleaf pine is most likely related to a combination of factors such as age, good resin-producing abilities, and heartwood decay (Conner et al. 2001).

Quality of Forest Vegetation Within Clusters

Based on guidelines set forth by the U.S. Fish and Wildlife Service, basal area of longleaf systems should range between 40 and 60 ft^2/ac, while the basal area of shortleaf pine forests should range between 40 and 80 ft^2/ac (U.S. Fish and Wildlife Service 2000). This study suggests that in active clusters at the Goethe State Forest, the basal area of longleaf (60 ft^2/ac) and slash (67 ft^2/ac) pine systems fall within these guidelines, and cover a minimum of 60 percent of the area within a half mile of the cluster center. Samples contained significantly more basal area dominated by slash pine throughout active ($P = 0.000$) and inactive ($P = 0.000$) clusters. Both classes of foraging areas contained cypress swamps, bay heads, and hardwood drainages that are mostly bordered by slash pines and occasionally by loblolly trees. These slash pine are abundant, given the high perimeter to area ratio as swamps were often oval-shaped or in strips. The presence of cypress swamps decreased the total area of potential forage within this zone. The moist conditions which surround them may contribute to the increased size of slash pines which exclusively bordered these areas, possibly affecting habitat suitability.

Diameter distribution of pines in both active and inactive clusters were similar in size. On the average, these pines, most likely, are not large enough to contain sufficient heartwood diameter (5-6 in) for cavity tree excavation (Conner et al. 2001). It is known that longleaf pines are selectively chosen if they contain red heart fungus, which facilitates the excavation process (Rudolph et al. 1995). Although the outer diameter of pines in active clusters at the Goethe State Forest may suit cavity excavation, the average age of sampled trees is 55.1 (SE=1.45 years), well below the suggested minimum age of 60 to 80 years. Age is most likely a limiting factor in nest cavity selection (U.S. Fish and Wildlife Service 2000). Although the standing timber may be extensive enough and of suitable size, the lack of potential cavities is the dominant factor limiting the red-cockaded woodpecker's survival (Hovis and Labisky 1996).

Results of this study indicate that there is less basal area dominated by large longleaf pines throughout the 500 ac zone, and large trees (>12 in) in active clusters have a lower average basal area compared to longleaf of all sizes (>4 in). The average basal area of large slash pines (70 ft^2/ac) was greater than the basal area of all slash pines > 4 in (67 ft^2/ac) in active clusters. This relationship may be the result of forest management and the abundance of cypress ponds, rather than selection by the red-cockaded woodpecker. Previous management activities such as timber harvesting within clusters are most likely the cause for the decrease in large longleaf pine basal area. The abundance of large slash pine basal area is most likely due to the area surrounding cypress ponds where environmental conditions favor rapid growth of the species.

The understory vegetation parallels the recommended guideline's definition of "good quality foraging habitat" since it is dense with fire tolerant and fire dependent species such as wiregrass, saw palmetto, gallberry and fetterbush. Wiregrass dominates approximately 60 percent of the samples where grasses were identified in active clusters. This is significantly larger then the 25 percent of grass samples dominated by wiregrass in inactive clusters and may be an indication that the present day red-cockaded woodpecker groups forage in areas which maintain site characteristics of earlier populations. However, it is difficult to determine the historical locations of red-cockaded woodpecker cavity sites and the surrounding understory vegetative conditions before state forest management practices began at the Goethe State Forest in the mid 1990's (Hovis 1996). It is possible that the clusters where wiregrass is less prevalent may serve as an indication of other contributing factors which caused the abandonment of clusters, such as infrequent burning, or anthropogenic disturbance.

The samples collected within the 500 ac foraging zone cover a larger area than has been generally documented for home ranges in central Florida. Among the largest documented home ranges are those in the Stanton Energy Center in Florida where habitat consists largely of pine savanna with sparse tree densities (DeLotelle et al. 1987). Average foraging ranges in Florida's studied populations are larger than in other southern states. This may be related to the lower density, younger and smaller size-class of pines associated with habitat in the species' southern margin. The amount and quality of available habitat are contributing factors to these estimates as home range sizes vary considerably within uniform habitat (Hovis and Labisky 1996). Conner et al. (2001) estimate 230 to 383 ac for home range sizes in central Florida. Because of the relatively young age of potential cavity trees at the Goethe State Forest, an expected foraging range of 320 ac was chosen to further understand habitat preference in this case study.

The 320 Acre Foraging Zone

Previous studies have shown that cavity trees are usually located in stands with a low overstory basal area. Red cockaded woodpecker colonies studied at Apalachicola National Forest had a basal area that was considerably lower (46 ft^2/ac) than in adjacent areas (65 ft^2/ac) (Hovis and Labisky 1985). Availability of longleaf and slash pine basal area in zones A and B was nearly equal in our study. Mean basal area in zone A (60.2 ft^2/ac) is not significantly different from the surrounding zone B (59.6 ft^2/ac). In this study, the density for both zones is relatively low (<78 ft^2/ac) and the habitat is considered open grown. Use of longleaf pine for gum naval stores is evident by many remaining scarred trees which have been selected for nest cavity construction by the woodpecker and are likely infected with red-heart fungus.

The basal area of available pine forage $\geq$4 in within zone A (60.2 ft^2/ac) is within the recommended guidelines for “good quality foraging habitat” for longleaf systems (U.S. Fish and Wildlife Service 2000). Nearly all samples of understory vegetation were less than 6 ft in total height. Groundcover at the Goethe State Forest is mostly contiguous, fire tolerant saw palmetto, and fire dependent herbs. Very few areas of canopy hardwoods were observed that were not within pre-identified areas. The mapped cypress and hardwood areas covered approximately 40 percent of available forage within 2110 ft of nest cavity trees. Compared to other studies that reported a cypress component within Florida habitat, the red-cockaded woodpecker population at the Goethe State Forest has adapted to habitat containing the largest area of cypress forest proportional to foraging zone size. The large percentage of cypress may indirectly support the species’ foraging needs as large slash pines (>17 in) occupy the perimeter where soil conditions are moist. Further analysis of the relationship between the red-cockaded woodpeckers use of slash pines bordering cypress swamps, the cypress swamp size, perimeter area, and frequency of occurrence may give insight to the impact of landscape features on habitat requirements.

Application of a Binary Logistic Regression Model

In this case study, binary logistic regression was used to explore the potential of one single-variable explanatory model and two multi-variable explanatory models to characterize and quantify association between habitat characteristics and habitat preference. The potential of different resource attributes were tested for likelihood and probability of association with areas preferred by red-cockaded woodpeckers at the Goethe State Forest. However, this study was not an exhaustive attempt on all aspects of the logistic regression. Likelihood estimates indicate forest habitat dominated by longleaf pine is positively associated with nesting habitat.

The iterative model building strategy used in this study was employed to design a simplified model for field application. The combination of forward model building through tests on individual variables and the selection of variables based on previous studies, allowed us to find the best subset of a large set of predictors. However, given that wiregrass is less abundant than saw palmetto, the interaction of saw palmetto and longleaf pine at the Goethe State Forest most likely would have produced significant results when tested for association with preferred forage. Because wiregrass is historically associated with the species and is easily identifiable in the field, it was incorporated into Model 2. When longleaf is not dominant ($b_2 = 0$), the likelihood of association for variables in Model 2_P is higher (67 percent) if large longleaf *and* wiregrass are present ($b_1 = 1$), compared to the likelihood if the combination is not present ($b_1 = 0$) (58 percent). The higher odds ratio of b_1 (2.25) compared to b_2 (1.54), where estimates greater than one indicate an association with nesting habitat compared to non-selected habitat, is also an indication that habitat preference is dependent on a combination of forest attributes.

Given the homogeneous nature of pine forest throughout the sampling area, and prominent wiregrass in active habitat, it appeared that tests would report similar results at different scales. However, the same models which indicate habitat preference at the population level did not produce similar results when tested at smaller scales. The results from models tested on north and south populations are indications that for hypothesis tests to be accurate, logistic regression requires large samples. Our results are due to the low number of samples that contained both wiregrass and large longleaf pines. Results may also be related to changes in the density of red-cockaded woodpeckers by forest region or due to the variation and availability of resource units, which can change the selection strategies and selection function. A separate resource selection function for several independent replications, with larger sample sizes, would be necessary to accurately depict resource preference within north and south regions.

Suggestions For Future Research

The use of a geographic information system to manage and interpret data collected throughout the Goethe State Forest brings a series of new ways to:

a) Characterize cypress pond distribution, density, and area within habitat.

b) Associate new flight and foraging preference data with existing forest stand characteristics and understory vegetation records.

c) Relate the effects and intensity of silvicultural practices to the health of red-cockaded woodpecker.

The database created for this study can be readily updated with new data collected by the Goethe State Forest staff as well as future researchers. This would facilitate spatial and temporal analyses, and consolidate records for assessment of management practices.

Investigation of the distribution of cypress ponds within red-cockaded woodpecker habitat could provide insight as to whether or not it is a contributing factor to the area or amount of available forage needed by the species at the Goethe State Forest. Analysis of pond characteristics such as area, density, and perimeter-to-area ratio may be used to interpret the influence of cypress ponds on the size and distribution of clusters. This type of analysis is dependent on existing and new information such as the spatial distribution of foraging habits.

This study used an estimated foraging radius based on published data collected at nearby red-cockaded woodpecker sites in central Florida to interpret associations between expected foraging area and vegetative characteristics. New information on the actual flight patterns and distance traveled by the red-cockaded woodpecker at the Goethe State Forest would be critical for an analysis of foraging area in relation to cypress pond characteristics. This information could be displayed showing the geographic distribution of foraging habits in relation to existing data from this study such as pine species, basal area, and tree diameter throughout foraging areas. New information such as cypress pond characteristics, stand age, fire events, timber harvests, and recreational activities could be used as factors tested to impact the distance or direction of foraging efforts by the red-cockaded woodpecker at the Goethe State Forest.

Existing forest inventory data, integrated with data on silvicultural practices and red-cockaded woodpecker recovery efforts would support a comprehensive analysis of the changes in habitat preference over time. This meaningful data should be incorporated into the decision-making process and may be used as a process model designed to enhance existing red-cockaded woodpecker populations.

These suggestions, as well as social issues associated with red-cockaded woodpecker restoration, illustrate the need for new information and provide opportunities for future research. The use of dynamic models and statistical analyses will continue to support the decision-making process. Development of new and specific restoration efforts will benefit greatly from continued cooperative research between the Florida Division of Forestry and the University system.

CHAPTER 5
MANAGEMENT IMPLICATIONS

Plans for restoration of red-cockaded woodpecker populations are mainly developed using guidelines designed by the United States Fish and Wildlife Service. Current management efforts at the Goethe State Forest are primarily supported by those guidelines. However, to prioritize new habitat restoration efforts, management objectives should consider the following:

a) The significant and strong association found between nesting cavities and longleaf pines > 13 in DBH within close range (1020 ft).

b) Introduction of prescribed fire or mechanical treatment to reduce dense saw palmetto coverage.

c) A minimum intensive management unit of 225 ac surrounding nest cavities.

Logistic regression models developed in this study clearly indicate the preference of longleaf pines > 13 in DBH within foraging areas surrounding nest cavities. In most management units where the red-cockaded woodpecker occurs, forest management strategies should continue to enhance the availability of these characteristics in frequently burned longleaf pine stands. Although various uneven-age timber harvesting techniques within management units can be used to retain some foraging value and provide financial gain, persistence of old trees should be emphasized. Regardless of species, trees greater than 100 years old should be omitted from timber sale, as they would leave red-cockaded woodpeckers without high quality forage, and potential excavation sites to use while stands mature.

Vegetation in the understory of sampled clusters is dominated by saw palmetto. The leaves of this plant contain chemical properties that, when ignited, could produce extremely intense fires. Given the small average diameter of pines found within foraging clusters, it is important to reduce the amount of saw palmetto through the use of controlled burning or mechanical treatment. Adjacency to sensitive areas and weather conditions may prohibit burning in some areas. An alternative solution to remove excessive saw palmetto or vegetation which may disturb the red-cockaded woodpecker's foraging habits, may be a series of treatments which include a combination of chemical treatment to large hardwoods and mechanical removal of large, dense saw palmetto. In an optimal situation, the forest understory should be diverse with forbs and grasses whose composition is dense enough to sustain a periodic controlled fire. Although the process may be time and cost intensive, immediate efforts to reduce understory height below 12 ft should focus on areas where vegetation is near or exceeds this level in nesting clusters. This effort would sustain the existing populations and prepare for less costly management alternatives such as translocation efforts to enhance the existing population.

Translocation and artificial cavity construction efforts used to create new colony sites should be targeted in longleaf dominated habitat adjacent to existing active clusters. These areas should contain a minimum of 225 ac of suitable pine forage with little or no hardwood midstory. This management unit size is based on test results for association of longleaf pine across three potential habitat zones, published research on red-cockaded woodpecker populations in central Florida, and efficiency of use in evaluation of field data for suitable habitat. A comparison between future estimates of forest characteristics and baseline data from this study may be used to evaluate management alternatives.

LIST OF REFERENCES

Affeltranger, C. 1971. The red-heart disease of southern pines. Pp. 96-99 in R. L. Thompson, ed. The Ecology and Management of the Red-Cockaded Woodpecker, Proceedings of a Symposium at Okefenokee National Wildlife Refuge. Folkston, GA.

Allen, D. H. 1991. An insert technique for constructing artificial Red-cockaded Woodpecker cavities. U.S. Forest Service General Technical Report. SE-73. 19pp.

Allison, P. D. 1999. Logistic regression: Using the SAS system: Theory and application. SAS Institute. Cary, NC. 288pp.

Azevedo, J. C. M., S. B. Jack, R. N. Coulson, and D. F. Wunneburger. 2000. Functional heterogeneity of forest landscapes and the distribution and abundance of the red-cockaded woodpecker. Forest Ecology and Management. 127:271-283.

Carter, J. H., J. R. Walters and P. M. Dixon. 1995. Red-cockaded Woodpeckers in the North Carolina Sandhills: A 12 Year Population Study. Pp. 248-258 in D. L. Kulhavy, R. G. Hooper and R. Costa, eds. Red-cockaded woodpecker: Recovery, ecology, and management. Center for Applied Studies in Forestry, Stephen F. Austin State University. Nacogdoches, TX.

Conner, R. N., D. C. Rudolph, and J. R. Walters. 2001. The Red-cockaded Woodpecker: surviving in a fire maintained ecosystem. University of Texas Press, Austin, TX. 363pp.

Conner, R. N., and D. C. Rudolph. 1991. Forest habitat loss, fragmentation, and Red-cockaded Woodpecker populations. Wilson Bulletin. 103:446-457.

Conner, R. N., D. C. Rudolph, R. Schaefer, D. Saenz, and C.E. Shackelford. 1999. Relationships among the red-cockaded woodpecker group density, nestling provisioning rates, and habitat. Wilson Bulletin. 111(4):494-498.

DeLotelle, R. S., R. J. Epting, and J. R. Newman. 1987. Habitat use and territory characteristics of red-cockaded woodpeckers in central Florida. Wilson Bulletin. 99(2):202-217.

Dennington, R. W., and R. M. Farrar. 1983. Longleaf pine management. United States Department of Agriculture, Forest Service Southern Region. Forestry Report R8-FR3. Pp. 17.

Engstrom, T. R., and G. Mikusinski. 1998. Ecological neighborhoods in red-cockaded woodpecker populations. The Auk. 115:473-478.

Engstrom, T. R., and F. J. Sanders. 1997. Red-cockaded woodpecker foraging ecology in an old growth longleaf pine forest. Wilson Bulletin. 109(2):203-217.

Epting, R. J., R. S. DeLotelle, and T. Beaty. 1995. Red-cockaded woodpecker territory and habitat use in Georgia and Florida. Pp. 59-67 in D. L. Kulhavy, R. G. Hooper and R. Costa, eds. Red-cockaded woodpecker: Recovery, ecology, and management. Center for Applied Studies in Forestry, Stephen F. Austin State University. Nacogdoches, TX.

Gaines, G. D., K. E. Franzreb, D. H. Allen, K. S. Laves, and W. L. Jarvis. 1995. Red-cockaded woodpecker on the Savannah River Site: A management success story. Pp 81-85 in D. L. Kulhavy, R. G. Hooper and R. Costa, eds. Red-cockaded woodpecker: Recovery, ecology, and management. Center for Applied Studies in Forestry, Stephen F. Austin State University. Nacogdoches, TX.

Grimm, L. G., and P. R. Yarnold. 1995. Reading and understanding multivariate statistics. American Psychological Association, Washington D.C. 373pp.

Hanula, J. L., and K. Franzreb. 1998. Source, distribution and abundance of macroarthropods on the bark of longleaf pine: Potential prey of the red-cockaded woodpecker. Forest Ecology and Management. 102:89-102.

Hardesty, J. L., K. E. Gault, and H. F. Percival. 1997. Ecological correlates of red-cockaded woodpecker foraging preference, habitat use and home range size in northwest Florida (Eglin AFB). Final Report, Research Work Order 99. The Nature Conservancy, Gainesville, FL.

Hooper, R. G. 1996. Arthropod biomass in winter and the age of longleaf pines. Forest Ecology and Management. 82:115-131.

Hooper, R. G., L. J. Niles, R. F. Harlow, and G. W. Wood. 1982. Home ranges of Red-cockaded woodpeckers in coastal South Carolina. The Auk. 99:675-682.

Hopkins, M. L., and T. E. Lynn. 1971. Some characteristics of Red-cockaded woodpecker cavity trees and management implications in South Carolina. Pp 140-169 in D. L. Kulhavy, R. G. Hooper and R. Costa, eds. Red-cockaded woodpecker: Recovery, ecology, and management. Center for Applied Studies in Forestry, Stephen F. Austin State University. Nacogdoches, TX.

Hosmer, D. W. Jr., and S. Lemeshow. 1989. Applied logistic regression. Wiley series in probability and mathematical statistics. Applied probability and statistics. Wiley, New York. 307pp.

Hovis, J. A. 1996. Status and management of the red-cockaded woodpecker on Goethe State Forest, Florida. Southeast Association Fish and Wildlife Agencies Annual Conference Proceedings. 50:254-263.

Hovis, J. A., and R. F. Labisky. 1996. Red-cockaded woodpecker. Pp. 81-102 in J. A. Rodgers, Jr., H. W. Kale II, and H. T. Smith, eds. Rare and endangered biota of Florida: Volume V. Birds. University Press of Florida, Gainesville, FL.

Hovis, J. A., and R. F. Labisky. 1985. Vegetative associations of red-cockaded woodpecker colonies in Florida. Wildlife Society Bulletin. 13:307-314.

Ligon, D. J. 1971. Some factors influencing numbers of the red-cockaded woodpecker. Pp. 30-43 in R.L. Thompson ed. The ecology and management of the Red-cockaded Woodpecker. Proceedings of a Symposium at Okefenokee National Wildlife Refuge. Folkston, GA.

Loeb, S. C., W. D. Pepper, and A. T. Doyle. 1992. Habitat characteristics of active and abandoned red-cockaded woodpecker colonies. Southern Journal of Applied Forestry. 16(3):120-125.

Manly, B. F., L. L. McDonald, and D. L. Thomas. 1993. Resource selection by animals. Chapman and Hall. Great Britain. 177pp.

Nesbitt, S. A., D. T. Gilbert, and D. B. Barbour. 1978. Red-cockaded woodpecker fall movements in a Florida flatwoods community. The Auk. 95:145-151.

Outcalt, K. W., and R. M. Scheffield. 1996. The longleaf pine forest: trends and current conditions. United Stated Department of Agriculture, Southern Research Station. Resource Bulletin SRS-9. Asheville, NC. Pp. 23.

Porter, M. L., and R. F. Labisky. 1986. Home range and foraging habitat of red-cockaded woodpeckers in northern Florida. Journal of Wildlife Management. 50(2):239-247.

Ross, W. G., D. L. Kulhavy, and R. N. Conner. 1997. Stand conditions and tree characteristics affect quality of longleaf pine for red-cockaded woodpecker cavity trees. Forest Ecology and Management. 91:145-154.

Rudolph, D. G. and R. C. Conner. 1994. Forest fragmentation and red-cockaded woodpecker population: an analysis at intermediate scale. Journal Field Ornithology. 65:365-375.

Thomlinson, J. R. 1996. Predicting status change in red-cockaded woodpecker cavity tree clusters. Journal of Wildlife Management. 60:350-354.

U.S. Fish and Wildlife Service. 2000. Technical/agency draft revised recovery plan for the red-cockaded woodpecker. U.S. Fish and Wildlife Service, Atlanta, GA. 229pp.

Walters, J. R., S. J. Daniels, J. H. Carter, III, P. D. Doerr, K. Brust, and J. M. Mitchell. 2000. Foraging habitat resources, preferences and fitness of red-cockaded woodpeckers in the North Carolina Sandhills. Fort Bragg Project Final Report. Virginia Polytechnic Institute and State University, Blacksburg, VA, and North Carolina State University, Raleigh, NC.

Walters, J. R., P. P. Robinson, W. Starnes and J. Goodson. 1995. The relative effectiveness of artificial cavity starts and artificial cavities in inducing the formation of new groups of Red-Cockaded Woodpeckers. Pp. 367-369 in D. L. Kulhavy, R. G. Hooper and R. Costa, eds. Red-cockaded woodpecker: Recovery, ecology, and management. Center for Applied Studies in Forestry, Stephen F. Austin State University. Nacogdoches, TX.

Zwicker, S. M. and J. R. Walters. 1999. Selection of pines for foraging by red-cockaded woodpeckers. Journal of Wildlife Management. 63(3):843-852.

BIOGRAPHICAL SKETCH

Douglas Owen Shipley was born in Hinsdale, Illinois, on 17 August 1976. In 1998, he received a B.S. in environmental resource management from Virginia Polytechnic Institute and State University. After graduation, he worked as a forester at the Seminole State Forest for the Florida Division of Forestry. In December 2002, he completed requirements for the Master of Science degree, at the University of Florida.