ASSESSING HABITAT QUALITY FOR THE ENDANGERED RED-COCKADED WOODPECKER (*Picoides borealis*)

Ken M. Convery

Thesis submitted to the Faculty of
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE
in
BIOLOGY

Jeffrey R. Walters, Chair
Robert H. Jones
Dean F. Stauffer

October 4, 2002

Blacksburg, Virginia

Key words: Red-cockaded woodpecker, *Picoides borealis*, habitat quality, home range, foraging partitions, foraging guidelines

Ken M. Convery

ASSESSING HABITAT QUALITY FOR THE ENDANGERED RED-COCKADED WOODPECKER (*PICOIDES BOREALIS*)

ABSTRACT

This project had 2 major objectives. The first objective was to assess how well the revised U.S. Fish and Wildlife Service Foraging Habitat Guidelines depict good quality habitat for the red-cockaded woodpecker (*Picoides borealis*) at Camp Lejeune, NC. To accomplish this, I used multiple linear and logistic regression to examine the relationships between fitness, habitat use, home range size, and habitat characteristics described in the guidelines. I assumed that habitat characteristics that confer quality were related to higher fitness, greater habitat use, and reduced home range size. To a large extent, the guidelines are validated. Red-cockaded woodpeckers responded favorably to habitat that mimics the historical, mature, and fire-maintained pine forests of the southeastern U.S., characterized by high densities of large pines, low densities of small and medium pines, and a lush herbaceous groundcover. Variables positively associated with habitat use and fitness were associated with reduced home range size, and those negatively associated with habitat use and fitness with increased home range size. Percent herbaceous groundcover was a significant regressor indicative of quality in every model. The second objective was to assess how well USFWS foraging partitions represent habitat used by red-cockaded woodpeckers. I conducted home range follows of 23 groups of red-cockaded woodpeckers and estimated the percentage of each home range encompassed by partitions of varying radii. The percentage of the actual home range included in the partition increased as a function of partition radius. The standard 800 m circular partition, on average, included 91% of the home range, but significant variation existed between groups.

DEDICATION

To my parents, Raymond and JoAnn Convery, for their unrelenting support, understanding, and unconditional love.

ACKNOWLEDGEMENTS

I thank my advisor, Jeffrey R. Walters, for his encouragement, support and guidance throughout this project. It has been a great pleasure and honor to work with Jeff.

I sincerely appreciate the advice and direction provided by my committee, Robert H. Jones and Dean F. Stauffer. Their helpful comments greatly improved this project.

I thank my fellow graduates students in the Avian Ecology Lab for their friendship, support and advice, with special thanks extended to Susan Daniels for comments that greatly improved this project. Thanks to Karen Schiegg and Gilberto Pasinelli for their thoughtful advice during the planning stages of this project.

This project was funded by the Department of Defense, Camp Lejeune Marine Corps Base. The work was accomplished through Research Work Orders with the U.S. Geological Survey Biological Resources Division, through the Virginia (RWO 47, RWO 69) Cooperative Research Unit. I thank M. Vaughan with the Virginia Unit, and S. Fennell with the national office, for their assistance. I thank the natural resources staff at Camp Lejeune for their support and assistance, particularly J. Hammond, K. Ogden, and J. Townson. Susan Cameron and B. Simmons collected much of the home range data.

Love and thanks to Abigail Vitale for always being the best.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1. Validation of Habitat Quality Definitions for Red-cockaded Woodpeckers

INTRODUCTION

Understanding the ecological relationships between animals and their habitat is fundamental to successful wildlife management. Without an appreciation for those habitat features that affect fitness it is impossible to make wise and informed management decisions. This is especially true for threatened and endangered species whose continued survival is often dependent on thoughtful and effective management. In the case of the red-cockaded woodpecker (*Picoides borealis*), our understanding of habitat requirements continues to grow because it is one of the most intensely studied vertebrates in North America. If management is to be effective, policies must constantly evolve to reflect current knowledge about the species. In this study, I assess how well the new U.S. Fish and Wildlife Service (USFWS) Foraging Habitat Guidelines for the red-cockaded woodpecker correspond with fitness and habitat use at Camp Lejeune, North Carolina.

Animal habitat relationships

Understanding animal habitat relationships has long been of interest to ecologists. Much of our current understanding developed from early ideas relating abiotic factors (temperature, humidity, etc.) to the distribution of birds. As early as 1904, Grinnell had developed a detailed range map for the chestnut-backed chickadee (*Parus rufescens*) and described environmental factors that limited its distribution (Grinnell 1904). In 1917, he superimposed a life-zone map of California over the distribution of the California thrasher (*Toxostoma redivivum*), noting the relationship between species presence and habitat "elements," such as altitude, temperature, and humidity (Grinnell 1917). Like many of the early ideas in ecology, these were largely geographic in nature.

By 1933, Lack had studied bird assemblages in Breckland Heath, England, and concluded that traditional factors explaining animal distributions, such as climate, food, and shelter, failed to account for observed patterns of habitat occupancy. He demonstrated the influence of habitat selection on the density of meadow pipits (*Anthus pratensis*), skylarks (*Alauda arvensis*), and willow warblers (*Phylloscopus trochilus)* by showing that these birds coexisted in two slightly different habitat types, but their local population density within these habitats varied predictably. He concluded that since each species was physiologically capable of occupying both habitats but did so at different densities, that species must prefer certain habitats to others. He suggested that the "psychological nature" of animals is a factor that should be considered when examining habitat occupancy. By the 1950's, the idea that animals preferentially "select" some habitats over others was well accepted (Svardson 1949), and in recent times, habitat use studies have become commonplace (Manly et al. 1993).

Whatever the mechanisms for habitat selection, animals should use resources in an attempt to maximize fitness under the current set of environmental conditions. If animals select habitats or habitat characteristics, then it is likely that poor (or good) decisions will affect their access to food and mates, intensity of competition and predation (Wiens 1985). These, of course, are all factors that contribute to fitness, and thus, natural selection should favor those individuals that select favorable habitats (Cody 1985). Deviations from this behavior would decrease fitness and thus be selected against. Researchers have used this fundamental principle to assess habitat quality for many species. It is thus usually *assumed* that selected resources are associated with high quality, and "avoided" or unused resources with low quality (Van Horne 1983).

It is true that habitat selection is somehow related to habitat quality. It would be hard to argue that an unoccupied habitat is of higher quality than another that is occupied. But relating habitat use to habitat quality without reference to demography may be fallacious (Van Horne 1983). That is, simply demonstrating that a resource is used does not confer quality to that resource. This idea is well illustrated by the source-sink concept (Pulliam and Danielson 1991), where dominant individuals occupying high quality habitat compel subdominant individuals to inhabit lower quality habitat. Although density of individuals may be greater in low quality habitat, productivity and survivorship is greater in the high quality areas. Any definition of habitat quality, therefore, should explicitly consider survival and productivity in addition to use (Van Horne 1983). In this study, I apply this principle to foraging habitat quality in red-cockaded woodpeckers.

Foraging habitat of red-cockaded woodpeckers

The red-cockaded woodpecker is one of seven woodpecker species (Family: Picidae) that regularly breed in the southeastern United States. Unique among this group, the red-cockaded woodpecker is a cooperative breeder that excavates nesting and roosting cavities in mature living pine trees. Endemic to southern pine forests and favoring especially the longleaf pine (*Pinus palustrus*) ecosystem, the species was common prior to European settlement of North America, but had reached critically low numbers by 1960, and was listed as a federally endangered species in 1970 (U.S. Fish and Wildlife Service 1970).

Despite this protection and a growing understanding of red-cockaded woodpecker natural history, populations continued to decline throughout the 70's and 80's (Conner and Rudolph 1989, James 1991). A main objective of the 1985 USFWS Recovery Plan was to describe foraging requirements of the species, and to communicate these findings to land managers, so that existing populations could be preserved and augmented (U.S. Fish and Wildlife Service 1985). The guidelines, adapted from a habitat use study of 18 groups in coastal South Carolina (Hooper and Lennartz 1981, Hooper et al. 1982, Hooper and Harlow 1986), stipulated that each group be provided with ≥51 ha of preferred foraging habitat within 0.8 km of the cavity tree cluster, the collection of nesting and roosting trees each group maintains. Forty percent of this area should include trees ≥60 years old, with at least 6350 pine trees ≥10" dbh, and a total basal area of 8,490 ft^2. These values represent habitat used by the 18 study groups.

Researchers have been unable to establish a relationship between the 1985 USFWS guidelines and measures of group fitness (Wood et al. 1985, Hooper and Lennartz 1995, Beyer et al. 1996, Hardesty et al. 1997, James et al. 2001, Walters et al. 2002; but see Lennartz et al. 1987, Delotelle and Epting 1992). Rather, groups with large home ranges may simply have access to many pines ≥10" dbh and groups with small home ranges may have access to fewer numbers of pine ≥10" dbh, but neither productivity nor group size is affected by this parameter. Groups that do not meet the guidelines are just as likely to be reproductively successful as those groups that are in compliance. Even in the same population in which the guidelines were developed, logging practices that reduced the amount of foraging habitat well below recommended levels did not result in a decrease in productivity (Hooper and Lennartz 1995). Indeed, there seems to be little or no relationship between 1985 guidelines and measures of group fitness, and thus, several researchers have suggested that the guidelines are inappropriate (Beyer et al. 1996, Hardesty et al. 1997, James et al. 2001, Walters et al. 2002, U.S. Fish and Wildlife Service 2003).

Of course, if fitness is unrelated to foraging habitat quality, or if groups have more resources than they need to exist, then a relationship would not be apparent (Walters et al. 2002). Recent research, however, suggests that foraging habitat quality and quantity do in fact affect group performance, but the USFWS metric, i.e. the number of pine stems ≥10” dbh, is an inappropriate measure of habitat quality (James et al. 1997, James et al. 2001, Walters et al. 2002). James and colleagues (1997, 2001) recently demonstrated a relationship between measures of group fitness and 2 factors that may be related to fire history: groundcover composition and size class distribution of pine stems. Rather than advocating any absolute number of pines, James et al. (2001) suggest a high density of large pines is beneficial, whereas a high density of small pines is detrimental. They showed that the difference between the density of large pines (>35 cm dbh) and that of small pines (<25 cm dbh) was a highly significant predictor of red-cockaded woodpecker group size. Furthermore, James et al. (2001) evaluated the influence of groundcover composition on group size, productivity, and density of groups in northern Florida. Those groups within areas with a high percentage of wiregrass relative to the percent cover of woody vegetation tended to be larger and more productive, and occupied smaller territories (based on density of groups) than other groups. Consistent with these results, Hardesty et al. (1997) found that productivity was related to high herbaceous content in the groundcover, low hardwood height and density, and few small pines within the home range. Finally, Walters et al. (2002) demonstrated that group size was negatively related to hardwood density and height, the density of medium sized pines (25.4-35.6 cm dbh), and positively related to the density of old-growth pines within the home range.

It has long been known that red-cockaded woodpeckers are negatively affected by hardwood midstory (Conner and Rudolph 1989). Recent results suggest that a midstory of any kind may be deleterious, whether pine or hardwood (James et al. 1997, James et al.

2001). It is thus clear that habitat quality does in fact affect red-cockaded woodpecker population dynamics. A picture of preferred red-cockaded woodpecker foraging habitat begins to emerge: red-cockaded woodpeckers prefer mature, open pine forests with large trees, little hardwood or pine midstory, and a lush, herbaceous groundcover (James et al. 2001). Interestingly, it appears that those habitat variables that positively affect fitness are those also associated with fire-maintained old growth longleaf pine forests. This assertion is supported by Engstrom and Sanders (1997), who demonstrated that groups in old growth longleaf pine had the highest productivity and smallest home ranges yet described.

Managing red-cockaded woodpeckers

Researchers have made great strides in understanding the demography and sociobiology of the red-cockaded woodpecker (Walters et al. 1988, Copeyon et al. 1991). This understanding has led to simple management tools such as artificial cavities and restrictor plates that have reversed declining population trends. Successfully managing foraging habitat of the red-cockaded woodpecker, however, has proven to be an elusive task. Nesting requirements can be met with a few large trees in a small area, whereas 75 ha or more of forest with specific attributes may be required to meet foraging requirements. Thus, it is clear that managing for red-cockaded woodpecker foraging habitat will have profound impacts on large amounts of land. It is also clear that a solid understanding of the foraging requirements will give land managers the freedom to achieve multiple use without endangering the red-cockaded woodpecker.

Successful wildlife management requires a flexible strategy that continually incorporates new information into management policies. Accordingly, much of the information learned since the release of the 1985 Recovery Plan has been incorporated into the revised plan being released next year (2003). To a large extent, foraging habitat guidelines have been completely revised to reflect the current knowledge about habitat relationships described above. While the old plan focused largely on the number of trees available as a foraging substrate, the revised plan aims at restoring habitat to mimic historical conditions, with forest structure an essential component. Structural features described in the revised plan include (1) a substantial herbaceous groundcover, (2) minimal pine and hardwood midstory, (3) minimal hardwood overstory, (4) a low to intermediate density of small and medium sized pines, and (5) a significant presence of large and old pines (U.S. Fish and Wildlife Service 2003) (Table 1.1).

While the USFWS should be applauded for their efforts to incorporate the best available information into the revised plan, it is largely left to the scientific community to validate the appropriateness of the new guidelines. To a large extent, the previous guidelines, while well intended, were seriously flawed. For an endangered species such as the red-cockaded woodpecker, misguided management attempts may have dire and long lasting consequences for the species' survival. Independent validation of these new guidelines is especially important because some of the recommendations are based on anecdotal information or results from unreplicated studies. Only one researcher, for example, has examined the relationship between habitat use and groundcover composition, and the relationship between groundcover and fitness has only been assessed in Florida, in the southern periphery of the species' range.

In this study, I used the relationship between habitat characteristics, fitness and habitat use to identify habitat features that may be components of good quality foraging habitat for the red-cockaded woodpecker. Specifically, I assessed how well the revised USFWS Foraging Habitat Guidelines correspond with good quality habitat for red-cockaded woodpeckers at Camp Lejeune, North Carolina. This project is unique in that, unlike other investigations of red-cockaded woodpecker habitat relationships, it is corroborative rather than exploratory in nature. That is, I used the USFWS guidelines to make predictions and test specific hypotheses. Finally, to assess how much habitat at Camp Lejeune meets the revised guidelines and to gauge the effort needed to comply with them, I classified habitat within the study area based on the number of characteristics in accordance with the guidelines. For habitat not meeting the guidelines, I list those attributes in need of management.

METHODS

Study species

The red-cockaded woodpecker is an endangered, cooperatively breeding species, endemic to the mature pine ecosystems of the southeastern United States, and especially favoring the longleaf pine ecosystem. They are unique among woodpeckers in their use of living pine trees for nesting and roosting (Ligon 1970). This trait and their cooperative breeding system combine to play a critical role in their population dynamics (Walters et al. 1988, Walters et al. 1992).

Social groups, consisting of a breeding pair and perhaps one or more helpers, maintain a cluster of cavity trees, which they use for roosting and nesting (Ligon 1970, Walters et al. 1988). Because cavity excavation is labor-intensive, and may take many years to complete, cavity trees are a critical and often limiting resource (Jackson 1994). To obtain a cluster of trees, and thus a potential breeding vacancy, young males typically exhibit one of 2 distinct life strategies (Walters et al. 1988). They may either disperse in search of a breeding vacancy or they may remain on their natal territory as non-breeders and assist with the rearing of future years' broods. Helpers may assist for many years or until a breeding vacancy arises in their natal cluster or a nearby one. Young females typically do not help and instead disperse in search of a breeding vacancy.

Surrounding the cluster tree area, groups defend year round territories, which they use for foraging (Ligon 1970, Walters et al. 1988). Home range sizes typically average 71-152 ha (Conner et al. 2001), vary considerably, and may be influenced by habitat quality (Nesbitt et al. 1983, DeLotelle et al. 1987), group size (Hooper et al. 1982), and the density of neighboring groups (Sherrill and Case 1980, Hooper et al. 1982, DeLotelle et al. 1987).

Extensive habitat loss and degradation are largely responsible for the species' decline. Historically, longleaf pine ecosystems covered most of the Atlantic and Gulf Coastal Plains, from eastern Texas to southeastern Virginia, encompassing as much as 37 million ha (Landers et al. 1995). Today, however, due to extensive logging and development, <1.2 million ha remain, and most of this bears little resemblance to pre-colonial conditions (Landers et al. 1995). In contrast to the mature, open and park-like savannas that once covered millions of hectares of contiguous forest, today's longleaf forests are second or third growth, and are typically found in small, isolated and degraded fragments. Natural fires and perhaps those set by Native Americans historically occurred every 1-3 years and maintained an open understory with few hardwoods and a diverse groundcover, have largely been suppressed (Frost 1998). As a result, many of today's longleaf forests are young and dense, with substantial hardwood midstory and little herbaceous groundcover (Ware et al. 1993).

While habitat loss is undoubtedly the single greatest cause of red-cockaded woodpecker population declines, habitat degradation is the primary cause of recent and potential further declines (Conner et al. 2001). Red-cockaded woodpeckers evolved in and are adapted to mature, open, and fire-maintained pine ecosystems of the southeastern United States. They require large, old, and living pine trees for cavity excavation, because only they have sufficient heartwood to hold a nesting and roosting cavity, and because they are more often infected with red heart disease (*Fomes pini*), which weakens the heartwood and thus facilitates excavation (Jackson 1994, Conner et al. 1995). These trees are rare in today's landscape, as is the open structure that fire-maintained pine ecosystems provide. So critical is an open midstory that red-cockaded woodpeckers will abandon their cavities if midstory encroaches on them (Conner and Rudolph 1989).

A thorough review of the species' biology can be found in Conner et al. (2001), and also in the new Red-cockaded Woodpecker Recovery Plan (U.S. Fish and Wildlife Service 2003).

Study area and population

Camp Lejeune is located in Onslow County in eastern North Carolina (Figure 1.1), and occupies 61,110 ha within the southern Atlantic Coastal Plain (Anonymous 1996). Home of the 2nd Marine Expeditionary Force, its primary purpose is military training, including infantry operations, helicopter operations, firing range operations, and other training and support activities (Anonymous 1996). The Marine Corps manages for red-cockaded woodpeckers in compliance with the Endangered Species Act of 1973.

For practical purposes Camp Lejeune is divided into 2 major sections: Main Base (44,517 ha, including 10,522 in open water) and Greater Sandy Run (16,593 ha).

Currently there are no known red-cockaded woodpecker clusters in the Greater Sandy Run area. Main Base is further divided into Mainside, Verona/Dixon Area, and Marine Corps Air Station. Within the Mainside area, G10, Combat Town, and Northeast sections are important centers of woodpecker activity. To the west and across the New River, a separate population exists in the Verona/Dixon area (Figure 1.2).

Approximately 75% of Main Base is forested with pine or pine/hardwood forests, much of this dominated by loblolly pine (*Pinus taeda*) (Anonymous 1996). Hardwoods are common along the floodplains of the major creeks. Pure longleaf pine stands are also present, and red-cockaded woodpeckers are primarily associated with these areas (Zwicker and Walters 1999). Most stands are intentionally burned on a five-year rotation, but red-cockaded woodpecker cluster sites are burned every 3 years (Anonymous 2001), and accidental fires frequently burn the G-10 and Combat Town areas, resulting in open stands with little midstory (Anonymous 1996). There is little topographic relief, with elevations ranging from sea level to 23 m above mean sea level. Soils are sand and sandy loam in the uplands, and muck soils in natural drainages (Anonymous 1996).

Study Population.--

Management of red-cockaded woodpeckers at Camp Lejeune has been a great success. Up from only 27 groups in 1991, the current population continues to grow at 57 groups (year 2000). This growth can be attributed in large part to active cavity tree management, designed to prevent territory abandonment and to create new territories (Walters et al. 1999).

For practical and biological purposes, the red-cockaded woodpeckers on Camp Lejeune can be considered 2 distinct populations, separated by approximately 10 km, including at least 2 km of open water in the New River. Dispersal between populations is rare, having occurred 3 times in 12 years (Walters et al. 1999). The eastern population consists of 3 distinct but biologically connected areas: G-10 Impact Area, Combat Town, and Northeast training areas. This population consists of 48 groups and may be the healthiest population in existence, as evidenced by high mean group size and fledgling production (Walters et al. 1999). The western (Verona/Dixon) population currently consists of only 9 groups and its long-term viability is a concern.

Study group selection

I selected 23 of the 50 groups present at the beginning of the study (1999) for analyses (Figure 1.2). Because military activity prevented the random selection of study groups and limited the number of potential study groups, I chose groups based on historic (1994-1998) group size and productivity, so that the study would include some historically large and relatively productive groups, some historically small and relatively unproductive groups, and groups of intermediate size and productivity. I hoped that this range of variability would increase the ability to detect habitat relationships to fitness. Groups with <5 years of data and groups that recently split into $\geq$2 groups were excluded from entering the sample.

Data collection

Demographic and cavity tree data.--

The demographic and cavity tree data for this project were collected as part of a continuing long-term study conducted by personnel from Virginia Polytechnic Institute and State University. Continuously monitored since 1986, all birds in these populations are uniquely marked for individual identification (Walters et al. 1999). Additionally, clutch size, brood size, nesting success, and the number of young fledged have been documented for each nest every year, as have group size, and the status of each member of each group (i.e. breeder, helper, etc.). A detailed description of data and collection methods is presented in Walters et al. (1998).

Additionally, the status of each cavity tree (start, active, inactive, relic) was also recorded each year. A cavity was considered 'active' if it was currently being used by a red-cockaded woodpecker, 'inactive' if it was not – but may have been within the last five years – and a 'relic' if it had been inactive for five or more consecutive years. Relic cavities may but rarely become active again. A cavity 'start' is a tree under excavation, and is indicated by a circular excavation into the sapwood. Geographic coordinates of the trees were obtained using a geographical positioning systems (hereafter GPS) receiver with real-time differential correction. Data used here were collected from 1996-2001.

Vegetation sampling.--

Forest Inventory.

Camp Lejeune commissioned a private environmental consulting firm (Dr. J. H. Carter III and Associates, Inc.) to complete a red-cockaded woodpecker foraging habitat inventory of the base. The inventory included all managed pine/pine-hardwood forest stands ≥30 years old, and some stands slightly younger. Throughout identified forest stands, sample plots (1/10 acre) were taken on a standardized grid measuring 5 chains (100.5 m; north to south) by 12 chains (241.2 m; east to west). Plot centers were georeferenced using a GPS receiver with real-time differential correction. For a complete description of data collected see Gulf Engineers and Consultants Inc, and Dr. J.H. Carter III and Associates Inc Environmental Consultants (2000).

Some unmanaged forested areas were not included in the original survey due to financial constraints and proximity to ammunition impact areas. Camp Lejeune personnel completed approximately 39 of these points in the southeast portion of the G-10 buffer zone (Figure 1.2). Data from these points are included in analyses. In addition to these points, I completed 160 points to supplement the forest inventory in the G-10 buffer area around woodpecker clusters 14, 39, 43, and 46 where the original survey was lacking. To establish point locations, I used geographical information systems (hereafter GIS) to extend the original grid across the desired area and used a GPS receiver to locate points in the field.

Groundcover Sampling.

Between May and July, 2000 I used a Garmin 12XL GPS unit to relocate those forest inventory points within 0.8 km of each cavity tree cluster center and those points within the home ranges of the 23 study groups, should the home range extend beyond 0.8 km. Cluster centers were calculated as the arithmetic mean of the cavity tree universal transmercator (UTM) coordinates for each group in 1999. In total I assessed the groundcover of approximately 1161 points. In many cases, the exact location of the original points could be determined by flagging left during the previous survey; in other cases the GPS unit was the sole navigational tool. A few points could not be approached because of military activity and were omitted.

At each of the inventory points, I established four 1 m^2 sampling subplots 5 m from the point in each of the four cardinal directions (N, S, E, W). A guide fashioned from meter sticks connected by wire was used to form a square and to delineate the sampling area. Within each subplot, I estimated the percent cover of graminoids, forbs, shrubs, vines, ferns, litter, bare ground, and other, using the Daubenmire Cover Scale (Daubenmire 1959). Cover classes were: 0-5%, 5-25%, 25-50%, 50-75%, 75-95%, 95-100%. All vegetation <0.5 m in height was evaluated. Some of the original forest inventory points, however, fell within large, impenetrable thickets, and in these cases percent cover for vines, ferns, litter, and bare ground was not estimated. For these plots shrubs were conservatively classified as 50-75%, and graminoids and forbs were each classified 0-5%. The total cover of graminoids and forbs combined formed herbaceous vegetation, which I use in analyses.

GIS Themes.

Stand boundary and attribute data (i.e. stand number, size, classification, etc.) come from the Red-cockaded Woodpecker Foraging Habitat Inventory Report and associated digital data (Gulf Engineers and Consultants Inc and Dr. J.H. Carter III and Associates Inc. Environmental Consultants 2000). Forest stand dominant cover type information is from the Integrated Geographic Information Repository at Camp Lejeune (Geographic Information Systems Office of the Business and Logistics Support Department 2000).

Foraging observations/home range estimation.--

Each of 23 groups was followed approximately 1 day per month from August 2000 through March 2001 (one non-breeding cycle), for a total of 8 follows. Due to logistical difficulties the eighth and final follow for 2 groups (CL l and CL 19) was delayed until September 2001. Follows were not conducted during the egg laying, incubation, and early fledgling stages (May-July) because groups typically forage in close proximity to the cluster area during these stages. A follow consisted of sustained contact with the group of birds, beginning shortly after sunrise (usually 10-30 minutes) and continuing for

8 hours or until contact with the birds was lost, or the follow was terminated due to inclement weather or military activity. For a follow to be considered complete, and thus included in analyses, a minimum of 5 hours (30 observations/fixes) of data must have been collected, and follows shorter than 5 hours were repeated until at least 5 hours could be attained. This criterion was chosen based on results of Hooper and Harlow (1986) and Nesbitt (1978). Hooper and Harlow (1986) followed 10 groups on 48 days and used this information to estimate the bias of shorter follows in 1-hour increments. They concluded that 5-hour estimates are relatively free from bias and are a good minimum standard. Similarly, using radio-telemetry, Nesbitt (1978) showed that 4 groups in Florida moved considerably in the morning hours and achieved their maximum distance (0.72 km) from the cluster area in the early afternoon; thereafter groups often loafed, sometimes in the same tree for up to 4 hours. These results suggest that a series of partial-day follows beginning in the morning and continuing 5-8 hours provide a relatively unbiased estimate of home range, and perhaps are an even better estimate of foraging movement than whole day follows.

At 10-minute intervals, the location of a sequentially selected individual bird was recorded using a Garmin 12XL GPS unit. Occasionally, the exact location of the selected bird could not be approached, because of vegetation, water, or military activity. In these cases, a GPS location (fix) was taken where possible and the bird's distance and compass bearing from that location were estimated. The actual coordinates of the bird were later calculated in Arcview GIS and used in analyses.

Data analysis

Explanatory variables.--

I tested 7 habitat characteristics reported to affect fitness in the new Red-cockaded Woodpecker Recovery Plan. Because the forest inventory was not originally intended to validate the Recovery Plan, however, not all of the variables described in the plan were available to test. Instead, I used those variables that most closely match those characteristics described in the plan. A summary of characteristics described in the plan and variables tested is presented in Table 1.1. In addition to these habitat variables, in some models I included up to 3 additional variables to account for covariation between habitat effects and other biological effects. For example, group size is known to affect fledgling production, so assessing the relationship between habitat variables and productivity without including group size as a covariate could lead to model misspecification. Likewise, I included home range size and the amount of unsuitable habitat in all models assessing the relationship between habitat features and fitness to help account for the amount of habitat available to each group. I defined unsuitable foraging habitat as unforested areas, pine/pine-hardwood stands too young (approx <30 yrs) to be included in the original forest inventory, forested areas dominated by hardwoods, and pine/pine-hardwood stands with representative age <30 years *and* representative dbh <17.78 cm (7 inches).

It should be noted that some forested areas were in restricted areas or on private property and could not be surveyed. I assessed the potential value of these areas using GIS and color (1998) and infrared (1996) aerial photography, and on-screen digitized the boundaries accordingly. Areas that were clearly denuded of trees or very sparsely covered were considered unsuitable, whereas areas that appeared forested were considered potential foraging habitat, even if attribute data were unavailable. Where possible, I ground-truthed these classifications. Finally, in some models I included density of neighboring red-cockaded woodpecker groups (hereafter local population density). Local population density was defined as the number of active cluster centers within 800 m of each study group in 1999. The use of these variables is discussed where appropriate.

Because highly correlated variables violate assumptions of many statistical techniques (including regression), I was unable to assess the importance of some variables described in the plan, such as basal area variables, which correspond closely with stem density. For the same reason, I was unable to include the composite variable, number of stems >25.4 cm dbh, in some analyses because it was comprised of 2 variables that were included: number of pine stems 25.4-35.6 cm dbh and the number of pine stems >35.6 cm dbh. Instead, for this variable, I assessed its importance in a single variable model (See Relationship Between Fitness and a Traditional Measure of Habitat Quality).

Home range estimation.--

Home range analyses and interpretation are complicated by the availability of different methods and by the fact that different software packages may produce different results with the same data (Lawson and Rodgers 1997). I used 2 programs to estimate home range size and area for each of the 23 study groups: the Animal Movement Analysis Extension V2.04 (Hooge and Eichenlaub 1997) to Arcview GIS, and Ranges V (Kenward and Hodder 1996). For each program, I employed 2 methods to estimate home range size: minimum convex polygon (MCP) and 95% fixed kernel (Worton 1989). Based on the results of Seaman and Powell (1996), Seaman et al. (1999), and Worton (1995), I used the fixed rather than the adaptive kernel because the fixed kernel tends to produce more accurate home range estimates, especially toward the periphery of the home range. As recommended by Seaman and Powell (1996), I chose the least squares cross validation (LSCV) method as the smoothing parameter for kernel analyses.

The MCP method has utility in that it is widely used and thus comparable to other studies. It has limitations in that it tends to be heavily influenced by outliers (Harris et al. 1990) and often overestimates home range size (Garrot and White 1990). The fixed kernel method is a nonparametric technique that produces a probabilistic model of an animal's movement in space (Worton 1989). Thus, a home range becomes a spatial representation of the likelihood of an animal being present within a given area. The choice of probability is left to the researcher. I used 95% fixed kernels for all analyses. The kernel method has utility in that it is a probabilistic model that is less dependent than other estimators on the assumption of statistical independence of observations (Swihart and Slade 1997, Millspaugh and Marszluff 2001). Its utility is limited in that the choice of the smoothing parameter and internal algorithms may affect the shape and size of the resultant home range, which in turn makes comparisons across studies that use different software difficult (Lawson and Rodgers 1997).

I used the incremental area analysis function in Ranges V to examine how home range size changes as successive observations are added to the dataset. In doing so, I was able to determine if the number of observations was sufficient to adequately estimate each home range by creating an area-observation curve (e.g., Gese et al. 1990). For this analysis, I randomized observations prior to analysis to account for seasonal variation in home range size. Because this process is computationally intensive, however, I was unable to use the kernel method for this analysis. Instead, I performed incremental area analysis with the MCP home ranges.

Regression assumptions and diagnostics.--

Most statistical tests rely on assumptions that, if not met, will result in increased type I or type II errors. Common problems that may weaken or invalidate multiple linear regression analyses are 1) omitted important variables 2) nonlinear relationship between the dependent and explanatory variables 3) non-constant error variance (heteroscedasticity) 4) multicollinarity among explanatory variables 5) nonnormal distribution of errors and 6) highly influential observations (i.e. outliers) (Hamilton 1992).

I examined the data for violations of these assumptions. My approach to diagnosing problems began simply by graphing the dependent and response variables. This approach served to highlight nonlinear relationships (problem 2, above) as well as identifying unusual and influential observations (problem 6). Influential observations were also identified by examining observations with studentized residuals greater than +/- 2. These extreme values are generally considered highly influential points, and may be indicative of measurement error or model misspecification (Myers 1989). I examined such observations to assess whether the values were erroneous. Valid observations with biological explanation were kept in the model. To diagnose heteroscedasticity (problem 3) and non-normal distribution of errors (problem 5), I examined residual plots of observed vs. predicted values. I diagnosed collinearity among explanary variables (problem 4, above) using a two-stage process. First, I used SAS procedure PROC CORR (SAS Institute Inc 1988a) to assess all variables for pairwise correlations. One variable from any pairwise correlation with a Spearman's rank-order correlation coefficient >0.7 was excluded from further analyses. This procedure effectively precluded basal area and stem density variables from being included in the same model. For statistical tests, I therefore chose to disregard basal area variables and instead analyzed stem density. Additionally, I diagnosed collinearity among variables using Variance Inflation Factors (VIF) for each multiple regression model (Myers 1989). As suggested by Myers (1989), variables with a VIF >10 were deleted from the model and the model was rerun without them.

Habitat use.--

I examined habitat use at 2 spatial scales: patch and stand. In managed areas, forest stands were those management units defined by Camp Lejeune as reported in the Forest Inventory Report and associated digital data (Gulf Engineers and Consultants Inc and Dr. J.H. Carter III and Associates Inc. Environmental Consultants 2000); in unmanaged areas, stands were uniform forested areas as identified using GIS and color and infrared photography. In general, stands were at least 4 ha. To define patches, I used Arcview GIS to create a 25 m buffer around vegetation sampling plots. Twenty-five meters was chosen because buffers >25 m were less likely to be accurately represented by the habitat described by the vegetation sample. Patches were considered used if one or more foraging locations fell within the patch; patches were otherwise considered not used.

I employed logistic regression to identify variables associated with patch use, the dependant variable being patch use (used/not used). I assessed the relationship between patch use and habitat variables using a two-stage approach. First, I used logistic regression to assess the importance of each variable in the presence of all other variables, without the use of variable selection methods. Next, I used the forward stepwise selection procedure (Myers 1989) to select the subset of variables that provided the best fitting model. I discuss the results of each of these methods. For the stepwise procedure, I used a significance level of 0.5 for variable entry and 0.10 for variable retention.

Variables for patch use were small pines, medium pines, large pines, small hardwoods, large hardwoods, midstory height, percent herbaceous groundcover, representative age (Table 1.1), and distance to the nearest cavity tree cluster center. I included distance from the nearest cluster center to account for central-place foraging behavior (Rosenberg and McKelvey 1999). Representative age was collected only at every other inventory point. For unknown points, I used simple linear regression to estimate age from representative dbh. In doing so, I calculated a separate regression model for each species of pine, and used the appropriate equation for each computation.

To assess habitat use at the stand level I employed multiple linear regression. As the response variable, I used the number of foraging observations per unit stand area within the kernel home range. Thus, the response value for a 5 ha stand used 10 times was 2 (10/5 = 2). This computation was necessary to account for the effects of stand size on stand use (all other things being equal, larger stands may be used more often than smaller stands). I used the same two-stage approach to analysis as described for patch use, with the first model used to assess the importance of each variable in the presence of all other variables, and the second model used to find the sub-set of variables that best describe the relationship between habitat attributes and stand use. In the latter analysis I computed all possible regressions and used the AIC (Akaike's Information Criterion) statistic to select the best model (Akaike 1973). Explanatory variables were the same as those in patch use, except distance was computed as the linear distance from the proximate boundary of each stand to the nearest cluster center. I used stand boundary rather than centroid to minimize the effects of stand size on this calculation. Habitat variables were calculated as the mean plot values within each stand using only those plots within the home range, except for stands without inventory points within the home range boundaries. In these cases, I used inventory points within the stand but outside the home range to calculate stand values.

It should be noted that diagnostic procedures for some of these models revealed a slight departure from the assumption of constant-error variance. This occurred because stands cannot be used <0 times, but the predicted value can be negative, resulting in residual plots with increased variance as the predicted value increases. Examination of studentized residuals also revealed 3 highly influential points (i.e. outliers) that slightly exacerbated the situation. Based on these findings, I attempted to correct the situation by transforming the response variable and/or removing the outliers. Although these modifications slightly improved the distribution of residuals and increased the overall model fit (R^2), the results did not change in any substantive way. The best model with corrections was identical to that without corrections, and no variables changed in significance in either the full or reduced model. As a result, for ease of interpretation, I chose to present the original models.

Effects of habitat quality on fitness.--

I employed multiple linear regression to assess the importance of habitat characteristics on 2 measures of fitness: fledgling production and group size. Group size is both a measure of population health and an indirect measure of fitness. Clusters with large groups (i.e. many helpers) have a population stabilizing effect, because they are less likely to become abandoned at the death of a breeder (Walters et al. 1988, Walters 1991). Larger groups also have reduced nest failure rates (Lennartz et al. 1987), overall higher productivity (Walters 1990), and higher breeder survival (Khan and Walters 2002).

Each of these variables was computed as the mean of the values from the breeding seasons of 1996-2001. As in patch and stand use, for each response variable I used a two-stage analysis. The first model included all the variables reported to be indicative of good quality foraging habitat (Table 1.1), plus covariates as necessary to account for other factors known to affect these fitness measures. All models included the following variables: small pines, medium pines, large pines, small hardwoods, large hardwoods, midstory height, percent herbaceous groundcover, age of representative pine, quantity of unsuitable foraging habitat within the home range, and home range size. I included home range size and unsuitable habitat to account for the amount of habitat available to each group. For the fledgling production model, I included group size because it is known to have a positive effect on productivity (Walters 1990).

In the second stage of analyses, I computed all possible regressions and used the AIC (Akaike's Information Criterion) statistic to select the best reduced model from the original (Akaike 1973). In this stage, I added local population density (# of territory centers within 0.8 km of each group) as a covariate for 3 reasons. First, model fit tended to improve with the inclusion of population density, indicating that population density was an important variable, and the omission of important variables is one of the most common errors in regression analyses (Hamilton 1992). Second, models already included home range size, and the addition of density may help account for the effect of neighbors on *territory* size, as opposed to home range size (Burt 1943). Finally, I wanted to compare my results with recent and important work by James et al. (1997, 2001), who found effects of habitat variables on population density.

Relationship between Fitness and a Traditional Measure of Habitat Quality.--
I employed simple linear regression to assess the relationship of the traditional measure of foraging habitat, the number of pine stems ≥25.4 cm dbh within the home range, to 2 measures of fitness: fledgling production and group size. Each of these variables was computed as described above. Diagnostic procedures for the group size model revealed a slight departure from the assumption of constant-error variance. This occurred because groups with fewer trees within their home range had much higher variability in group size, resulting in residual plots with increased variance as the predicted value increases. Based on these findings, I attempted to correct the situation by transforming the response variable. Although transformations slightly improved the distribution of residuals, the results did not change in any substantive way. Model statistics for the original and transformed models were nearly identical. As a result, for ease of interpretation, I chose to present the original model.

Relationship between home range size and habitat quality.--
I employed multiple linear regression to assess the effects of habitat characteristics on home range size. The response variable was estimated kernel home range size (hectares). I used the same two-stage analyses as elsewhere, with the first model used to assess the importance of each variable in the presence of all other variables, and the second model used to find the sub-set of variables that best describe the relationship between habitat attributes and home range size. The first model included those variables indicative of good quality foraging habitat, as reported in the Recovery Plan (Table 1.1), plus group size (for the year of the foraging observations, 1999) and the quantity of unsuitable foraging habitat within the home range as a covariates. The second model included these variables plus local population density, for reasons explained above. I again computed all possible regressions and used the AIC statistic to select the best model.

Amount of 'good quality' habitat.--
I classified each forest inventory point within the estimated kernel home ranges based on its compliance with 7 characteristics of 'good quality' foraging habitat in the Recovery Plan. Thus, a point in full compliance met all 7 characteristics, a point lacking only one received a score of 6, and so forth. I also classified each stand within each home range

based on the number of characteristics in compliance with the foraging guidelines, and listed for each stand with at least 4 components in compliance, those elements in need of management. As for stand use analyses, only inventory points within the home ranges were used to calculate stand values, unless a stand only had points beyond the home range boundaries. In these cases, I used inventory points within the stand but outside the home range to calculate stand values.

Because averaging plot values (to obtain stand values) tended to artificially reduce the amount of good quality habitat, stand classifications are slightly suspect. For example, while nearly 50% of habitat points were classified as ‘good’ for midstory condition, only 22% of stands met this criterion. Consider 2 plots in the same stand with midstory height of 1 m and 4 m, respectively. At 1 m, the first plot meets the guidelines for midstory height (<2.1 m), while the second plot does not. If averaged to obtain a stand value of 2.5 m, the entire area of the stand fails to meet the criterion. For this reason, I chose to base much of my discussion on habitat points rather than stands.

I used the midpoint of each stem size class to calculate basal area. Thus, for pines 25.4-30.5 cm dbh (10-11 inch), I calculated the basal area for 27.9 cm dbh (11 inch) trees. Likewise, to calculate midstory height, I used the midpoint of each height class, and for midstory density, I considered plots classified as ‘open’ or ‘light’ to be good. Again, for a description of variables collected in the forest inventory, see Gulf Engineers and Consultants Inc. and Dr. J.H. Carter III and Associates Inc. Environmental Consultants (2000).

Principal components analysis.--

To better understand the multivariate nature of habitat within red-cockaded woodpecker home ranges, I employed principal components analysis (PCA). As in other ordination techniques, the goal of PCA is to identify major gradients that describe much of the variability in a data set, while reducing extraneous or redundant information (McGarigal et al. 2000). In addition to simplifying the interpretation of the habitat data, my goal in using PCA was to discern why some habitat variables previously identified as important resources for red-cockaded woodpeckers were not significant in my analyses.

As data for the PCA, I used the habitat values from each forest inventory plot within the home ranges. Because I used PCA only for exploratory purposes, and not for inferential testing of hypotheses, rigorous concern over the assumptions of PCA, such as multivariate normality, independent random sample, absence of outliers, and linear relationships among variables, is not warranted (McGarigal et al. 2000). All of these assumptions are rarely met with ecological data (McGarigal et al. 2000).

I followed decision rules suggested by Tabachnick and Fidell (1989) to assess the importance of principal component loadings. Analyses were conducted using SAS procedure PROC FACTOR (SAS Institute Inc 1988b), and the covariance matrix was used in eigenanalysis.

RESULTS

Estimation of home ranges

Ninety-five percent kernel home ranges calculated with the Animal Movement Extension varied from 39.0-145.4 ha, with a mean of 80.2 (SE 5.3) ha (Table 1.2), whereas (95% kernel) home ranges computed with Ranges V ranged from 22.9-111.8 ha with a mean of 50.4 (SE 4.8) ha. The smaller home ranges computed with Ranges V resulted from undersmoothing of the kernels (Silverman 1986), but I could not determine the exact mechanism for the difference. It was not unexpected, however, to get results that differed between programs (Larkin and Halkin 1994, Lawson and Rodgers 1997). This result is common and may occur for many reasons, as reviewed by Kenward (2001). Because the home ranges produced from Animal Movement Extension appeared to better represent the actual habitat used by foraging red-cockaded woodpeckers, I chose to use them for further analyses. Both programs gave identical results for minimum convex polygon home ranges, with a mean of 103.0 ha (SE 6.3) and a range of 60.7-168.8 ha (Table 1.2).

Effort was sufficient to adequately estimate home range for the time period included in the study. The incremental area analysis (area-observation plots) illustrated that the number of locations (i.e. fixes) was sufficient for each home range to reach an asymptote (Figure 1.3).

Habitat use

Patch use.--

Patch use by foraging red-cockaded woodpeckers was positively related to the density of large and medium pines and to percent herbaceous groundcover, and negatively related to the distance from the cavity tree center (Table 1.3). Patches with limited herbaceous groundcover were used less frequently than expected (based on availability) and those with more herbaceous cover were used more often than expected ($X^2 = 16.4$, $P<0.006$, $n = 490$) (Figure 1.4). Patches with intermediate densities of herbaceous groundcover (10-30%) were used in proportion to their availability. Red-cockaded woodpeckers used patches with >50 large trees/ha more often than expected (Figure 1.5), but this result was not significant ($X^2 = 7.42$, $P<0.115$, $n = 490$), perhaps due to a scarcity of high density patches. Means for all variables are compared between used and unused patches in Table 1.4.

The same variables significant in the reduced model are significant in the full model, but no other variables were significant (Table 1.5).

Stand use.--

The best model of red-cockaded woodpecker stand use included large pines, small hardwoods, percent herbaceous groundcover, and distance from the cluster center (Table 1.6). As with patch use, percent herbaceous groundcover and large pines were positively associated with stand use. Number of small hardwoods was negatively related to stand use, as was distance to the cluster center, which was by far the strongest regressor in the model (Figure 1.6). In the presence of all other variables, stand use was positively related to percent herbaceous groundcover and inversely related to the distance to the cluster center (Table 1.7).

Effects of habitat quality on fitness

Group size.--

The best model to explain variation in group size included medium pines, small hardwoods, herbaceous groundcover, representative age, home range size, unsuitable foraging habitat, and local population density (Table 1.8). Herbaceous groundcover Figure 1.7), local population density, and home range size were positively associated with group size, while amount of unsuitable foraging habitat, small hardwoods, and medium sized pines were negatively associated with group size. The density of small hardwoods was the most significant predictor in this model. In fact, small hardwoods alone accounted for 15% of the variation in group size in a simple linear model (Figure 1.8; $F = 4.98$, $P<0.037$, adj $R^2 = 0.15$).

Three variables in the full model were significant regressors at the 0.05 level. Group size was positively related to herbaceous groundcover and home range size, and inversely related to the density of medium pines (Table 1.9). All these variables were included in the best reduced model discussed above. Group means of habitat variables are presented in Appendix I.

Fledgling production.--

The best model of fledgling production included density of medium pines, large pines and large hardwoods, percent herbaceous groundcover, midstory height, home range size, unsuitable habitat, and local population density (Table 1.10). Only 3 variables described in the Recovery Plan were not included in this model: density of small pines, density of small hardwoods, and tree age. Local population density, home range size (Figure 1.9), percent herbaceous groundcover and large pines were all positively associated with fledgling production. Significant variables negatively associated with fledgling production were large hardwoods (Figure 1.10) and midstory height. In the presence of all other variables, no single regressor was significant at the 0.05 level (Table 1.11).

Relationship between fitness and a traditional measure of habitat quality

I found no significant relationship between the number of pines $\geq$25.4 cm dbh within home ranges and either mean group size (Figure 1.11; $F = 0.92$, $P<0.349$, adj $R^2 = -0.004$) or fledgling production (Figure 1.12; $F = 1.05$, $P<0.318$, adj $R^2 = 0.002$).

Relationship between home range size and habitat quality

To a large extent, variation in home range size can be explained by a single habitat variable: percent herbaceous groundcover. Even when regressed alone, herbaceous groundcover accounts for 30% of the variation in home range size (Figure 1.13). The higher the percent herbaceous groundcover the smaller the home range. The best multi-variable model, chosen using the AIC statistic, explains 59% of the variation, and includes medium pines, small hardwoods, herbaceous groundcover, group size, and unsuitable foraging habitat (Table 1.12). With the exception of herbaceous groundcover, all variables were positively related to home range size, that is, they tend to be associated with larger home ranges.

In the presences of all other variables only 2 regressors, herbaceous groundcover and unsuitable habitat (Figure 1.14), were significant at the 0.05 level (Table 1.13). As in the reduced model, greater herbaceous groundcover was associated with smaller home ranges and more unsuitable habitat with larger home ranges.

Amount of 'good quality' habitat

I classified 453 of 502 forest inventory plots within the 23 home ranges, excluding unsuitable habitat; 49 plots (9%) were missing one or more data elements and could not be classified. Additionally, I classified 341 stands within the home ranges, representing 1844 ha (including home range overlap). Based on stand area analyses, 80% of the area within home ranges was classified according to the number of characteristics in compliance, 16% was classified unsuitable, and 4% had incomplete data (Figure 1.15). Only 10 inventory points (2%) met all 7 characteristics of good quality habitat, and over half (53%) of the points met 3 criteria or fewer (Figure 1.16). Nineteen percent of the points were lacking in only 1 or 2 characteristics. Based on stand analyses, only one group (CL 47) had any habitat in full compliance and most groups (16 of 23) had only habitat lacking 3 or more characteristics (Appendix II). The group in cluster 14, notable because it has been historically large and productive, had no habitat with >4 characteristics of good quality.

Overall, the most limiting characteristic was the low density and age of large pine stems, as only 17% of these plots are in compliance with the guidelines for these characteristics (Figure 1.17). The basal area of medium trees and percent canopy hardwoods are clearly not limiting, and other characteristics vary from 34%-47% compliance (Figure 1.17).

Interpretation of principal components

The first 5 principal components account for 74% of the variation in the data set (Appendix III). Principal component 1 largely describes the gradient from sites with a significant midstory composed of small hardwoods to more open sites with an herbaceous groundcover. The number and height of hardwoods is inversely correlated with herbaceous groundcover. Principal component 2 represents the gradient from sites with a significant presence of small pines to sites with larger and older trees. Factors 3-5 are more difficult to interpret, but largely reflect variation in the number of medium sized pines, herbaceous groundcover and large pines, respectively.

DISCUSSION

Nearly without exception, explanatory variables have consistent relationships with the dependent variables tested that confirm new views of foraging habitat quality. Variables positively associated with habitat use and fitness are associated with reduced home range size, and those negatively associated with habitat use and fitness with increased home range size (Table 1.14). Thus, in large part, the foraging habitat guidelines presented in the Recovery Plan are validated here, and the fact that the results from an array of studies are so consistent is evidence that predictor variables are truly related to bird responses.

Some variables described in the plan were not significant regressors in any of the analyses presented here. In particular, the density of small pines and representative age were conspicuously unimportant variables. Separating the effects of tree age and size is difficult. This is true at all spatial scales, but is especially difficult at scales larger than the individual tree, as in this study, because stand and home range values are averages from many inventory plots. In an examination of individual tree selection at Camp Lejeune, Zwicker and Walters (1999) showed that red-cockaded woodpeckers select older trees independent of size. They illustrated that tree selection first exceeded availability at approximately 60 years of age and trees >100 years were strongly selected; trees <50 years of age were selected against. In my study, a lack of variation in tree age (as computed) and a shortage of old trees may have hampered my ability to detect these bird-habitat relationships. Mean home range tree age was 61 years and varied only from 56-71 years (Appendix I). Likewise, mean patch age was also 61 years (Table 1.4). Based on the work of Zwicker and Walters (1999), these values represent the threshold at which red-cockaded woodpeckers begin to respond favorably to tree age. Hardesty et al. (1997) also documented a preference for old trees at the individual tree scale, but other researchers also have failed to detect effects of tree age on fitness at the home range scale.

Detecting the effects of habitat structure on fitness and habitat use is complicated by the choice of pine size classes used in analysis and site-specific ecology. To a large extent, the creation of size classes (i.e. small pines), as in the Recovery Plan, is a management convenience and a simplification of reality, because animals likely do not perceive classes, but a continuum of sizes. Nevertheless, classes are used and the choice of classes may, if inappropriate, obscure real animal-habitat relationships. This fact is well illustrated in the inability of researchers to find a relationship between fitness and a traditional measure of habitat quality (# of pines $\geq$25.4 cm; See Introduction). The appropriateness of any particular class may also depend on site-specific ecology, because soil type, growing season, climate, fire history, and other factors may affect the size class distribution of trees present at a particular site. Thus, while specific classes such as small pines (i.e. <25.4 cm dbh) may be good general guidelines, they may not be appropriate throughout the red-cockaded woodpecker's range. Furthermore, regardless of the choice of parameters, simple classes may be inappropriate. For example, James et al. (2001) found the number of large pines minus the number of small pines was more significant than either variable alone. In this study, my goal was to test the size classes defined in the red-cockaded woodpecker foraging habitat guidelines, not to create new ones. It is possible that small pines, as defined in the habitat guidelines, is an inappropriate class, that the number of small pines has no effect on fitness or habitat use, or that a relationship exists but I was unable to detect it. Unlike age, however, there was substantial variation in the density of small pines within the study area (Appendix III).

Home range size

The mean home range size (80.2 ha and 103.0 ha for the fixed kernel and MCP methods, respectively) of the study groups was unexceptional when compared to other populations, especially nearby populations in coastal South Carolina (harmonic mean: 87.0 ha), Georgia (MCP: 80.1 ha), and the North Carolina Sandhills (95% kernel: 83.0 ha) (Walters et al. 2002) (Figure 1.18). Range-wide home range estimates vary from 40.5 to 161.9 ha (U.S. Fish and Wildlife Service 2003), but direct comparisons are complicated by differing methods used to compute home range. Even comparing results from a particular method, such as fixed kernel, may be tenuous because many programs use different internal default values and algorithms to compute the smoothing parameter (Lawson and Rodgers 1997). In this study, I used the estimated kernel home range size for most analyses because it tends to exclude unused areas and thus produces a better representation of defended home range than other methods. The MCP method consistently produced larger home ranges, which often contained areas of clearly unsuitable habitat such as cleared land, as well as areas that were rarely used. That said, for purposes of allocating habitat to threatened and endangered species, the MCP method should be considered the conservative approach (Burt 1943).

The estimates presented here are of home range, which is distinct from territory. I use the terms as defined by Burt (1943), where territory is the defended part of the home range, and home range is the area that animals use in search of food and other resources. Home range should thus be larger than territory. I could not estimate territory size because most groups had unmonitored adjacent groups as neighbors, and because I was unable to consistently record disputes with neighboring groups. Two other researchers have addressed this issue, however. In a study of 18 groups in Georgia, Epting (1985) estimated that 84% of the home range was defended. Hooper et al. (1982), in coastal South Carolina, estimated territory size and territory overlap at 78% and 9%, respectively of the home range. Based on this information, it is likely that territory size at Camp Lejeune is approximately 20% smaller than the value I report for home range.

Home range size varied considerably from group to group, with a range of 39-145.4 ha and 60.7-168.8 ha for the kernel and MCP methods, respectively. This result too, is consistent with other studies that have examined red-cockaded woodpecker home range size. Hardesty et al. (1997) showed that the smallest home range in northern Florida was only one-eighth the size of the largest range, and in Georgia, the smallest home range was one-fifth the size of the largest (Epting et al. 1995). Such variability seems to be the rule rather than the exception.

Variation in home range size may be influenced by any number of biological and physical factors (Conner et al. 2001), including group size, density of neighboring groups, the spatial distribution of cavity trees, the habitat matrix, and habitat quality. In this study, I found that home range size was related to all of the above, except local population density, and the distribution of cavity trees, which I did not test. The relationship between habitat quality and home range size is discussed in the following section.

Group size was positively related to home range size, but understanding the mechanism for the relationship is difficult. Home range could be driving group size or, alternatively, group size may be driving home range size. Under the former scenario, groups with large home ranges have more resources than other groups and thus are more productive, thereby increasing group size. In the latter case, large groups may require more habitat simply because they are larger, or they may be better able to defend larger territories, thereby affecting home range size. These scenarios are not mutually exclusive, however, and it is possible that both situations apply.

Home range size was not associated with local population density. This seems counterintuitive and is contrary to work by Hooper et al. (1982) in South Carolina, who showed that population density was a very significant predictor of home range size. In that study, density and group size alone accounted for nearly 80% of variation in home range size. Home range, however, should not be confused with territory. If home ranges overlap one another, density can have little or no role in home range size because groups share common areas.

Relationship between home range size and habitat quality

Previous research has suggested that red-cockaded woodpecker home range size is inversely related to habitat quality: the better quality the habitat, the smaller the home range. In support of this assertion, researchers have pointed to studies in old-growth longleaf pine forest, where some of the smallest home ranges have been reported (Engstrom and Sanders 1997), and to the periphery of the species' range, where the largest home ranges are found. On the northeastern periphery of the range, on the coast of Virginia, home ranges have been reported at 120 ha (Bradshaw 1995), and in Florida, on the southern periphery, 109 ha (Hardesty et al. 1997) and 129 ha (DeLotelle et al. 1995). These sites represent second-growth pine woodlands, and in the case of the Florida studies, sites with limited productivity. Research in a mature longleaf pine forest in Georgia, however, revealed home ranges averaged only 42 ha. Researchers have also established a relationship between habitat characteristics and home range size (Hooper et al. 1982, Hardesty et al. 1997, Bowman et al. 1998, Walters et al. 2002). Although largely anecdotal, this information suggests that home ranges of red-cockaded woodpeckers in habitat that resembles old growth conditions may be smaller than elsewhere.

In this study, to a large extent, variation in home range size can be explained by a single habitat variable: percent herbaceous groundcover. Even when regressed alone, herbaceous groundcover accounts for 30% of the variation in home range size (Figure 1.13), and it was the most important variable in most models. The density of small pines had the opposite effect on home range size, and tended to be associated with larger home ranges. The significance of these 2 variables indicates that habitat structure plays a key role in determining home range size. Groundcover is closely linked with forest structure, midstory density, and fire history, and herbaceous groundcover is often present in mature, open pine ecosystems but rarely in dense forests. High pine density and hardwood midstory have the same effect of reducing the amount of light reaching the forest floor, preventing the establishment of an herbaceous groundcover. Frequent fire, as occurred historically, has the opposite effect of reducing midstory of any kind and promoting the development of an herbaceous groundcover. That an open forest structure was associated with habitat use and fitness indicates that red-cockaded woodpeckers have smaller home ranges in higher quality habitat. These results are consistent with the conceptual definition of high quality habitat in the Recovery Plan, and support the conclusions of Hardesty et al. (1997), James et al. (2001) and Walters et al. (2002). Notably, while others have shown that forest structure affects home range size, this is the first study to document a direct relationship between home range size and herbaceous groundcover.

Habitat use

The results from patch and stand use analyses are remarkably consistent (Table 1.14). Both analyses reveal a positive relationship between large pines, herbaceous groundcover and habitat use, and a negative association between use and distance from the cluster center. The only other variables retained in the best models, both non-significant, were medium pines, which was positively associated with patch use, and small hardwoods, which was negatively related to stand use. Use of patches exceeded availability when herbaceous groundcover composed greater than approximately 30% of the forest floor (Figure 1.4), and when density of large trees exceeded approximately 50 trees/ha (Figure 1.5). These values are strikingly similar to those presented in the Recovery Plan (herbs >40%; >45 trees/ha). These findings support the idea that red-cockaded woodpeckers are responding to habitat components that mimic historical conditions, namely habitat with large trees and an herbaceous groundcover component, corresponding to the definition of good quality habitat in the Recovery Plan.

The ecological basis for the relationship between habitat use and herbaceous groundcover is not clearly understood. In fact, despite significant excitement about groundcover as an important component of good quality habitat, this is only the second study, Hardesty et al. (1997) being the first, to document a direct relationship between groundcover and red-cockaded woodpecker habitat use. To a large extent, previous research has largely focused on the relationship between herbaceous groundcover in the vicinity of the cluster and measures of group fitness (James et al. 1997, James et al. 2001). The mechanism behind the relationship between habitat use and groundcover is likely indirect, because red-cockaded woodpeckers rarely forage on the ground (Hooper and Lennartz 1981). James et al. (1997) proposed that groundcover composition is a reflection of fire history, which in turn affects abundance and/or nutritional content of arthropod communities that originate in the groundcover and eventually make their way up the tree boles on which red-cockaded woodpeckers forage. In fact, much of the arthropod biomass present on tree boles originates in the groundcover (Hanula and Franzreb 1998), and fire history does affect arthropod communities on the forest floor (Provencher et al. 1998). Whether arthropod abundance on the tree boles and groundcover composition are related, however, remains to be seen, and one study found no such relationship (Hanula et al. 2000). Another is currently in progress and preliminary results indicate that such a relationship exists (Taylor 2002).

That red-cockaded woodpeckers are negatively affected by midstory density (Hooper and Harlow 1986, Bradshaw 1995, Epting et al. 1995, Doster and James 1998) and height (Walters et al. 2002) is well established. But none of this research has examined the relationship between groundcover and midstory, which are likely linked. A dense midstory prevents light from penetrating to the forest floor, impeding the development of an herbaceous groundcover. Researchers have suggested that midstory affects foraging habitat quality by impeding the movement of foraging birds (Conner et al. 1999, Collins et al. 2002). While it is possible that midstory directly affects red-cockaded woodpeckers in some way, the significance of groundcover complicates the picture. Managers have used fire, herbicides, and mechanical means to control midstory. My results suggest that fire may improve foraging habitat by reducing midstory *and* promoting an herbaceous groundcover. While effective at controlling midstory, herbicidal and mechanical methods are less effective than fire at promoting a lush, diverse herbaceous groundcover (Provencher et al. 2001). For this reason, prescribed burning should be the first choice among methods of midstory control.

The mechanism by which large pines are beneficial for foraging is poorly understood as well. It has been suggested that, on a per tree basis, large trees provide more foraging surface than smaller trees and thus lessen the need for birds to continually move from tree to tree (Conner et al. 2001 p.190). Aerial movement requires energy and may increase the risk of predation (Rodriguez et al. 2001). Others have suggested that larger trees have more deeply fissured bark and may harbor more arthropods on which the birds forage (Hanula et al. 2000). In fact, Hooper (1996) found that overall arthropod biomass tended to increase with longleaf age up to 86 years, and continued to increase on dead limbs thereafter. The results presented here shed no light on the mechanism involved, but support the idea that higher densities of large and possibly older trees are beneficial.

The effect of distance from the cluster on habitat use, while intuitive, has received little attention in studies of habitat use (Rosenberg and McKelvey 1999). In the present study, distance to the cluster center was strongly and negatively associated with both stand and patch use, and was the most important regressor in every model. All other things being equal, red-cockaded woodpeckers seem to use habitat that is nearer rather than farther from the cluster center. Possible costs associated with foraging further from the cluster center include the energetic costs of travel, the risk of increased predation, and the inability to defend cavity trees from cavity modifiers (e.g. piliated woodpecker), usurpers, and in the breeding season, nest predators. Thus, habitat quality cannot simply be defined in terms of habitat structure, but instead must consider the spatial context of the habitat matrix. The new Red-cockaded Woodpecker Recovery Plan addresses this issue, and suggests that at least 50 percent of good quality foraging habitat be within 400 m of the cluster center.

Fitness

Relating habitat characteristics to measures of fitness is the most valuable tool researchers have in assessing habitat quality (Van Horne 1983). In this study, I used 2 measures of fitness – fledgling production and group size – to examine this relationship. The results with respect to the 2 fitness measures are consistent and to a large extent support the recommendations in the Recovery Plan. I found that fitness is enhanced by foraging habitat that mimics the historical, mature, fire-adapted, pine ecosystems of the southeastern U.S., characterized by large pines, significant herbaceous groundcover, and low densities of hardwoods and medium pines.

My results are important for several reasons. First, this is the first *confirmatory* study to show a relationship between habitat structure, groundcover composition, and red-cockaded woodpecker fitness. To a large extent, the foraging guidelines were developed based on the results of exploratory studies. As reviewed by Anderson et al. (2001), these types of studies have a high probability of producing spurious results because of the typically high number of tests performed and the lack of objective-driven research hypotheses. In this study, I analyzed only those variables (and necessary covariates) in the Recovery Plan hypothesized to affect red-cockaded woodpecker fitness and habitat use, and made specific *a priori* predictions about their biological effects. My results support important work by Hardesty et al. (1997) James et al. (1997, 2001), and Walters et al. (2002), that collectively show that red-cockaded woodpeckers respond favorably to mature, open pine forests. James et al. (2001) showed that group size and productivity increased with the density of large pines and abundant herbaceous groundcover, but decreased with abundance of small pines. On Eglin Air Force Base, Hardesty et al. (1997) demonstrated that high densities of small and medium pines reduced group size and productivity, but herbaceous groundcover increased both. In North Carolina, Walters et al. (2002) failed to examine groundcover directly but they nevertheless found that group size was related to habitat structure often associated with a significant herbaceous groundcover. Because my results confirm those of exploratory studies, greater confidence should now be allocated to them, and the foraging guidelines in general.

Second, confirmatory studies add even greater confidence when experiments are spatially replicated (Anderson et al. 2001); that is, when similar results are found at different physical locations. This is the first study outside of Florida to find a direct relationship between groundcover composition and red-cockaded woodpecker fitness. Previously, only Hardesty et al. (1997) on Eglin Air Force Base and James et al. (1997, 2001) on Apalachicola National Forest of Florida had demonstrated such a relationship. Collectively, it is clear that herbaceous groundcover is somehow related to red-cockaded woodpecker fitness, and this effect is not restricted to a particular site or physiogeographic region.

My results and those discussed above, suggest that habitat structure is the key to habitat quality for red-cockaded woodpeckers, and that the importance of structure extends to the forest floor. While individual habitat components may be important (i.e. large trees), habitat quality is best understood only with consideration of the collection of features that make up the habitat. Why structure and groundcover are so important remains unclear, but the coevolution of red-cockaded woodpeckers and the southern pine ecosystem seems to be critical (James et al. 1997, James et al. 2001).

Perhaps no other natural event has shaped the vegetation structure, composition, and plant-animal relationships of southern pine ecosystems as much as fire. Fire history plays an important role in habitat structure by affecting the size class distribution of pines, midstory density (Provencher et al. 1998), and herbaceous groundcover (Platt et al. 1988). Of 400 plant species of the longleaf pine ecosystem examined by Walker (1993), over 90% were adapted to fire, and fire suppression is one of the main agents of their decline. Longleaf pines as well are exquisitely adapted to fire (Landers 1991).

Numerous animal species, including the red-cockaded woodpecker, also show adaptations to fire (Engstrom 1993). In fact, perhaps the most unusual aspect of red-cockaded woodpecker behavior is likely an adaptation to fire: its propensity to excavate cavities in living pine trees (Ligon 1970). As a result of frequent fire, standing dead trees (i.e. snags) likely were historically uncommon in the longleaf pine ecosystem, and red-cockaded woodpeckers may have evolved the ability to excavate into living trees because of the scarcity of snags. Indirectly then, fire has also led to the evolution of the red-cockaded woodpecker's cooperative breeding system (Walters 1990, Walters et al. 1992).

That the red-cockaded woodpecker responds favorably to conditions that mimic historical fire-maintained longleaf ecosystems should not be surprising. Natural selection acts upon individuals that are best (or least) able to reproduce under the current set of environmental conditions, and for millennia the current set of conditions was largely the longleaf ecosystem with all of its biotic and abiotic features. The red-cockaded woodpecker evolved within the longleaf ecosystem and presumably has adapted to vegetative or structural features that, however indirectly, affect habitat use and increase fitness. Thus, past evolution has determined the present day ecological niche (Hutchinson 1957) of the red-cockaded woodpecker. Departures from historical conditions may, in effect, shift individuals to the periphery of their ecological niche, where reproduction and/or survival is reduced. The notion that animals adapt to conditions in which they evolve is fundamental to ecology and evolutionary biology, and understanding the implications of adaptations is paramount in understanding habitat and ecological relationships. James et al. (2001) address this concept in more detail and use covariation between bird fitness and habitat structure to develop a theoretical niche for the red-cockaded woodpecker.

That vertical structure is important explains why traditional measures of habitat quality (i.e. # pines ≥25.4 cm dbh) are unrelated to fitness. This metric simply describes the amount of foraging substrate available but altogether disregards the important effects of vertical structure (i.e. crown and shrub layers) on habitat quality. Furthermore, in this study, as in others, red-cockaded woodpeckers responded differently to 2 size classes that make up this component variable (medium pines: 25.4 cm-35.6 cm dbh; and large pines: ≥35.6 cm dbh), thereby obscuring any real relationships between the variable and fitness. In this study, large pines were positively related to fitness and habitat use, while medium pines were negatively related to fitness. This pattern is evident from other studies as well. Walters et al. (2002) demonstrated that medium pines were negatively related to group size, while James et al. (2001) showed that large pines positively affect group size and reproduction. When combined to form one component variable (i.e. # pines ≥25.4 cm dbh), I found no relationship with measures of fitness; Wood et al.(1985), Hooper and Lennartz (1995), Beyer et al. (1996), and Walters et al. (2002) also failed to find such a relationship, while Hardesty et al. (1997) and James et al. (2002) found a significant and negative relationship between this variable and fitness. My results support the idea that pines ≥25.4 cm dbh is an inappropriate measure of habitat quality for red-cockaded woodpeckers.

Amount of 'good quality' habitat

In this study, home range size was positively related to both group size and fledgling productivity, indicating that as home range size increases so does fitness. This result supports the work of Hardesty et al. (1997) who found that successful groups (producing >2 fledglings in 2 years) had home ranges 46% larger than unsuccessful groups. But home range size also is inversely related to habitat quality. These seemingly contradictory results can be reconciled by postulating that high quality habitat is in short supply. Habitat features that confer quality are in fact associated with smaller home ranges, but there may be so little of this habitat available that birds must expand their home range to meet their foraging requirements. The results from patch and stand classifications support this assertion. Very little habitat meeting the USFWS definition of 'good' quality exists within the home ranges of the 23 study groups. Only 2% of inventory points met all 7 guidelines, and only 21% were in compliance with 5 or more characteristics. Over 50% of the patches met 3 or fewer of the criteria (Figure 1.16), and these figures exclude the approximately 16% of habitat that is unforested, too young, or dominated by hardwoods (Figure 1.15). While neither the density of medium pines nor canopy hardwoods seemed to be limiting factors, other individual characteristics were in compliance in less than half of the plots (Figure 1.17). The age and density of large pines appears to be especially limiting, as only 17% of plots were in compliance with this characteristic.

Clearly, very little habitat meeting the USFWS definition of 'good' quality exists within the study area, but nevertheless the Camp Lejeune population remains healthy and continues to grow (Walters et al. 2000). How can this apparent contradiction be explained? First, the guidelines are a simplified attempt to describe habitat that promotes red-cockaded woodpecker fitness. They mimic the historical, open, and mature pine ecosystems of the southeastern U.S. They also represent a compromise between overly simplified guidelines and a complex multivariate model that managers would have difficulty implementing because they seldom have access to detailed information. Researchers have long attempted to identify optimal habitat for many species, but the perceptual world of animals is elusive, therefore guidelines can seldom perfectly achieve this goal. Despite the recommendation that hardwood midstory be <2.1 m, for example, red-cockaded woodpeckers are unlikely to reject otherwise suitable habitat because a few oaks are 2.2 m in height, or because the trees are 59 years old, not 60. The guidelines are intended to direct management efforts toward the desired forest structure. In reality, some components are probably more important than others, but structure appears to be the key. Woodpeckers survive where suitable structure exists despite the lack of herbaceous groundcover, but will not persist with groundcover and no trees. The guidelines make no distinction, and as such, that is how they were tested here. Because of this, seemingly good habitat may 'score' poorly because of a few centimeters here, and an extra tree there, and these deviations may not be biologically meaningful.

Second, while to a large extent the guidelines are appropriate for Camp Lejeune, it is possible that they could be improved with consideration of site-specific ecology. The Recovery Plan, in fact, allows for deviations from the guidelines if site-specific research shows that a different pine basal area or size class distribution and stem density of pines is more appropriate for the population under study. In this study, I did not assess the importance of basal area (only stem density) on fitness, home range size, or habitat use, so I cannot offer improvements to the guidelines in this respect. However, patches with large pines (≥35.6 cm dbh) were selected by woodpeckers only at classes above 50 stems/ha, a result remarkably consistent with the guidelines, giving some measure of confidence to that characteristic. Relationships between small pines (<25.4 cm dbh) and measures of fitness or habitat use, however, were weak or nonexistent, possibly indicating some modification of cutoff values may be appropriate given more study.

Third, though healthy, it is difficult to assess the potential of the Camp Lejeune population. Lejeune is considered healthy relative to many other populations, but given the results presented here, it is likely that other populations too are lacking in habitat meeting the USFWS definition of 'good' quality; thus, their productivity and group size may also be hampered by inadequate habitat. To a large extent, then, the baseline to which comparisons are made is inappropriate. A better standard would be pre-colonial conditions, but demographic data do not exist for this period. Instead, perhaps comparisons are best made with a population partially inhabiting the fire-maintained, old growth longleaf forest of the Wade Tract, Georgia, where groups have the smallest reported home ranges, largest group size and highest productivity (Engstrom and Sanders 1997). Thus, while the Camp Lejeune population may be healthy relative to other populations lacking good quality habitat, the full potential may only be expressed when habitat conditions improve.

Finally, home range size is inversely related to habitat quality. Red-cockaded woodpeckers are thus compensating for low quality habitat by holding larger home ranges. The biggest impact of improved habitat quality might then be smaller home ranges and higher population density, not a substantial increase in the number of fledglings produced on a group-by-group basis.

MANAGEMENT RECOMMENDATIONS

My results support the growing body of evidence that red-cockaded woodpeckers respond favorably to mature, open stands with large trees and the presence of an herbaceous groundcover. Not coincidentally, these are the conditions that mimic the historical southern pine ecosystems in which the species evolved. My results also indicate that there is substantial room for habitat improvement at Camp Lejeune, and that management efforts intended to improve habitat quality for the red-cockaded woodpecker may be rewarded with increased population health.

To a large extent, foraging habitat improvement for the red-cockaded woodpecker may be accomplished with efforts to restore the pine ecosystem in general. As such, an ecosystem level approach may provide healthy habitat for many species and reduce the need for costly, labor-intensive techniques that primarily benefit single species.

More than any other management technique, the application of prescribed burning has the greatest potential in restoring and maintaining healthy southern pine ecosystems (Frost 1998). Repeated burns effectively control woody shrubs and are more effective at promoting the development of a diverse herbaceous groundcover than either herbicidal or mechanical methods (Provencher et al. 2001). Restoration will be best accomplished with the application of a burning regime that mimics historical conditions with respect to frequency, season, and intensity of fire (Masters et al. 1996). On the Atlantic Coastal Plain, natural fires occurred as frequently at 1-3 years, and typically during the growing (lightening) season (Frost 1998). Accordingly, managers at Camp Lejeune should increase the frequency of prescribed burns from 5 years to 3 years or less, in all suitable and potentially suitable foraging habitat. I emphasize foraging habitat and not just nesting habitat (i.e. cluster sites, which are currently burned every 3 years), as my results indicate that good quality foraging habitat resembles good quality nesting habitat. Management of the two should thus become increasingly integrated. Furthermore, for greatest benefits, managers are advised to concentrate burning efforts during the early to mid growing season, when fire is more efficient at removing woody species, less likely to damage pine stems, and has greater positive effects on herbaceous groundcover (Sparks et al. 1998, Sparks et al. 1999). Post-harvesting site preparation may also have significant and long-lasting effects on groundcover composition (Provencher et al. 1998), and because groundcover is a critical component of good quality foraging habitat, managers should consider site preparation methods that minimize soil disturbance.

While silviculture may be an important tool for red-cockaded woodpecker management, especially for restoring second growth stands to a suitable open forest structure, the goals of timber production and red-cockaded woodpecker management may conflict at times. This is especially true regarding timber rotation ages. Current timber rotations at Camp Lejeune for longleaf and loblolly pines are 120 years and 80 years, respectively. Regeneration techniques vary but are typically even-aged, and 'reserve' trees are left standing to provide potential nesting habitat. My results indicate that large, and thus possibly older, trees are important for foraging as well as nesting habitat. At no age are older trees less valuable than younger trees. To the best of my knowledge this is a universal result. Accordingly, there is no optimal rotation time for red-cockaded woodpecker management. Timber rotation serves only the goals of timber production. If improving habitat quality for red-cockaded woodpeckers is the main objective, timber rotations, if necessary, should be as long as possible. In addition to an ecosystem approach, management efforts directed at individual groups may be appropriate, especially for groups with low productivity and a lack of good quality habitat.

Appendix II identifies, for each group, those stands missing 3 or fewer characteristics of good quality habitat, and lists, for each stand, the missing component(s). These stands should be considered candidates for habitat improvement, because, in many cases, the effort required to bring them up to standard is minimal. For example, stands missing only the herbaceous groundcover component may be improved in time simply by the application of fire and/or seeding. Many other stands are missing large and/or old trees. It will take time to bring them into in full compliance, but they can nevertheless be improved as red-cockaded woodpecker foraging habitat with simple management efforts. Assigning priority for stands might be based on the need of particular woodpecker groups lacking in good quality habitat or on the effort needed to improve stands. Regardless, if this approach is useful, stands not included in this study can be classified using the same or similar method and improved as necessary. Of course, before any management activities are implemented, on-the-ground verification is critical, as this approach has some problems and some stands are likely misclassified (see Amount of Good Quality Habitat).

Because good quality habitat was so rare, I was unable to identify the minimum and optimal foraging base for red-cockaded woodpeckers at Camp Lejeune. No groups met (or even approached) the Recovery Plan standard of 49 ha of good quality habitat. However, most groups had at least 49 ha of potentially suitable habitat (not unsuitable) within their home ranges. Using the approach described above, it should be possible to bring most groups up to standard.

Management of red-cockaded woodpeckers at Camp Lejeune has been a great success. Up from only 27 groups in 1991, the current population continues to grow at 57 groups (year 2000), and is one of the healthiest populations in existence (Walters et al. 1999). Much of this growth can be attributed to wise management and the efforts of the natural resources staff at Camp Lejeune. Further success is expected, but habitat restoration must become a key strategy to accommodate the long-term needs of both the red-cockaded woodpecker and military training.

LITERATURE CITED

Akaike, H. 1973. Information theory as an extension of the maximum likelihood principle. Pages 267-281 *in* B. N. Petrov and F. Csaki, editors. Second International Symposium on Information theory. Akademiai Kiado, Budapest.

Anderson, D. R., W. A. Link, D. H. Johnson, and K. P. Burnham. 2001. Suggestions for presenting the results of data analyses. Journal of Wildlife Management **65**:373-378.

Anonymous. 1996. Draft comprehensive long range red-cockaded woodpecker habitat management plan. Marine Corps Base, Camp Lejeune, North Carolina.

Anonymous. 2001. Draft Integrated natural resources management plan (INRMP). Marine Corps Base, Camp Lejeune.

Beyer, D. E., Jr., R. Costa, R. G. Hooper, and C. A. Hess. 1996. Habitat quality and reproduction of red-cockaded woodpecker groups in Florida. Journal of Wildlife Management **60**:826-835.

Bowman, R., D. L. Leonard, Jr., L. K. Backus, P. M. Barber, A. R. Mains, L. M. Richman, and D. Swan. 1998. Demography and habitat characteristics of the red-cockaded woodpecker (*Picoides borealis*) at the Avon Park Air Force Range: Final Report 1994-1998. Archbold Biological Station, Lake Placid, Florida.

Bradshaw, D. S. 1995. Habitat use by a relict population of red-cockaded woodpeckers in southeastern Virginia. Pages 482-488 *in* D. L. Kulhavy, R. G. Hooper, and R. Costa, editors. Red-cockaded woodpecker: Recovery, ecology, and management. Center for Applied Studies in Forestry, Stephen F. Austin University, Nacogdoches, TX.

Burt, W. H. 1943. Territoriality and home range concepts as applied to mammals. Journal of Mammalogy **24**:346-352.

Cody, M. L. 1985. An introduction to habitat selection in birds. *in* M. L. Cody, editor. Habitat selection in birds. Academic Press, Orlando, Florida.

Collins, C. S., R. N. Conner, and D. Saenz. 2002. Influence of hardwood midstory and pine species on pine bole arthropods. Forest Ecology and Management **164**:211-220.

Conner, R. N., and D. C. Rudolph. 1989. Red-cockaded woodpecker colony status and trends on the Angelina, Davy Crockett, and Sabine National Forests. SO-250, USDA Forest Service Research Paper SO-250.

Conner, R. N., D. C. Rudolph, and L. H. Bonner. 1995. Red-cockaded woodpecker population trends and management on Texas national forests. Journal of Field Ornithology **66**:140-151.

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

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, Texas.

Copeyon, C. K., J. R. Walters, and J. H. Carter. 1991. Induction of red-cockaded woodpecker group formation by artificial cavity construction. Journal of Wildlife Management **55**:549-556.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science **33**:43-64.

Delotelle, R. S., and R. J. Epting. 1992. Reproduction of the red-cockaded woodpecker in central Florida. Wilson Bulletin **104**:285-294.

DeLotelle, R. S., R. J. Epting, and G. Demuth. 1995. A 12-year study of red-cockaded woodpeckers in central Florida. Pages 259-269 *in* D. L. Kulhavy, R. G. Hooper, and R. Costa, editors. Red-cockaded woodpecker: Recovery, ecology and management. Center for Applied Studies in Forestry, Stephan F. Austin University, Nacogdoches, Texas.

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**:202-217.

Doster, R. H., and D. A. James. 1998. Home range size and foraging habitat of red-cockaded woodpeckers in the Ouachita Mountains of Arkansas. Wilson Bulletin **110**:110-117.

Engstrom, R. T. 1993. Characteristic mammals and birds of the longleaf pine forests. Pages 127-138 *in* S. M. Hermann, editor. The longleaf pine ecosystem: Ecology, restoration and management. Tall Timbers Fire Ecology Conference Proceedings, No. 18, Tall Timbers Research Station, Tallahassee, Florida.

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

Epting, R. J., R. S. DeLotelle, and T. Beaty. 1995. Red-cockaded woodpecker territory and habitat use in Georgia and Florida. Pages 270-276 *in* D. L. Kulhavy, R. G. Hooper, and R. Costa, editors. Red-cockaded woodpecker: recovery, ecology, and management, Center for Applied Studies in Forestry, Stephen F. Austin State Univ., Nacogdogches, Texas.

Frost, C. C. 1998. Presettlement fire frequency regimes of the United States: A first approximation. Pages 70-81 *in* T. L. Pruden and L. A. Brennan, editors. Fire in ecosystem management: Shifting the paradigm from suppression to prescription. Tall Timbers Fire Ecology Proceedings, No. 20, Tall Timbers Research Station, Tallahassee, Florida.

Garrot, R. A., and G. C. White. 1990. Analysis of wildlife radio tracking data. Academic Press, San Diego, California.

Geographic Information Systems Office of the Business and Logistics Support Department. 2000. Integrated geographic information repository (IGIR). Marine Corps Base Camp Lejeune.

Gese, E. M., D. E. Andersen, and O. J. Rongstad. 1990. Determining home range size of resident coyotes from point and sequential locations. Journal of Wildlife Management **54**:501-506.

Grinnell, J. 1904. The origin and distribution of the chestnut-backed chickadee. Auk **21**:364-382.

Grinnell, J. 1917. The niche-relationships of the California thrasher. Auk **34**:427-433.

Gulf Engineers and Consultants Inc, and Dr. J.H. Carter III and Associates Inc. Environmental Consultants. 2000. Final Report. Forest inventory report - Red-cockaded woodpecker foraging habitat inventory. Marine Corps Base, Camp Lejeune, North Carolina.

Hamilton, L. C. 1992. Regression with graphics: A second course in applied statistics. Brooks/Cole Publishing Company, Belmont, California.

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.

Hanula, J. L., K. E. Franzreb, and W. D. Pepper. 2000. Longleaf pine characteristics associated with arthropods available for red-cockaded woodpeckers. Journal of Wildlife Management **64**:60-70.

Hardesty, J. L., K. E. Gault, and H. F. Percival. 1997. Ecological correlates of red-cockaded woodpecker (*Picoides borealis*) foraging preference, habitat use and home range size in northwest Florida (Eglin Air Force Base). Final Report, Reseach Work Order 99.

Harris, S., W. J. Cresswell, P. G. Forde, W. J. Trewhella, T. Woollard, and S. Wray. 1990. Home-range analysis using radio-tracking data - A review of problems and techniques particularly as applied to the study of mammals. Mammal Review **20**:97-123.

Hooge, P. N., and B. Eichenlaub. 1997. Animal movement extension to Arcview (version 1.1) [computer program]. Alaska Biological Science Center, USGS, Anchorage, Alaska.

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

Hooper, R. G., and R. F. Harlow. 1986. Forest stands selected for foraging red-cockaded woodpeckers. Research Paper SE-259, US Forest Service.

Hooper, R. G., and M. R. Lennartz. 1981. Foraging behavior of the red-cockaded woodpecker in South Carolina. Auk **98**:321-334.

Hooper, R. G., and M. R. Lennartz. 1995. Short-term response of a high density red-cockaded woodpecker population to loss of foraging habitat. *in* D. L. Kulhavy, R. G. Hooper, and R. Costa, editors. Red-cockaded woodpecker: Recovery, ecology and management. Center for Applied Studies in Forestry, College of Forestry, Stephen F. Austin State University, Nacogdoches, Texas.

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

Hutchinson, G. E. 1957. Concluding remarks. Cold Springs Harbor symposium on quantitative Biology **22**:415-427.

Jackson, J. A. 1994. Red-cockaded woodpecker (*Picoides borealis*). Pages 1-20 *in* A. Poole and F. Gill, editors. The Birds of North America: Life Histories for the 21st Century. Academy of Natural Sciences, Philadelphia, PA (USA).

James, F. C. 1991. Signs of trouble in the largest remaining population of red-cockaded woodpeckers. Auk **108**:419-423.

James, F. C., C. A. Hess, B. C. Kicklighter, and R. A. Thum. 2001. Ecosystem management and the niche gestalt of the red-cockaded woodpecker in longleaf pine forests. Ecological Applications **11**:854-870.

James, F. C., C. A. Hess, and D. Kufrin. 1997. Species-centered environmental analysis: Indirect effects of fire history on red-cockaded woodpeckers. Ecological Applications **7**:118-129.

Kenward, R. E. 2001. A manual for wildlife radio tagging. Academic Press, San Diego, California.

Kenward, R. E., and K. H. Hodder. 1996. Ranges V: An analysis system for biological location data [computer program]. Institute of Terrestrial Ecology, Wareham, UK.

Khan, M. Z., and J. R. Walters. 2002. Effects of helpers on breeder survival in the red-cockaded woodpecker (*Picoides borealis*). Behavioral Ecology and Sociobiology **51**:336-344.

Lack, D. 1933. Habitat selection in birds with special reference to the effects of afforestation on the Breckland avifauna. Journal of Animal Ecology **2**:239-262.

Landers, J. L. 1991. Disturbance influences on pine traits in the southeastern United States. Pages 61-98 *in* S. M. Hermann, editor. High-intensity fire in wildlands: Management challenges and options. Tall Timbers Fire Ecology Conference Proceedings, No. 17., Tall Timbers Research Station, Tallahassee, Florida.

Landers, J. L., D. H. Van Lear, and W. D. Boyer. 1995. The longleaf forests of the Southeast: requiem or renaissance? Journal of Forestry **93**:39-44.

Larkin, R. P., and D. Halkin. 1994. Wildlife software: A review of software packages for estimating animal home ranges. Wildlife Society Bulletin **22**:274-287.

Lawson, E. J. G., and A. R. Rodgers. 1997. Differences in home-range size computed in commonly used software programs. Wildlife Society Bulletin **25**:721-729.

Lennartz, M. R., R. G. Hooper, and R. F. Harlow. 1987. Sociality and cooperative breeding of red-cockaded woodpeckers, *Picoides borealis*. Behavioral Ecology and Sociobiology **20**:77-88.

Ligon, J. D. 1970. Behavior and breeding biology of the red-cockaded woodpecker. Auk **87**:255-278.

Manly, B. F. J., L. L. McDonald, and D. L. Thomas. 1993. Resource Selection by Animals: Statistical design and analysis for field studies, 1st edition. Chapman & Hall, London, UK.

Masters, R. E., C. W. Wilson, G. A. Bukenhofer, and M. E. Payton. 1996. Effects of pine-grassland restoration for red-cockaded woodpeckers on white-tailed deer forage production. Wildlife Society Bulletin **24**:77-84.

McGarigal, K., S. Cushman, and S. Stafford. 2000. Multivariate statistics for wildlife and ecology research. Springer, New York.

Millspaugh, J. J., and J. M. Marszluff, editors. 2001. Radio Tracking and Animal Populations. Academic Press, San Diego, California.

Myers, R. H. 1989. Classical and modern regression with applications. Brooks/Cole, Pacific Grove, California.

Nesbitt, S. A., A. E. Jerauld, and B. A. Harris. 1983. Red-cockaded woodpecker summer range sizes in southwest Florida. *in* D. A. Wood, editor. Red-cockaded woodpecker symposium II proceedings. Florida Game and Freshwater Fish Commission, Tallahassee, Florida.

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

Platt, W. J., W. Evans, and M. M. Davis. 1988. Effects of fire season on flowering forbs and shrubs in longleaf pine forests. Oecologia **76**:353-363.

Provencher, L., K. E. M. Galley, B. J. Herring, J. Sheehan, N. M. Gobris, D. L. Gordon, G. W. Tanner, J. L. Hardesty, H. L. Rodgers, J. P. McAdoo, M. N. Northrup, S. J.

McAdoo, and L. A. Brennan. 1998. Post-treatment analysis of restoration effects on soils, plants, arthropods, and birds in sandhill systems at Eglin Air Force Base, Florida. Annual report to Natural Resources Division, Eglin Air Force Base, Niceville, Florida. Public Lands Program, The Nature Conservancy, Gainesville, FL.

Provencher, L., B. J. Herring, D. R. Gordon, H. L. Rodgers, K. E. M. Galley, G. W. Tanner, J. L. Hardesty, and L. A. Brennan. 2001. Effects of hardwood reduction techniques on longleaf pine sandhill vegetation in northwest Florida. Restoration Ecology **9**:13-27.

Pulliam, H. R., and B. J. Danielson. 1991. Sources, sinks, and habitat selection - a landscape perspective on population dynamics. American Naturalist **137**:S50-S66.

Rodriguez, A., H. Andren, and G. Jansson. 2001. Habitat-mediated predation risk and decision making of small birds at forest edges. Oikos **95**:383-396.

Rosenberg, D. K., and K. S. McKelvey. 1999. Estimation of habitat selection for central-place foraging animals. Journal of Wildlife Management **63**:1028-1038.

SAS Institute Inc. 1988a. SAS Procedures Guide, Release 6.03 Edition. SAS Institue Inc, Cary, NC.

SAS Institute Inc. 1988b. SAS/STAT User's Guide, Release 6.03 Edition. SAS Institute Inc, Cary, NC.

Seaman, D. E., J. J. Millspaugh, B. J. Kernohan, G. C. Brundige, K. J. Raedeke, and R. A. Gitzen. 1999. Effects of sample size on kernel home range estimates. Journal of Wildlife Management **63**:739-747.

Seaman, D. E., and R. A. Powell. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology **77**:2075-2085.

Sherrill, D. M., and V. M. Case. 1980. Winter home ranges of four clans of red-cockaded woodpeckers in the Carolina Sandhills. Wilson Bulletin **92**:369-375.

Silverman, B. W. 1986. Density estimation for statistics and data analysis. Chapman and Hall, London.

Sparks, J. C., R. E. Masters, D. M. Engle, M. W. Palmer, and G. A. Bukenhofer. 1998. Effects of late growing-season and late dormant-season prescribed fire on herbaceous vegetation in restored pine-grassland communities. Journal of Vegetation Science **9**:133-142.

Sparks, J. C., R. E. Masters, D. M. Engle, M. E. Payton, and G. A. Bukenhofer. 1999. Influence of fire season and fire behavior on woody plants in red-cockaded woodpecker clusters. Wildlife Society Bulletin **27**:124-133.

Svardson, G. 1949. Competition and habitat selection in birds. Oikos **1**:157-174.

Swihart, R., and N. Slade. 1997. On testing for independence of animal movements. Journal of Agricultural, Biological, and Environmental Statistics **2**:48-63.

Tabachnick, B. G., and L. S. Fidell. 1989. Using Multivariate Statistics. Harper and Row, New York.

Taylor, T. B. 2002. Influence of groundcover composition on red-cockaded woodpecker prey base. Masters thesis. Virginia Polytechnic Institute and State University, Blacksburg.

U.S. Fish and Wildlife Service. 1970. United States list of endangered fish and wildlife. Federal Register 35:16047.

U.S. Fish and Wildlife Service. 1985. Red-cockaded woodpecker recovery plan. U.S. Fish and Wildlife Service, Atlanta, GA.

U.S. Fish and Wildlife Service. 2003. Recovery plan for the red-cockaded woodpecker (*Picoides borealis*): Second revision. U.S. Fish and Wildlife Service, Atlanta, Georgia.

Van Horne, B. 1983. Density as a misleading indicator of habitat quality. Journal of Wildlife Management **47**:893-901.

Walker, J. 1993. Rare and vascular plant taxa associated with the longleaf pine ecosystems: Patterns in taxonomy and ecology. Pages 105-125 *in* S. M. Hermann, editor. The longleaf pine ecosystem: Ecology, restoration, and management. Tall Timbers Fire Ecology Conference Proceedings, No. 18, Tall Timbers Research Station, Tallahassee, Florida.

Walters, J. R. 1990. Red-cockaded woodpecker: a 'primitive' cooperative breeder. *in* P. B. Stacey and W. D. Koenig, editors. Cooperative breeding in birds. Cambridge University Press, London, UK.

Walters, J. R. 1991. Application of ecological principles to the management of endangered species: The case of the red-cockaded woodpecker. Annu. Rev. Syst. **22**:505-523.

Walters, J. R., C. K. Copeyon, and J. H. Carter, III. 1992. Test of the ecological basis of cooperative breeding in red-cockaded woodpeckers. Auk **109**:90-97.

Walters, J. R., S. J. Daniels, J. H. Carter III, and P. D. Doerr. 2002. Defining quality of red-cockaded woodpecker foraging habitat based on habitat selection and fitness. Journal of Wildlife Management **In Press**.

Walters, J. R., P. D. Doerr, and J. H. Carter, III. 1988. The cooperative breeding system of the red-cockaded woodpecker. Ethology **78**:275-305.

Walters, J. R., R. R. Meekins, and B. L. Simmons. 1998. Biology and management of red-cockaded woodpeckers on Camp Lejeune Marine Base, North Carolina. Phase 1 Final Report (1997 - 1998). Marine Corps, Camp Lejeune, North Carolina.

Walters, J. R., Phillip D. Doerr, and J.H. Carter III. 1988. The cooperative breeding system of the red-cockaded woodpecker. Ethology **78**:275-305.

Walters, J. R., B. L. Simmons, and S. E. Hopkins. 2000. Biology and management of red-cockaded woodpeckers on Camp Lejeune Marine Base, North Carolina. Phase 3 Final Report (1999 - 2000). Dept of Biology, Virgninia Polytechnic Institute and State University, Blacksburg, VA.

Walters, J. R., B. L. Simmons, R. R. Meekins, and A. M. Livings. 1999. Biology and management of red-cockaded woodpeckers on Camp Lejeune Marine Base, North Carolina. Phase 2 Final Report (1998-1999). Marine Corps, Camp Lejeune, North Carolina.

Ware, S., C. Frost, and P. D. Doerr. 1993. Southern mixed hardwood forest: the former longleaf pine forest. Pages Pp. 447-496 *in* W. H. Martins, S. G. Boyce, and A. C. Echternacht, editors. Biodiversity of the southeastern United States: lowland terrestrial communities. John Wiley and Sons, Inc, New York.

Wiens, J. A. 1985. Habitat selection in variable environments: shrub-steppe birds. Pages 227-251 *in* M. L. Cody, editor. Habitat selection in birds. Academic Press, New York.

Wood, G. W., L. J. Niles, R. M. Hendricks, J. R. Davis, and T. L. Grimes. 1985. Compatability of even-aged timber management and red-cockaded woodpecker conservation. Wildlife Society Bulletin **13**:5-17.

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home range studies. Ecology **70**:164-168.

Worton, B. J. 1995. Using Monte Carlo simulation to evaluate kernel-based home range estimators. Journal of Wildlife Management **59**:797-800.

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

 Chapter 1

Table 1.1. Characteristics of good quality habitat, as defined in the USFWS Foraging Habitat Guidelines, and the explanatory variables in this study used to evaluate them

Characteristic	Components	Measured/Analyzed	Name of variable
a). 45 or more stems/ha of pines that are >60 years in age and > 35 cm dbh. Minimum basal area for these pines is 4.6 m2/ha.	▪ # pine stems/ha ≥35 cm dbh ▪ Tree age ▪ BA pines/ha ≥35 cm dbh	* * **	Large pines Age
b). Basal area of pines 25.4-35 cm dbh is between 0 and 9.2 m^2/ha.	▪ BA pines/ha 25.4-35 cm dbh	# pines stems/ha 25.4-35 cm	Medium pines
c). Basal area of pines <25.4 cm dbh is below 2.3 m^2/ha *and* below 50 stems/ha.	▪ BA pines/ha <25.4 cm dbh ▪ # pines stems/ha <25.4 dbh	** *	Small pines
d). Basal area of all pines ≥25.4 cm dbh is at least 9.2 m^2/ha.	▪ BA pines/ha ≥25.4 cm dbh	# pines stems/ha ≥25.4 cm dbh	
e). Groundcovers of native bunchgrass and/or other native, fire-tolerant, fire-dependent herbs total >40% of groundcover and midstory plants and are dense enough to carry growing season fire at least once every 5 years.	▪ % Herbaceous groundcover	*	Herbaceous groundcover
f). No hardwood midstory exists, or if a hardwood midstory is present it is sparse and <2.1 m in height.	▪ Hardwood midstory (density) ▪ Hardwood midstory (height)	# Hardwood stems/ha <25.4 cm dbh *	Small hardwoods Midstory height
g). Canopy hardwoods are absent or <10% of the number of canopy trees in longleaf forests and <30% of the number of canopy trees in loblolly and shortleaf forests.	▪ % canopy hardwoods	# Hardwood stems/ha ≥25.4 cm dbh	Large hardwoods

* same as described in Components, ** did not analyze

Table 1.2. Ninety-five percent fixed kernel and minimum convex polygon (MCP) home ranges for 23 study groups at Camp Lejeune, NC, computed with Animal Movement Extension for Arcview. Each group was followed approximately one day per month for 8 months, and the group's location was recorded at 10-minute intervals using a global positioning system (GPS) receiver. Number of locations refers to the number of observations used to calculate the home range.

Group	95% Fixed kernel home range (ha)	MCP Home range (ha)	Number of locations
1	94.5	106.8	311
2	54.6	60.7	294
3	65.1	87.6	327
4	55.3	71.0	355
7	78.7	105.7	314
8	107.7	156.6	320
9	96.5	96.1	309
10	39.0	84.3	335
11	75.6	117.1	297
14	84.4	103.7	298
18	89.7	112.4	336
19	83.1	168.8	298
20	93.8	117.6	327
22	50.8	92.3	276
33	97.4	113.0	300
35	132.3	156.9	319
39	80.1	82.3	308
42	63.8	68.4	314
43	80.0	86.8	318
44	145.4	152.0	335
46	50.4	62.9	328
47	84.2	99.7	304
48	42.0	65.6	348
Mean (SE)	80.2 (5.3)	103.0 (6.3)	316.1 (3.9)

Table 1.3. Relationships of habitat characteristics to likelihood of patch use. Best model chosen using logistic regression with the stepwise selection procedure (p<0.5 for entry, p<0.1 for retention). The area within 25 m of a vegetation sampling plot represents a patch, and a patch was used if one or more observations occurred within it. Distance is distance to cavity tree cluster. Other variables defined in Table 1.1.

Variable	Estimate	St Error	Chi-Square	P-value
Medium pines	0.003	0.002	3.8	0.058
Large pines	0.006	0.003	4.1	0.044
Herbaceous groundcover	0.011	0.004	8.2	0.004
Distance	-0.002	0	26.1	<0.001

Model fitting statistics: n = 490, X2 = 49.8, df = 4, P < 0.0001

Percent concordant: 68.4, percent disconcordant: 32.1

Table 1.4. Mean ± SE values for plots used and unused by foraging red-cockaded woodpeckers. The area within 25 m of a vegetation sampling plot represents a patch, and a patch was used if one or more observations occurred within it.

Variable	Used n = 220	Not Used n = 282	Total n = 502
Density of pines (trees/ha)			
Small pines (<25.4 cm dbh)	168.8 ± 10.7	166.6 ± 10.6	167.6 ± 10.7
Medium pines (25.4-35.6 cm dbh)	60 ± 2.4	52 ± 2.6	55.5 ± 2.5
Large pines (>35.6 cm dbh)	28.2 ± 1.5	21.7 ± 1.3	25.6 ± 1.4
Density of hardwoods (trees/ha)			
Small hardwoods (<25.4 cm dbh)	16.2 ± 2.5	14.5 ± 2.1	15.3 ± 2.3
Large hardwoods (>25.4 cm dbh)	0.7 ± 0.2	1.8 ± 0.4	1.3 ± 0.3
Midstory height (m)	3.4 ± 0.2	3.9 ± 0.2	3.7 ± 0.2
Herbaceous groundcover (%)	32.8 ± 1.2	25.2 ± 1.1	28.6 ± 1.1
Representative age (yrs)	61.2 ± 0.7	60.5 ± 0.9	60.8 ± 0.8

Table 1.5. Relationships of patch use to habitat characteristics in the full model. The area within 25 m of a vegetation sampling plot represents a patch, and a patch was used if one or more observations occurred within it. Distance is distance to cavity tree cluster. Other variables defined in Table 1.1

Variable	Estimate	St Error	Chi-Square	P-value
Small pines	0.000	0.000	0.2	0.669
Medium pines	0.003	0.002	2.9	0.088
Large pines	0.007	0.003	3.9	0.047
Small hardwoods	0.002	0.003	0.5	0.459
Large hardwoods	-0.01	0.017	0.4	0.548
Herbaceous groundcover	0.01	0.004	5.5	0.019
Midstory height	0.002	0.034	0.0	0.946
Age	-0.006	0.006	0.9	0.342
Distance	-0.002	0.000	23.0	0.001

Model fitting statistics: n = 453, X2 = 44.2, df = 4, P < 0.0001

Percent concordant: 67.8, percent disconcordant: 31.9

Table 1.6. Relationships of stand use to habitat characteristics in the best model. Best reduced model chosen using the AIC statistic. Stands were management units defined by Camp Lejeune; in unmanaged areas, stands were uniform forested areas as identified using GIS and color and infrared photography. Stand use was number of foraging observations per stand/stand area within the home range. Distance is distance to cavity tree cluster. Other variables defined in Table 1.1

Variable	Estimate	St Error	T-value	P-value
Large pines	0.010	0.007	1.4	0.152
Small hardwoods	-0.008	0.005	-1.8	0.067
Herbaceous groundcover	0.045	0.01	4.3	0.001
Distance	-0.004	0.001	-5.5	0.001

$F_{4, 155}$ = 16.3, P = 0.0001, adj R^2 = 0.28, n = 156

Table 1.7. Relationships of stand use to habitat characteristics in the full model. Stands were management units defined by Camp Lejeune; in unmanaged areas, stands were uniform forested areas as identified using GIS and color and infrared photography. Stands use was number of foraging observations per stand/stand area within the home range. Distance is distance to cavity tree cluster. Other variables defined in Table 1.1

Variable	Estimate	St Error	T-value	P-value
Small pines	0.000	0.001	0.3	0.788
Medium pines	0.005	0.005	1	0.318
Large pines	0.01	0.008	1.3	0.192
Small hardwoods	-0.01	0.005	-1.8	0.067
Large hardwoods	0.019	0.051	0.4	0.713
Herbaceous groundcover	0.047	0.011	4.1	<0.001
Midstory height	0.036	0.097	0.4	0.71
Age	0.001	0.019	0.1	0.938
Distance	-0.004	0.001	-5.4	<0.001

$F_{9, 153} = 7.48$, P = 0.0001, adj $R^2 = 0.28$, n = 154

Table 1.8. Relationships of mean group size (1996-2001) to habitat characteristics in the best model. Best model chosen with the AIC statistic. Values for habitat characteristics are the mean of plot values within each home range. See Table 1.1 and text for definitions of variables.

Variable	Estimate	St Error	T-value	P-value
Medium pines	-0.027	0.008	-3.4	0.003
Small hardwoods	-0.022	0.079	-2.8	0.014
Herbaceous groundcover	0.044	0.014	3.9	0.001
Age	0.034	0.029	1.3	0.213
Home range size	0.020	0.006	3.2	0.006
Unsuitable habitat	-0.017	0.015	-1.7	0.104
Local population density	0.278	0.116	2.4	0.030

$F_{7, 22} = 5.8$, P = 0.002, adj $R^2 = 0.60$, n = 23

Table 1.9. Relationships of mean group size (1996-2001) to habitat characteristics in the full model. Values for habitat characteristics are the mean of plot values within each home range. See Table 1.1 and text for definitions of variables.

Variable	Estimate	St Error	T-value	P-value
Small pines	0.000	0.002	-0.2	0.817
Medium pines	-0.028	0.011	-2.6	0.023
Large pines	-0.004	0.012	-0.3	0.751
Small hardwoods	-0.009	0.012	-0.8	0.457
Large hardwoods	-0.143	0.133	-1.1	0.304
Herbaceous groundcover	0.057	0.021	2.7	0.021
Midstory height	0.016	0.148	0.1	0.914
Age	0.028	0.040	0.7	0.492
Home range size	0.021	0.008	2.7	0.019
Unsuitable habitat	-0.028	0.018	-1.6	0.144

$F_{10, 22}$ = 2.4, P = 0.073, adj R^2 = 0.39, n = 23

Table 1.10. Relationships of mean fledgling production (1996-2001) to habitat characteristics in the best model. Best model chosen using the AIC statistic. Values for habitat characteristics are the mean of plot values within each home range. See Table 1.1 and text for definitions of variables.

Variable	Estimate	St Error	T-value	P-value
Medium pines	-0.019	0.006	-3	0.01
Big pines	0.015	0.007	2.2	0.047
Large hardwoods	-0.158	0.057	-2.8	0.016
Herb groundcover	0.027	0.012	2.3	0.036
Midstory height	-0.159	0.083	-1.9	0.075
Home range size	0.02	0.005	4.3	0.001
Unsuitable habitat	-0.026	0.011	-2.3	0.035
Local population density	0.231	0.099	2.3	0.035

$F_{8, 22}$ = 4.2, P = 0.009, adj R^2 = 0.54, n = 23

Table 1.11. Relationships of mean fledgling production (1996-2001) to habitat characteristics to in the full model. Values for habitat characteristics are the mean of plot values within each home range. See Table 1.1 and text for definitions of variables.

Variable	Estimate	St Error	T-value	P-value
Small pines	0.000	0.001	0.0	0.997
Medium pines	-0.010	0.01	-1.1	0.307
Large pines	0.011	0.009	1.2	0.246
Small hardwoods	0.015	0.889	1.7	0.125
Large hardwoods	-0.209	0.1	-2.1	0.06
Herbaceous groundcover	0.019	0.019	1	0.347
Midstory height	-0.128	0.106	-1.2	0.256
Age	-0.007	0.029	-0.2	0.825
Home range size	0.014	0.007	2	0.075
Unsuitable habitat	-0.023	0.014	-1.7	0.122
Group size	0.307	0.207	1.5	0.166

$F_{11, 22}$ = 2.4, P = 0.079, adj R^2 = 0.42, n = 23

Table 1.12. Relationships of home range size to habitat characteristics to in the best model. Best model chosen using the AIC statistic. Home range size was the 95% kernel home range, calculated using the Animal Movement Extension for Arcview. Values for habitat characteristics are the mean of plot values within each home range. See Table 1.1 and text for definitions of variables.

Variable	Estimate	St Error	T-value	P-value
Medium pines	0.455	0.281	1.6	0.124
Small hardwoods	0.603	0.285	2.1	0.05
Herbaceous groundcover	-1.613	0.348	-4.6	0.001
Unsuitable habitat	1.465	0.381	3.9	0.001
Group size	13.871	6.042	2.3	0.035

$F_{5, 22}$ = 7.44, P = 0.001, adj R = 0.59, n = 23

Table 1.13. Relationships of to home range size to habitat characteristics in the full model. Home range size was the 95% kernel home range, calculated using the Animal Movement Extension for Arcview. Values for habitat characteristics are the mean of plot values within each home range. See Table 1.1 and text for definitions of variables.

Variable	Estimate	St Error	T-value	P-value
Small pines	0.023	0.059	0.4	0.704
Medium pines	0.646	0.336	1.9	0.079
Large pines	-0.211	0.421	-0.5	0.625
Small hardwoods	0.569	0.417	1.4	0.198
Large hardwoods	1.087	4.223	0.3	0.801
Herb groundcover	-1.886	0.477	-4	0.002
Midstory height	-3.238	4.618	-0.7	0.497
Age	-1.050	1.415	-0.7	0.472
Unsuitable habitat	1.410	0.434	3.3	0.007
Group size	15.674	7.637	2.1	0.063

$F_{10, 22} = 3.46$, $P = 0.023$, adj $R^2 = 0.53$, $n = 23$

Table 1.14. Summary of variables included in best models, as chosen by the AIC statistic. See Table 1.1 and text for definitions of variables. + indicates positive relationship. – indicates negative relationship. Absence of symbol indicates variable was not present in the best model.

	Dependent variables				
Independent variables	Group Size	Fledgling Productivity	Stand Use	Patch Use	Home Range Size
Small pines					
Medium pines	-	-		(+)	(+)
Large pines		+	(+)	+	
Small hardwoods	-		(-)		+
Large hardwoods		-			
Herbaceous groundcover	+	+	+	+	-
Midstory height		(-)			
Age	(+)				
Home range size	+	+			
Unsuitable habitat	(-)	-			+
Group size					+
Distance			-	-	
Local population density	+	+			

= variable not tested

( ) = included in best model but not significant at 0.05

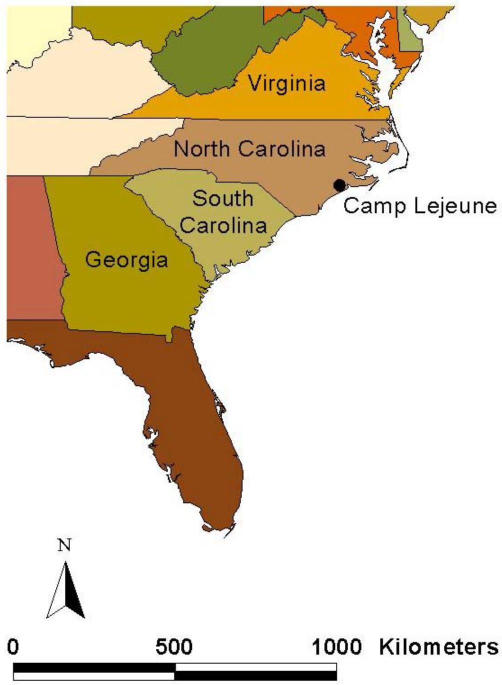

Figure 1.1. Location of Camp Lejeune Marine Base, North Carolina.

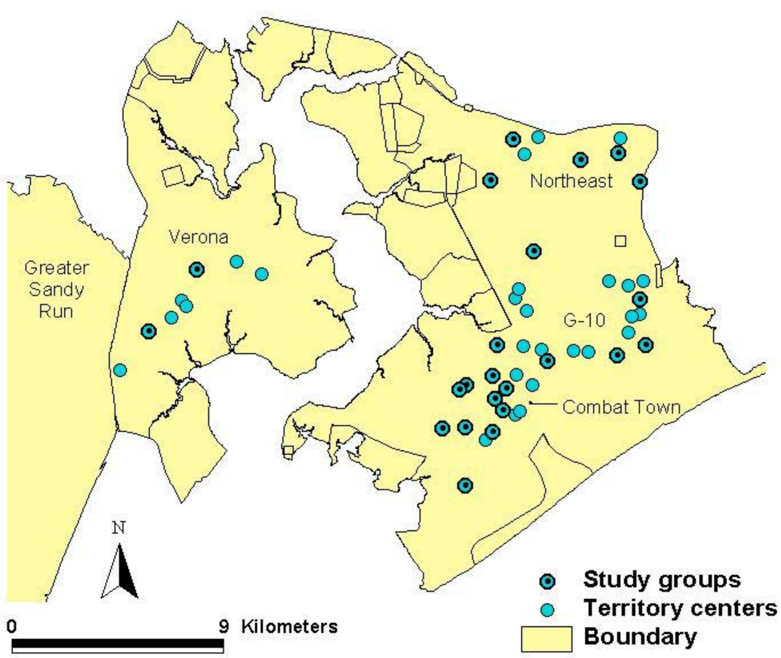

Figure 1.2. Distribution of red-cockaded woodpecker groups on Camp Lejeune Marine Base in 1999. Emphasis added to 23 study groups.

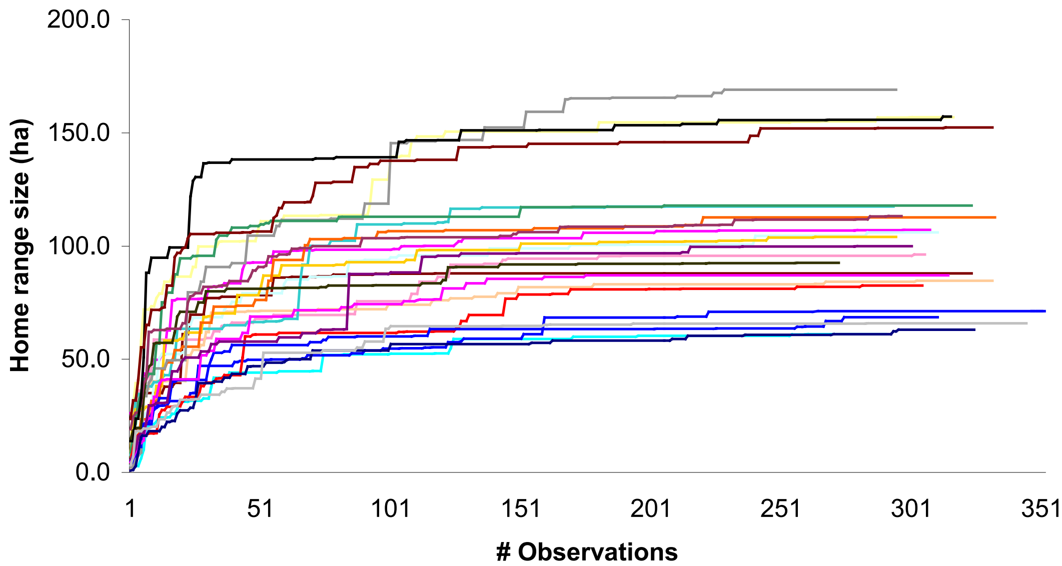

Figure 1.3. Estimated MCP home range size as a function of sampling effort for 23 study groups. Effort varied from 276 to 355 observations with mean of 316. Observations randomized prior to analysis to account for seasonal variation in home range size. See Table 1.2 for the number of observations for individual groups.

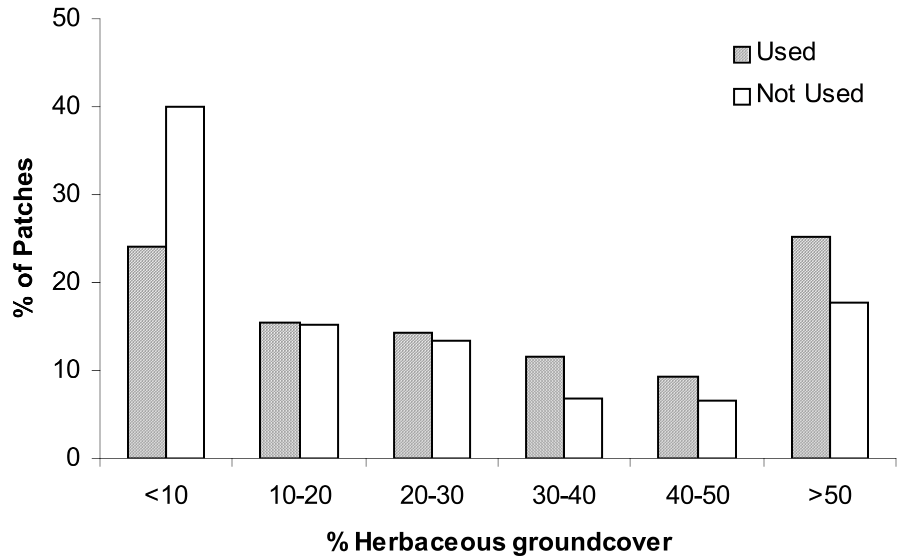

Figure 1.4. Percent of patches used and not used as a function of % herbaceous vegetation in the groundcover. The area within 25 m of a vegetation sampling plot represents a patch, and a patch was used if one or more observations occurred within it. N = 490.

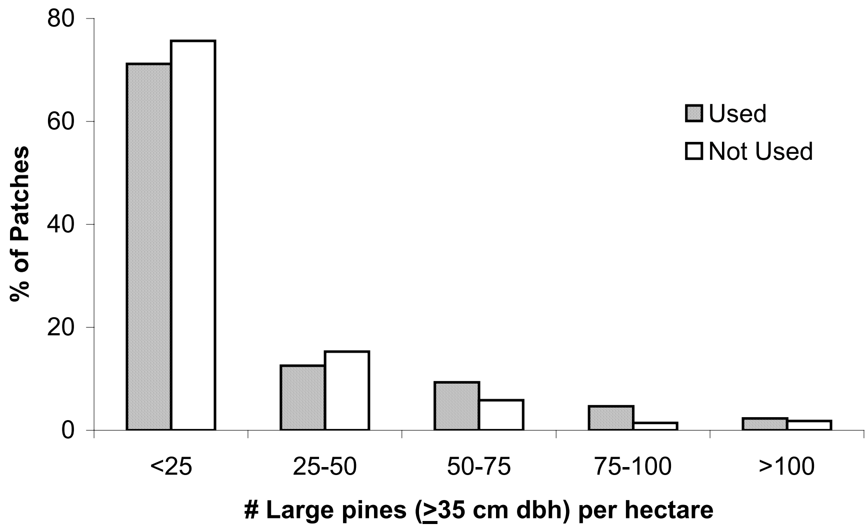

Figure 1.5. Percent of patches used and not used as a function of the density of large pines (≥35.6 cm dbh) per hectare. The area within 25 m of a vegetation sampling plot represents a patch, and a patch was used if one or more observations occurred within it. N = 490.

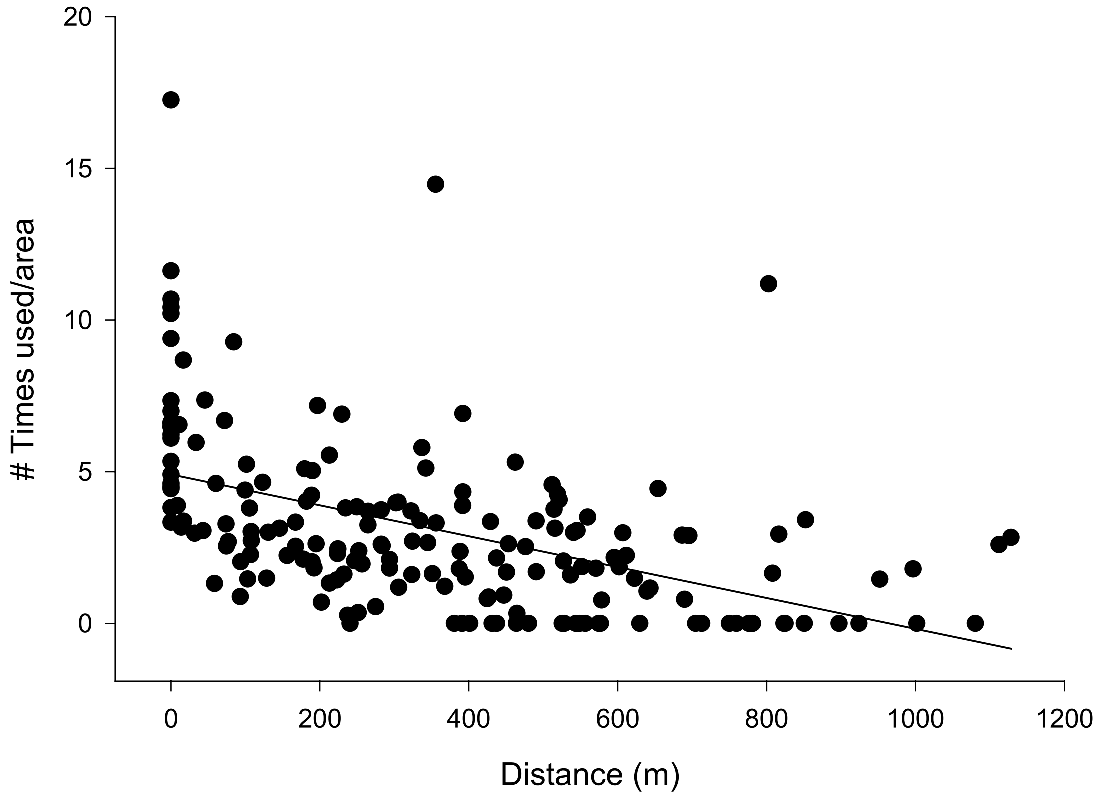

Figure 1.6. Relationship between stand use and distance to the nearest cluster tree center. Stand use was the number of times used divided by the area of the stand within the home range. Distance was computed as the linear distance in meters from each stand boundary to the nearest cluster center. Cluster centers were calculated as the arithmetic mean of the cavity tree universal transmercator (UTM) coordinates for each group in 1999.

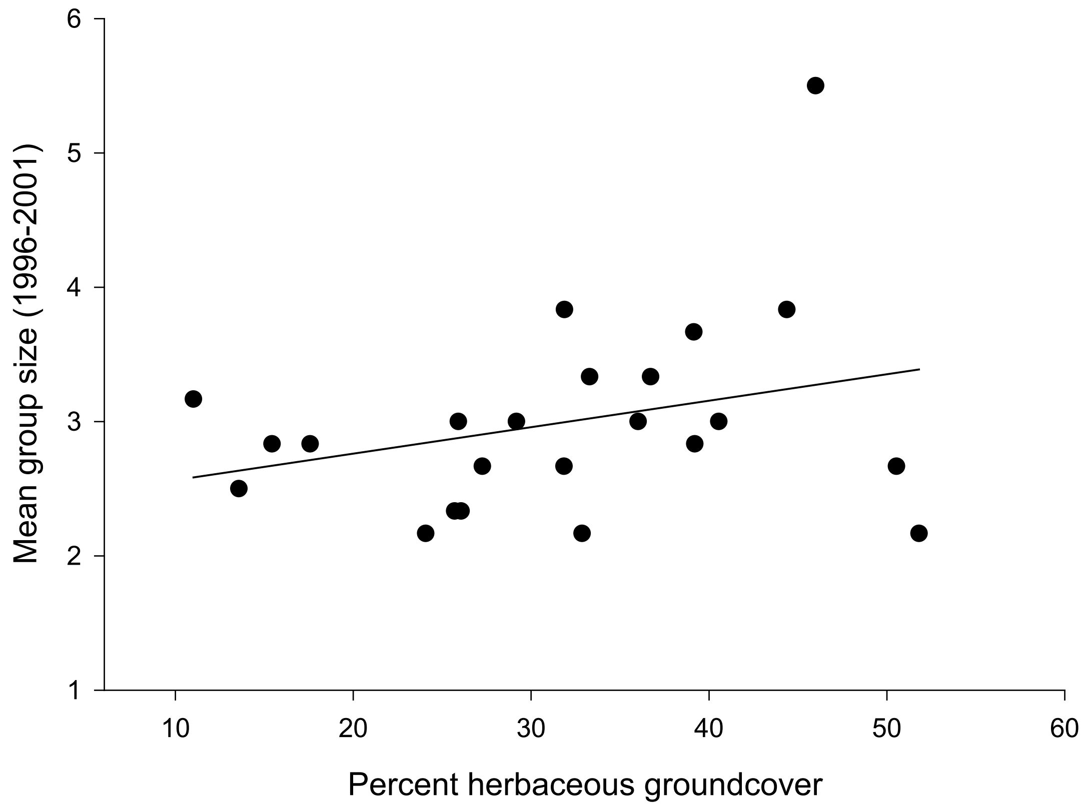

Figure 1.7. Relationship between mean group size and percent herbaceous groundcover. Values for percent herbaceous groundcover were the mean of plot values within each home range.

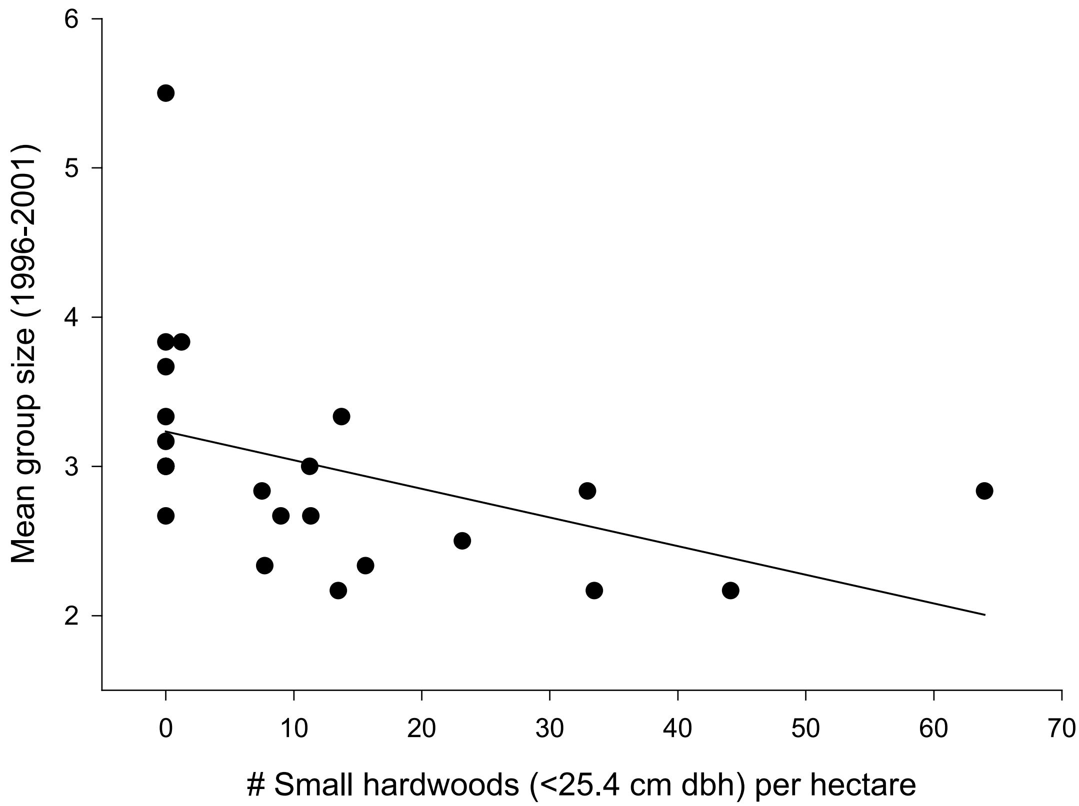

Figure 1.8. Relationship between mean group size and density of small hardwoods (<25.4 cm dbh) within 23 home ranges. Values for density of small hardwoods were the mean of plot values within each home range. Home range size was the 95% fixed kernel home range, calculated using the Animal Movement Extension for Arcview GIS.

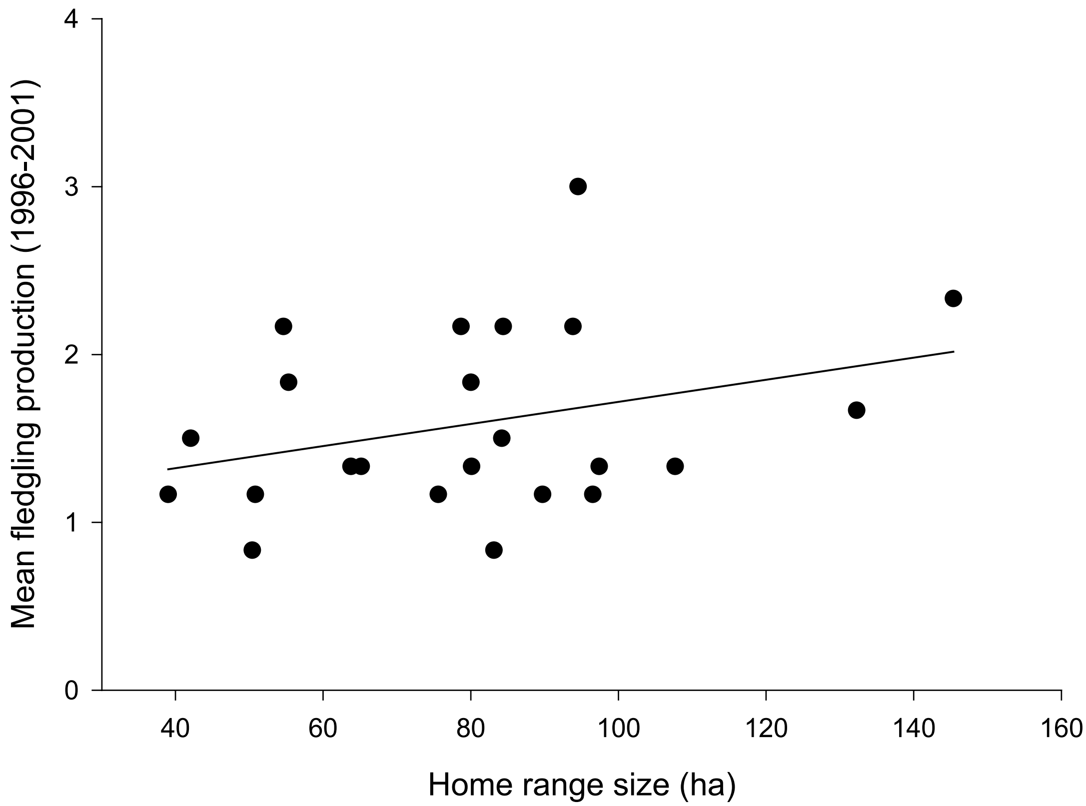

Figure 1.9. Relationship between mean fledgling production and home range size and for 23 study groups. Home range size was the 95% fixed kernel home range, calculated using the Animal Movement Extension for Arcview.

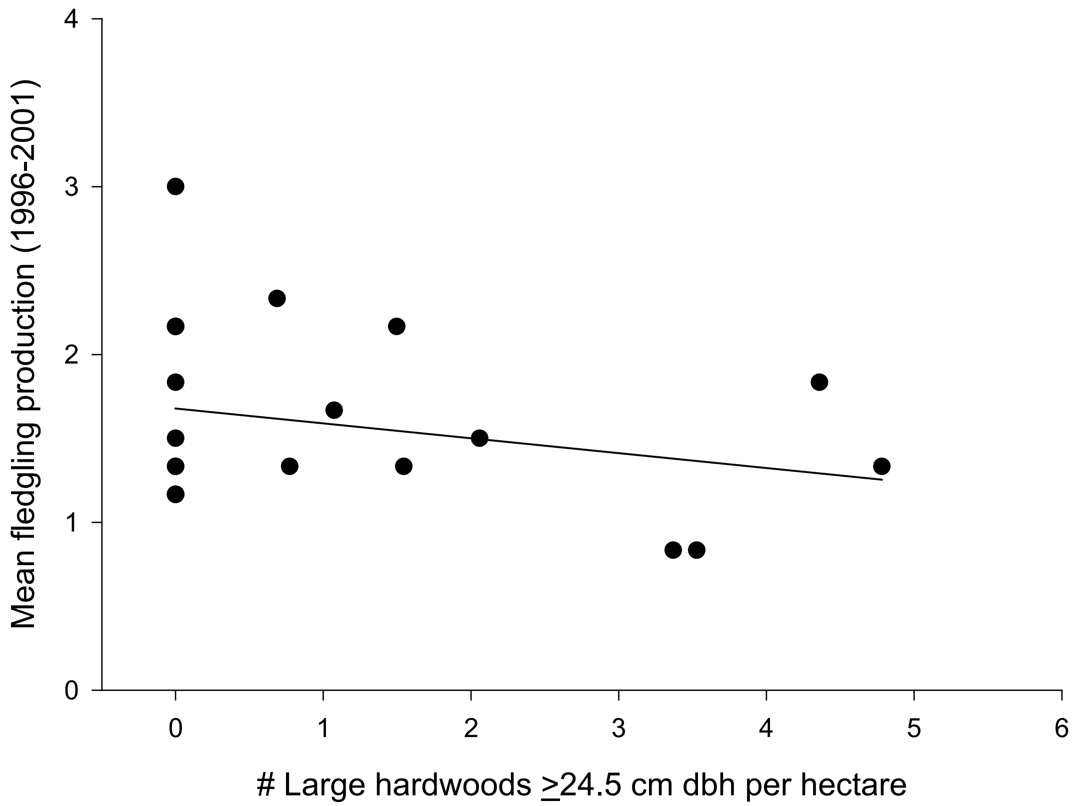

Figure 1.10. Relationship between mean fledgling production and the density of large hardwoods (≥25.4 cm dbh) within 23 home ranges. Values for density of large hardwoods were the mean of plot values within each home range. Home range size was the 95% fixed kernel home range, calculated using the Animal Movement Extension for Arcview GIS.

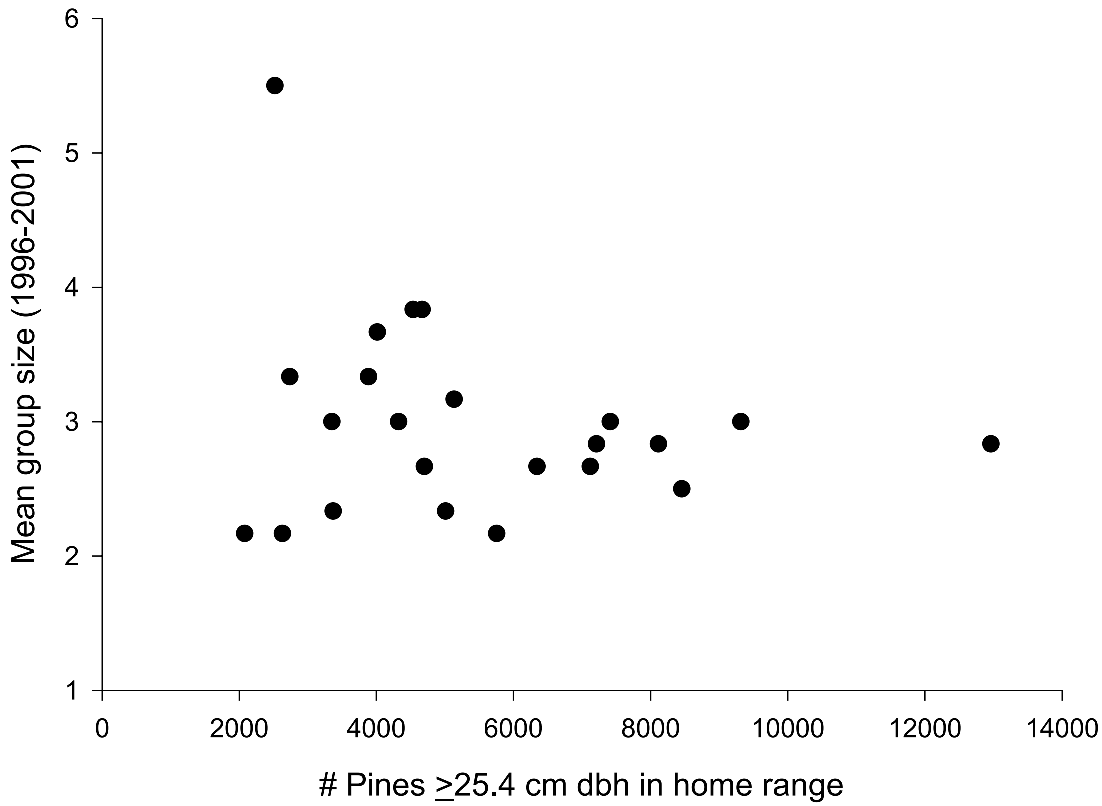

Figure 1.11. Relationship between mean group size a traditional measure of habitat quality (# pines ≥25.4 cm dbh within home range) for 23 study groups at Camp Lejeune, NC. Number of pines calculated as the mean of plot values within each home range multiplied by the area of the home range excluding unsuitable habitat. Unsuitable habitat was defined as unforested areas, forested areas <30 years of age and representative dbh <17.8 cm (7 inches) or dominated by hardwoods. Home range size was the 95% fixed kernel home range, calculated using the Animal Movement Extension for Arcview GIS.

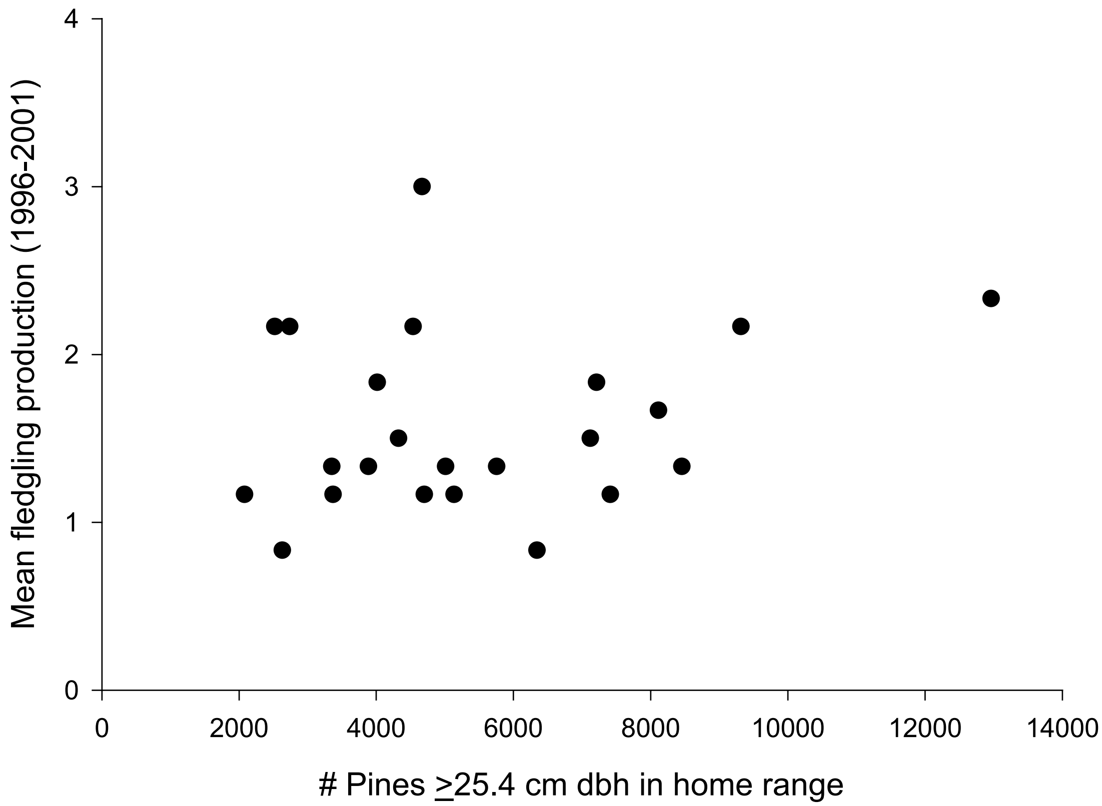

Figure 1.12. Relationship between fledgling production and a traditional measure of habitat quality (# pines ≥25.4 cm dbh within home range) for 23 study groups at Camp Lejeune, NC. Number of pines calculated as the mean of plot values within each home range multiplied by the area of the home range excluding unsuitable habitat. Unsuitable habitat was defined as unforested areas, forested areas <30 years of age and representative dbh <17.8 cm (7 inches) or dominated by hardwoods. Home range size was the 95% kernel home range, calculated using the Animal Movement Extension for Arcview GIS

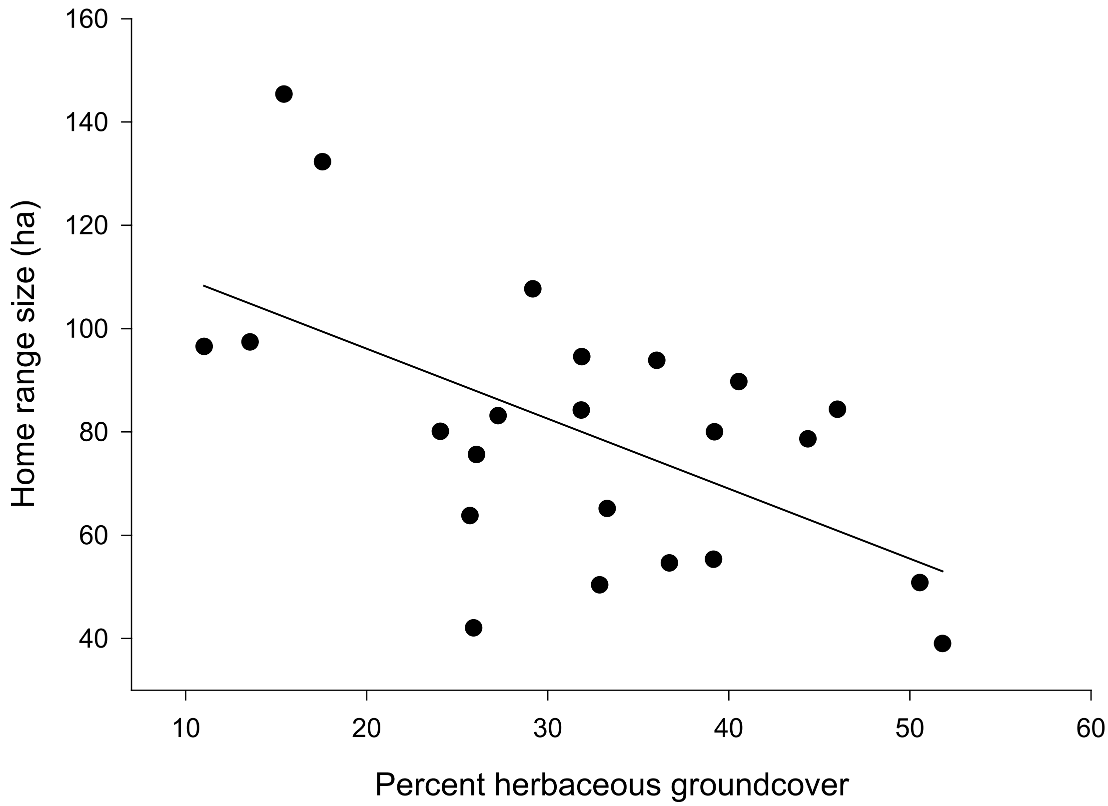

Figure 1.13. Relationship between home range size and percent herbaceous groundcover within the home range. In a simple linear regression, groundcover is a significant variable ($F = 10.2$, $P<0.004$, adj $R^2=0.30$). Groundcover was calculated as the mean of all plots within each home range.

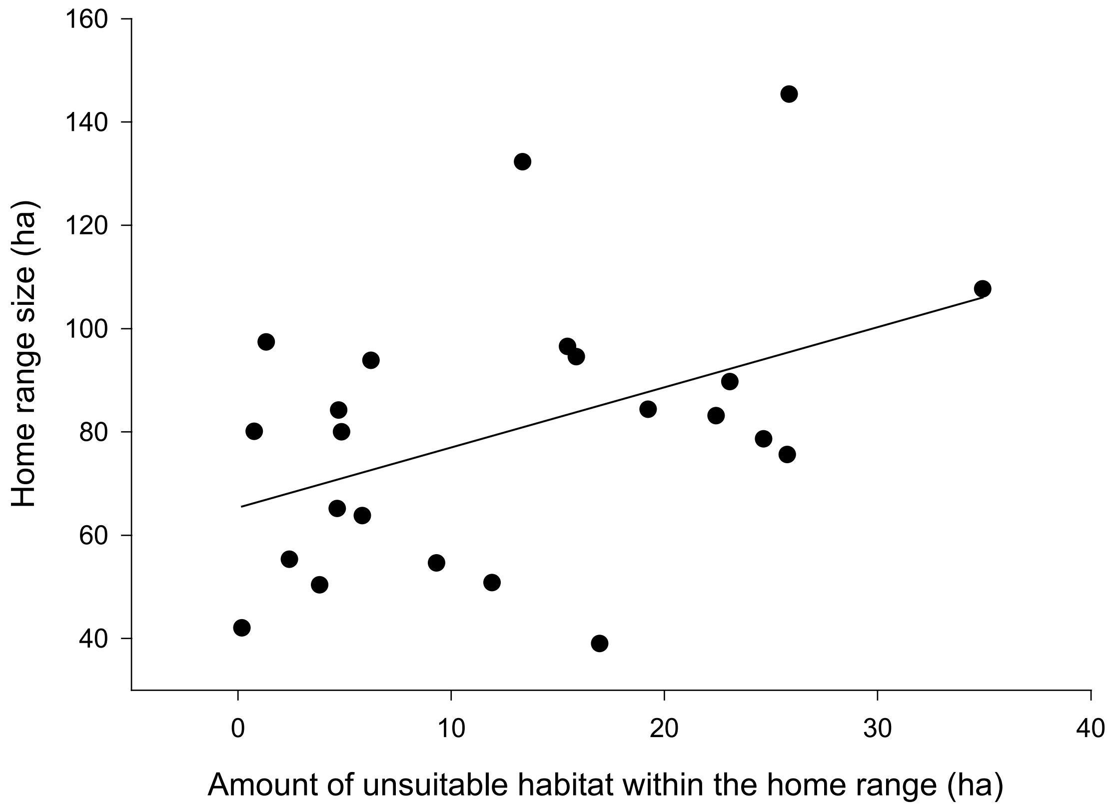

Figure 1.14. Relationship between home range size and unsuitable habitat within the home range size. Unsuitable habitat was defined as unforested areas, forested areas <30 years of age with representative dbh <17.8 cm (7 inches) or forested areas dominated by hardwoods.

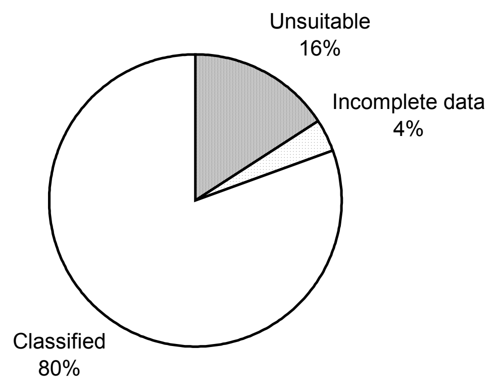

Figure 1.15. Assessment of habitat (area) within 23 estimated kernel home ranges. Stands were classified based on the number of characteristics meeting the definition of 'good' quality in the USFWS Red-cockaded Woodpecker Recovery Plan (see Figure 1.16). Stands missing one or more data elements were not classified. Unsuitable habitat was defined as unforested areas, forested areas <30 years of age and representative dbh <17.8 cm (7 inches) or forested areas dominated by hardwoods.

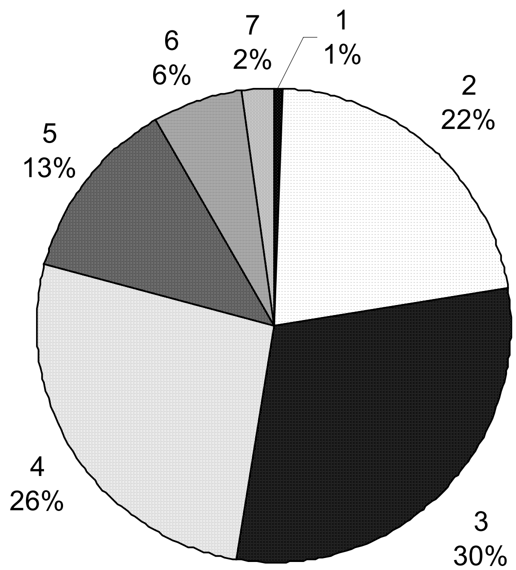

Figure 1.16. Percentage of forest inventory points in compliance with 1-7 characteristics, respectively, of 'good' quality habitat described in the new Red-cockaded Woodpecker Recovery Plan. N = 453. See Table 1.1 for a description of characteristics. Excludes unsuitable habitat, defined as unforested areas, forested areas <30 years of age and representative dbh <17.8 cm (7 inches) or forested areas dominated by hardwoods. Also excludes 9% of points due to missing data.

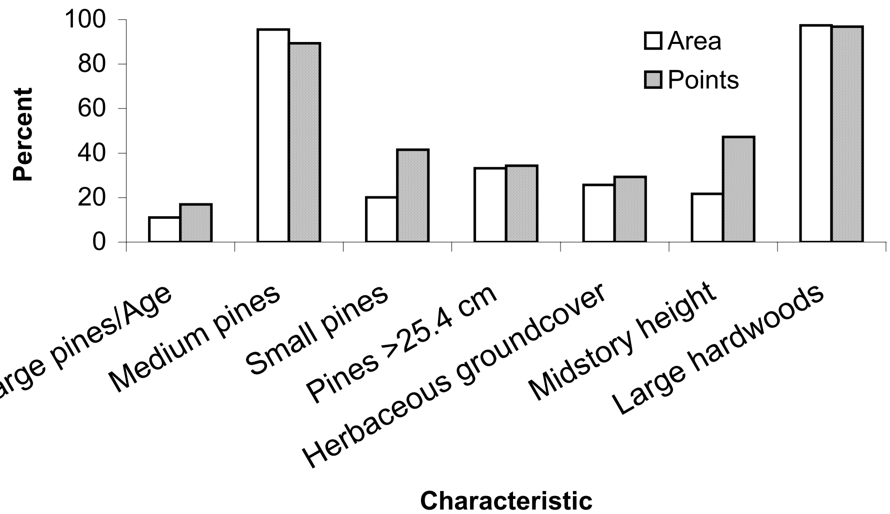

Figure 1.17. Percentage of forest inventory points and area in compliance with each of 7 characteristics of good quality foraging habitat described in the new Red-cockaded Woodpecker Recovery Plan. See Table 1.1 for a description of characteristics. Area represents the area within the estimated kernel home ranges of 23 study groups; points are 453 inventory points within the same home ranges. Both scales exclude unsuitable habitat, defined as unforested areas, forested areas <30 years of age and representative dbh <17.8 cm or forested areas dominated by hardwoods. Four percent of stand area and 9% of points were excluded from this analysis because of missing data.

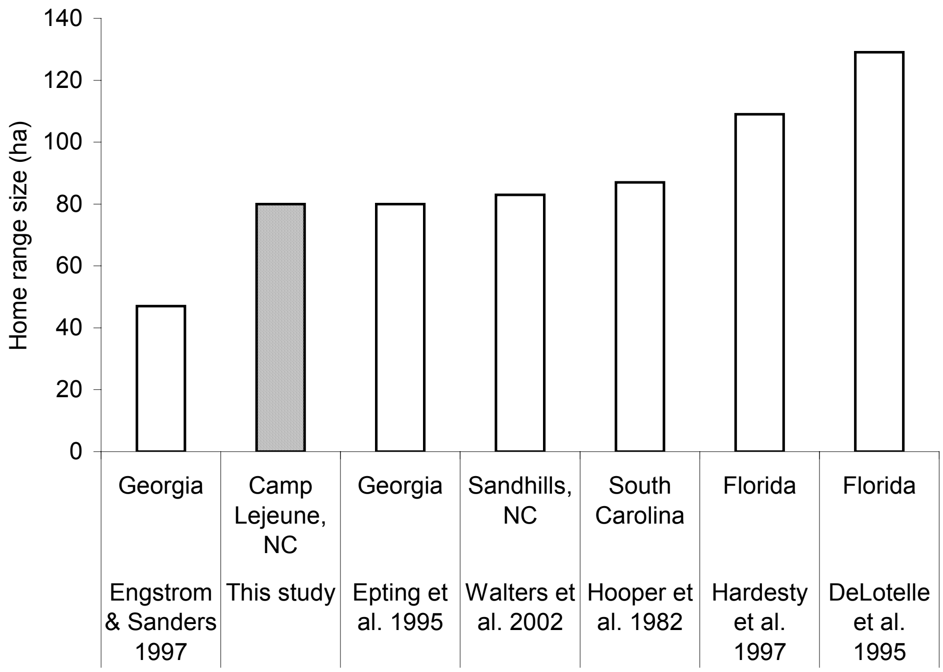

Figure 1.18. Home range size at Camp Lejeune compared to other populations. Methods used to compute home range may differ. See text for details.

Appendix I. Mean (± SE) habitat values for 23 home ranges, calculated by averaging forest inventory plots within each home range.

Group	Small pines (<25.4 cm dbh)/ha	Medium pines (25.4-35.6 cm dbh)/ha	Large pines (≥35.6 cm dbh)/ha	Small hardwoods (<25.4 cm dbh)/ha	Large hardwoods (≥25.4 cm dbh)/ha	% Herbaceous groundcover	Midstory height (m)	Age (yrs)
1	255.7	39.5	19.8	1.2	0.0	31.9	2.0	58.7
2	96.1	43.9	16.5	13.7	0.0	36.7	1.3	60.6
3	155.7	59.3	4.9	0.0	0.0	33.3	4.0	71.4
4	135.9	68.8	7.1	0.0	0.0	39.2	2.6	59.6
7	120.3	65.9	18.1	0.0	0.0	44.4	3.0	65.4
8	246.0	40.4	5.6	0.0	0.0	29.2	2.2	58.8
9	131.3	54.8	8.5	0.0	0.0	11.0	3.9	61.8
10	321.2	67.4	27.0	13.5	0.0	51.8	4.7	60.8
11	134.0	48.1	19.5	15.6	0.0	26.1	5.3	57.4
14	416.8	32.1	6.6	0.0	0.0	46.0	3.7	63.0
18	92.0	76.9	34.3	0.0	0.0	40.6	1.7	57.9
19	71.9	55.0	49.4	9.0	3.4	27.3	4.3	60.4
20	133.3	65.1	41.2	11.2	1.5	36.0	3.3	57.2
22	112.6	93.3	27.5	0.0	0.0	50.5	1.8	66.8
33	147.5	56.4	31.7	23.2	0.8	13.6	4.9	60.3
35	127.3	46.7	21.5	7.5	1.1	17.6	4.4	61.3
39	67.8	51.0	21.5	33.5	4.8	24.1	2.3	66.2
42	140.5	46.3	40.2	7.7	1.5	25.7	4.0	55.7
43	132.3	64.7	31.3	64.0	4.4	39.2	3.8	57.2
44	100.9	72.8	35.7	32.9	0.7	15.4	4.3	62.1
46	197.7	47.7	8.8	44.1	3.5	32.9	2.6	61.5
47	474.6	68.0	21.6	11.3	2.1	31.8	4.0	55.8
48	67.4	47.2	56.2	0.0	0.0	25.9	4.3	63.3
Mean (± SE)	168.6 (22.4)	57.0 (3.0)	24.1 (3.0)	12.5 (3.5)	1.0 (0.3)	31.7 (2.3)	3.4 (0.2)	61.0 (0.8)

Grand totals may differ slightly from Table 1.4 because some forest inventory points are in multiple home ranges.

Appendix II. Amount (ha) and quality of foraging habitat within the 95% kernel home ranges of 23 study groups. All Stands with $\geq$4 characteristics are listed and the missing elements are identified; areas with <4 elements are grouped. * areas with incomplete data, ** unsuitable habitat = unforested areas, forested areas <30 years of age and representative dbh <17.8 cm or dominated by hardwoods. Compartment 101 and stands therein represent forested areas not managed for timber, such as the G-10 impact area. These areas were delineated from aerial photos, as described in the text. Characteristics are described in Table 1.1.

				Missing characteristic								
CI	Compartment #	Stand #	# Characteristics	a	b	c	d	e	f	g		Area (ha)
1	44	4	6					X				4.5
1	33	4	4	X		X	X					20.5
1	34	6	4	X			X		X			7.5
1	44	2	4	X		X	X					10.5
1			3									22.9
1			2									6.1
1			*									6.6
1			**									15.9
											Total	94.5
2	33	1	4	X		X	X					21.9
2			3									20.6
2			*									2.7
2			**									9.3
											Total	54.6
3	45	7	4	X			X	X				2.1
3			3									43.4
3			2									14.7
3			*									0.3
3			**									4.7
											Total	65.1

Appendix II continued.

				Missing characteristic								
CL	Compartment #	Stand #	# Characteristics	a	b	c	d	e	f	g		Area (ha)
4	33	6	4	X		X	X					6.7
4			3									45.5
4			*									0.7
4			**									2.4
											Total	55.3
7			3									28.7
7			2									13.3
7			*									4.3
7			**									24.6
											Total	126.3
8	44	8	4	X			X	X				6.0
8	45	5	4	X		X	X					4.9
8	45	61	4	X		X	X					3.2
8			3									15.9
8			2									36.9
8			*									5.9
8			**									34.9
											Total	107.7

Appendix II continued.

				Missing characteristic								
CL	Compartment #	Stand #	# Characteristics	a	b	c	d	e	f	g		Area (ha)
9			3									3.6
9			2									72.2
9			*									5.3
9			**									15.4
											Total	96.5
10	44	14	4	X		X	X					2.8
10	44	16	4	X		X			X			9.0
10	44	63	4	X		X	X					1.4
10			3									2.2
10			*									6.6
10			**									17.0
											Total	39.0
11	44	63	4	X		X	X					2.1
11			3									14.9
11			2									22.9
11			*									9.8
11			**									25.8
											Total	211.1

Appendix II continued.

CL	Compartment #	Stand #	# Characteristics	Missing characteristic a	b	c	d	e	f	g		Area (ha)
14			3									40.2
14			2									21.0
14			*									3.9
14			**									19.2
											Total	84.4
18	24	1	5	X		X						41.3
18			3									17.0
18			2									0.8
18			*									7.5
18			**									23.1
											Total	89.7
19	19	3	6						X			13.1
19	18	7	5	X			X					0.7
19	20	14	4	X				X	X			15.9
19	20	24	4	X				X	X			3.5
19			3									16.6
19			2									5.8
19			*									5.2
19			**									22.4
											Total	83.1

Appendix II continued.

				Missing characteristic								
CL	Compartment #	Stand #	# Characteristics	a	b	c	d	e	f	g		Area (ha)
20	6	7	4	X		X	X					3.7
20	21	5	4			X		X	X			1.9
20			3									52.9
20			2									14.8
20			*									1.6
20			**									6.2
											Total	338.4
22	5	15	4	X		X	X					19.9
22	5	19	4			X		X	X			0.1
22	22	20	4	X	X	X						6.3
22			3									6.9
22			2									5.7
22			*									0.0
22			**									11.9
											Total	50.8
33	26	13	4			X		X	X			7.1
33	26	20	4			X		X	X			22.5
33			3									24.4
33			2									38.3
33			*									3.8
33			**									1.3
											Total	97.4

Appendix II continued.

				Missing characteristic								
CL	Compartment #	Stand #	# Characteristics	a	b	c	d	e	f	g		Area (ha)
35			3									54.0
35			2									64.9
35			**									13.3
											Total	132.3
39	55	23	4	X			X	X				7.6
39	101	6	4	X		X		X				8.3
39			3									13.8
39			2									24.9
39			1									1.7
39			*									8.2
39			**									0.8
											Total	426.9
42	51	8	4	X				X	X			8.8
42			3									32.2
42			2									16.6
42			*									0.3
42			**									5.8
											Total	63.8

Appendix II continued.

CL	Compartment #	Stand #	# Characteristics	Missing characteristic								Area (ha)
				a	b	c	d	e	f	g		
43	99	1	6					X				6.7
43	101	9	5	X			X					3.4
43	32	16	4	X			X		X			12.7
43	32	17	4	X		X			X			3.8
43	32	18	4					X	X	X		1.1
43	32	32	4	X		X			X			5.1
43			3									33.0
43			2									0.1
43			1									8.9
43			*									0.4
43			**									4.9
											Total	80.0
44	7	16	5	X				X				9.2
44	7	5	4			X		X	X			62.1
44	7	19	4	X		X	X					0.9
44			3									22.0
44			2									18.9
44			**									25.8
											Total	218.9

Appendix II continued.

				Missing characteristic								
CL	Compartment #	Stand #	# Characteristics	a	b	c	d	e	f	g		Area (ha)
46			3									1.9
46			2									26.8
46			*									17.9
46			**									3.8
											Total	50.4
47	5	9	7									15.3
47	5	2	5			X			X			0.3
47	6	4	4	X			X	X				2.6
47			3									15.1
47			2									46.2
47			**									4.7
											Total	84.2
48	33	6	6					X				0.6
48	33	10	6					X				2.3
48	34	4	5					X	X			14.8
48	34	3	4	X				X	X			15.2
48			2									8.9
48			*									0.2
48			**									0.2
											Total	42.0

Appendix III. Summary of principal components analysis of 8 habitat variables.

Eigenvalues and variance

Axis	Eigenvalue	Variance (%)
1	1.567	19.59
2	1.473	18.41
3	1.088	13.6
4	0.938	11.73
5	0.877	10.96
6	0.813	10.16
7	0.697	8.71
8	0.549	6.86

First 5 factors (eigenvectors). Values represent factor loadings

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Small pines	-0.02	-0.798	-0.121	0.08	0.166
Medium pines	-0.007	0.226	-0.757	0.448	-0.314
Large pines	0.260	0.564	-0.061	0.262	0.643
Small hardwoods	0.663	-0.019	0.081	0.390	-0.153
Large hardwoods	0.518	0.042	0.537	0.201	-0.371
Herbaceous groundcover	-0.523	-0.024	0.412	0.558	0.226
Midstory height	0.705	-0.127	-0.129	-0.252	0.319
Age	-0.140	0.670	0.122	-0.307	-0.151

2. Red-cockaded Woodpecker Home Ranges and Foraging Partitions

INTRODUCTION

Recovery of the endangered red-cockaded woodpecker requires sound management based on thorough knowledge of the species biology. Researchers have developed an understanding of nesting requirements, and have developed management tools based on this understanding that have stabilized or reversed downward population trends (Walters 1991, Costa and Walker 1995, U.S. Fish and Wildlife Service 2003). Long-term success, however, will require an equally thorough knowledge of the species foraging requirements. Researchers are beginning to understand the structural components of foraging habitat that affect red-cockaded woodpecker fitness (James et al. 1997, James et al. 2001, Walters et al. 2002), but allocating high quality foraging habitat to individual groups poses some logistical problems. In this study, I assessed how well the USFWS method to allocate habitat to individual groups succeeds in protecting habitat birds actually use.

Ideally, the allocation of habitat should be based on the results of home range follows, but this is rarely done because of the extensive time and resources required. Instead, the U.S. Fish and Wildlife Service recommends the use of "foraging partitions." For geographically isolated groups, foraging partitions delineate habitat within 0.8 km (0.5 mi) of the cluster center and are simply represented by a circle (Figure 2.1). In situations where two or more groups exist <1.6 km from one another, and circular partitions would otherwise overlap, thiessen polygons (hereafter thiessen partitions) are used to describe the area assigned to each group, so that no habitat is shared between groups (Figure 2.2) (Lipscomb and Williams 1996). Ostensibly, partitions serve to help provide suitable quantity and quality of foraging habitat and to buffer groups from deleterious land use practices. Some timber extraction and other potentially harmful activities, however, are permitted, so long as 49 ha of good quality habitat remains within the partition (U.S. Fish and Wildlife Service 2003). The partition approach seems reasonable enough and provides managers with the ability to easily delimit potential red-cockaded woodpecker habitat boundaries. But, aside from the fact that red-cockaded woodpeckers are limited in the distance they forage from the cluster center, there is little evidence to show that these partitions accurately represent the actual habitat used by foraging red-cockaded woodpeckers.

To address this issue, I conducted home range follows of 23 groups of red-cockaded woodpecker's at Camp Lejeune Marine Corps Base, NC, and estimated the percentage of each home range encompassed by partitions of varying radii. In doing so, I assessed how well the USFWS method to allocate habitat to individual groups reflects actual habitat used by foraging red-cockaded woodpeckers. Furthermore, I assessed the relationship between habitat quality and partition radius by identifying trends in habitat composition as a function of partition radius.

METHODS

Study area and population

Camp Lejeune is located in Onslow County in eastern North Carolina (Figure 2.3), and occupies 61,110 ha within the southern Atlantic Coastal Plain (Anonymous 1996). Home of the 2nd Marine Expeditionary Force, its primary purpose is military training, including infantry operations, helicopter operations, firing range operations, and other training and support activities (Anonymous 1996). The Marine Corps manages the base for red-cockaded woodpeckers in compliance with the Endangered Species Act of 1973. Management of red-cockaded woodpeckers at Camp Lejeune has been a great success. Up from only 27 groups in 1991, the population had increased to 62 groups by 2001. This growth can be attributed in large part to intensive cavity tree management designed to prevent territory abandonment and to create new territories (Walters 2003).

I selected 23 of the 50 groups present at the beginning of the study (year 1999) for analyses. Because military activity prevented the random selection of study groups and limited the number of potential study groups, I chose groups based on historic (1994-1998) group size and productivity, so that the study would include some historically large and relatively productive groups, some historically small and relatively unproductive groups, and groups of intermediate size and productivity.

Data collection

Foraging observations and home range estimation.--

Each of 23 groups was followed approximately 1 day per month from August 2000 through March 2001 (one non-breeding cycle), for a total of 8 follows. Due to logistical difficulties the 8^{th} and final follow for 2 groups was delayed until September 2001. Follows were not conducted during the egg laying, incubation, and early fledgling stages (May-July) because groups typically forage in close proximity to the cluster area during these stages. A follow consisted of sustained contact with the group, beginning shortly after sunrise (usually 10-30 minutes) and continuing for 8 hours or until contact with the birds was lost, or the follow was terminated due to inclement weather or military activity.

For a follow to be considered complete, and thus included in analyses, a minimum of 5 hours of data must have been collected, and follows <5 hours were repeated until at least 5 hours could be attained. This criterion was chosen based on Hooper and Harlow (1986) and Nesbitt et al. (1978), whose results suggest that a series of partial-day follows beginning in the morning and continuing 5-8 hours provide a relatively unbiased estimate of home range, and perhaps are an even better estimate of foraging movement than whole day follows.

At 10-minute intervals, the location of a sequentially selected individual bird was recorded using a Garmin 12XL GPS unit. Occasionally, the exact location of the selected bird could not be approached, because of vegetation, water, or military activity. In these cases, a GPS location (fix) was taken where possible and the bird's distance and compass bearing from that location were estimated. The actual coordinates of the bird were later calculated in Arcview GIS and used in analyses.

Cavity tree data.--

Cavity tree data for this project were collected as part of a continuing long-term study (Walters 2003). Geographic coordinates of cavity trees were obtained using a geographical positioning systems (hereafter GPS) receiver with real-time differential correction. Data used here were collected in 1999.

Vegetation sampling.--

Camp Lejeune commissioned a private environmental consulting firm (J. H. Carter III and Associates, Inc.) to complete a red-cockaded woodpecker foraging habitat inventory of the base. The inventory included all managed pine/pine-hardwood forest stands 30 years old, and some stands slightly younger. Stands were timber management units and were typically 2 ha or larger. Throughout identified forest stands, sample plots (1/10 acre) were taken on a standardized grid measuring 5 chains (100.5 m; north to south) by 12 chains (241.2 m; east to west). Plot centers were georeferenced using a GPS receiver with real-time differential correction. All trees within each plot were tallied and placed into 5 cm dbh classes, and hardwood midstory height was estimated. For a complete description of data collected see Gulf Engineers and Consultants Inc. and Dr. J.H. Carter III and Associates Inc. Environmental Consultants (2000).

Some unmanaged forested areas were not included in the original survey due to financial constraints and proximity to ammunition impact areas. Camp Lejeune personnel completed approximately 39 of these points in the southeast portion of the G-10 buffer zone. Data from these points are included in analyses. In addition to these points, I completed 160 points to supplement the forest inventory in the G-10 buffer area around woodpecker clusters 14, 39, 43, and 46 where the original survey was lacking. To establish point locations, I used geographical information systems (hereafter GIS) to extend the original grid across the desired area and used a GPS receiver to locate points in the field.

Between May and July, 2000 I used a Garmin 12XL GPS unit to relocate those forest inventory points within 0.8 km of each cavity tree cluster center and also those points beyond 0.8 km of the cavity trees but still within the home ranges of the 23 study groups. Cluster centers were calculated as the arithmetic mean of the cavity tree universal transmercator (UTM) coordinates for each group in 1999. In many cases, the exact location of the original points could be determined by flagging left during the previous survey; in other cases the GPS unit was the sole navigational tool. A few points could not be approached because of military activity and were omitted.

At each of the inventory points, I established 4 1-m^2 sampling subplots 5 m from the point in each of the four cardinal directions (N, S, E, W) to sample the groundcover to supplement the forest inventory data. A guide fashioned from meter sticks connected by wire was used to form a square and to delineate the sampling area. Within each subplot, I estimated the percent cover of graminoids and forbs, collectively analyzed as herbaceous groundcover, using the Daubenmire Cover Scale (Daubenmire 1959). Cover classes were: 0-5%, 5-25%, 25-50%, 50-75%, 75-95%, 95-100%. All vegetation <0.5 m in height was evaluated. Some of the original forest inventory points, however, fell within large, impenetrable thickets. For these plots graminoids and forbs were each classified as 0-5% cover.

GIS themes.--

Stand boundary and attribute data (i.e. size, classification, etc.) come from the Red-cockaded Woodpecker Foraging Habitat Inventory Report and associated digital data (Gulf Engineers and Consultants Inc and Dr. J.H. Carter III and Associates Inc. Environmental Consultants 2000). Forest stand dominant cover type information is from the Geographic Information Systems Office of the Business and Logistics Support Department (2000).

Data analysis

Home range estimation.--

I used the Animal Movement Analysis Extension (Hooge and Eichenlaub 1997) to Arcview GIS to estimate home range size and area for each of the 23 study groups. I employed two methods to estimate home range size: minimum convex polygon (MCP) and 95% fixed kernel (Worton 1989). Based on the results of Seaman and Powell (1996), Seaman et al. (1999), and Worton (1995), I used the fixed rather than the adaptive kernel because the fixed kernel tends to produce more accurate home range estimates, especially toward the periphery of the home range. I used 95% probability contour intervals. As recommended by Seaman and Powell (1996), I chose the least squares cross validation (LSCV) method as the smoothing parameter for kernel analyses.

Home range vs. foraging partitions.--

I estimated the percentage of home range within foraging partitions created using two distinct methods. The first method was identical to that described in the Red-cockaded Woodpecker Recovery plan (U.S. Fish and Wildlife Service 2003), except that I created partitions with radii of 400 m, 500 m, 600 m, 700 m, and 900 m from the cluster center, in addition to the standard 800 m. I created foraging partitions for all groups present in the study area, regardless if home range data were available. Using this method, whether a group was allocated a circular or thiessen partition depended on partition radius and the proximity of neighbors. If circular partitions would otherwise overlap, non-overlapping thiessen partitions were used in their place. Thus, a group may have a circular partition at

400 m but a thiessen partition at 500 m, and so on. For this reason, sample size may change for each type of partition at each radius. I used Arcview GIS to create all partitions. The construction of thiessen partitions was aided with the extension Create Thiessen Polygons (Ammon 2000). Partitions were centered on the arithmetic mean of the cavity tree universal transmercator (UTM) coordinates for each group in 1999.

I estimated the percentage of each group's home range encompassed by these partitions – whether thiessen or circular – for each of the tested radii. This analysis was conducted irrespective of habitat composition within the home range or partition. Analyses were conducted by intersecting kernel home ranges with foraging partitions using the intersect function of Arcview GIS.

The above analysis indicated the percentage of the home range of a group encompassed by the partition assigned to it, but for thiessen partitions it underestimates the percentage protected by partitions. This occurs because home ranges sometimes extend beyond the truncated boundary of the thiessen partition into a neighboring foraging partition, but do not extend beyond the partition radius. To assess what percentage of the home range is actually protected at any given radius, I created circular partitions for all 23 study groups irrespective of overlap. As described above, I estimated the percentage of each group's home range encompassed by the circular partition assigned to the group. I examined this relationship for 400 m, 500 m, 600 m, 700 m, 800 m and 900 m radius partitions.

I compared how well the standard method performed relative to circular partitions. Because circular partitions must, by definition, perform as well or better than thiessen partitions (based on percentage of home range encompassed within the partition), and because the 2 methods lack independence, I did not use statistical tests to assess relative performance. Instead, I calculated the mean difference between the 2 methods, and 95% confidence intervals for the difference in the percentage of home range included in partitions, for each tested radius.

To better understand how far home ranges extended from the cavity tree cluster, I estimated the distance from the most distant boundary of the home range to the cluster center. This analysis was performed using the measuring tool in Arcview GIS.

Habitat quality and partition radius.--

I examined 7 habitat characteristics reported to affect fitness in the new Red-cockaded Woodpecker Recovery Plan (U.S. Fish and Wildlife Service 2003). Because the forest inventory was not originally intended to validate the Recovery Plan, however, not all of the variables described in the plan were available to test. Instead, I used those variables that most closely match characteristics described in the plan. A summary of characteristics described in the plan and variables tested is presented in Table 2.1. Some forested areas were in restricted areas or on private property and could not be surveyed. I assessed the potential value of these areas using GIS and color (1998) and infrared (1996) aerial photography, and on-screen digitized the boundaries accordingly. Areas that were clearly denuded of trees or very sparsely covered were considered unsuitable, whereas areas that appeared forested were considered potential foraging habitat, even if attribute data were unavailable. Where possible, I ground-truthed these classifications.

I assessed the relationship between habitat quality and partition radius by identifying trends in habitat composition as a function of partition radius, using circular foraging partitions. To achieve this, I classified each forest stand within the study area based on its compliance with the 7 characteristics of good quality foraging habitat described in the new Recovery Plan (U.S. Fish and Wildlife Service 2003) (Table 2.1). Thus, a stand in full compliance met all 7 characteristics, a stand lacking only one received a score of 6, and so forth. Because very few stands met all or most of the criteria, I further classified stands based on whether they met 4 or more criteria or 3 or fewer. I use these classifications in analyses, and label them 'better quality habitat' and 'lower quality habitat,' for stands with 4 or more characteristics and 3 or fewer characteristics, respectively.

To calculate stand values I averaged habitat point values for all habitat points within each stand. I used the midpoint of each stem size class to calculate basal area. Thus, for pines 25.4-30.5 cm, I calculated the basal area for 27.9 cm trees. Likewise, to calculate midstory height, I used the midpoint of each height class, and for midstory density, I considered plots classified as 'open' or 'light' to be good. I also identified unsuitable foraging habitat within partitions. I defined unsuitable habitat as unforested areas, pine/pine-hardwood stands too young (approx <30 yrs) to be included in the original forest inventory, forested areas dominated by hardwoods, and pine/pine-hardwood stands with representative age <30 years and representative dbh <17.78 cm (7 inches). Finally, some areas (approximately 5%) were classified as unknown, because one or more habitat elements could not be measured. Thus, I classified the entire study area into one of 4 classes: better (>4 characteristics) and lower quality habitat (<3 characteristics), unsuitable, and unknown. I used the intersect function in Arcview GIS to calculate the percentage of each of these classes as a function of partition radius.

Because larger partitions overlap smaller partitions, extensive correlation existed between variables in partitions of various radii. For this reason, statistical tests comparing partition radii could not be performed. Instead, I present descriptive statistics and rely on trends to foster discussion.

RESULTS

Estimation of home ranges

Mean home ranges calculated with the Animal Movement Extension were 80.2 (SE 5.2) and 103.0 ha (SE 6.3) for the 95% fixed kernel and MCP methods, respectively (Convery 2002). Kernel home ranges appeared to be a reasonable representation of reality, whereas the MCP home ranges often included areas of clearly unsuitable habitat that were rarely if ever used. Kernel home ranges varied from 39.0-145.4 ha, while the MCP home ranges varied from 60.7-168.8 ha.

Effort was sufficient to adequately estimate home range for the time period included in the study. Incremental area analysis (area-observation plots) illustrated that the number of locations (i.e. fixes) was sufficient for each home range to reach an asymptote.

Evaluation of partitions

Thiessen method.--

The smallest (400 m) and largest (900 m) partitions created using the thiessen method encompassed a mean of 48 and 83% of the estimated kernel home ranges, respectively, with values for other radii falling between (Table 2.2). At the 800 m radius a mean of 80% of the home range was encompassed by the partition. Variation between groups was large (Figure 2.4), with some home ranges receiving much greater protection than others. For example, for 4 of 23 study groups <70% of their home range was included in their own partition at the 800 m radius (Table 2.2).

Circular partitions.--

The smallest (400 m) and largest (900 m) circular partitions encompassed 49 and 95% of the estimated kernel home ranges, respectively, with values for other radii falling between (Table 2.3). The standard 800 m partition encompassed 91% of home range area. Again, however, variation between groups was large, especially for smaller partitions (Figure 2.5). The minimum and maximum values for the 500 m partition, for example, were 36% and 94%, respectively, a range of 58%. In other words, in one case, only 36% of a group's home range fell within the partition allocated to the cluster. The range of values for the 800 m partition was 37%.

The maximum linear distance the estimated home ranges extended from the cluster center varied from 650 to 1700 m, with a mean of 969 m (Figure 2.6).
As partition radius increased the percentage of the partition area within the home range decreased (Figure 2.7). On average, 73% of the smallest partitions (400 m) overlapped with the kernel home ranges, whereas only 30% of the largest (900 m) partitions were used for foraging. On average, 36% of the 800 m partition overlapped with the kernel home ranges, which means that 64% of the partitions went unused.

Thiessen method vs. circular partitions.--
Circular partitions always encompass a larger percentage of the estimated home range than thiessen partitions (Figure 2.8), and this difference was greater at larger radii (Figure 2.9). At the 800 m radius, the upper and lower values for the 95% confidence interval around this difference were 6 and 16%, respectively.

Habitat composition vs. partition radius.--
An examination of habitat composition as a function of partition radius revealed two weak but important trends. First, the percentage of better and lower quality (but potentially suitable) habitat within the partition decreased as partition radius increased (Figure 2.10). On average, the smallest partitions (400 m) were composed of 23% better quality habitat, but this figure declined to 13% for the largest partitions. Likewise, the percentage of lower quality habitat declined from 66% in 400 m to 57% in 900 m partitions. Second, the percentage of unsuitable habitat within partitions increased as a function of partition radius (Figure 2.10). These trends were consistent across all radii.

DISCUSSION

Ultimately, the extent to which foraging partitions accommodate red-cockaded woodpecker groups depends on home range size and shape. If all home ranges were identical then designing a foraging partition would be an easy task. In reality, however, home ranges vary dramatically among and within populations, and this complicates the choice of partition radius. In this study, 95% fixed kernel home ranges varied from 39 to 154 ha, and range-wide home range estimates vary from 40.5 to 161.9 ha (U.S. Fish and Wildlife Service 2003). This variation has important consequences for foraging partitions, because individual groups are not always protected by measures that work well on average. Land managers may delight in the fact that on average 91% of home range area is 'protected' by the standard 800 m radius partitions. However, 8 of 23 home ranges received less protection than this, and for 3 groups, <80% of their home range was protected. In one case only 63% of a group's home range was protected at this radius. Why circular partitions performed poorly in some cases may be partially explained by the distribution of neighboring groups and habitat quality within the partition. The 3 groups whose 800 m radius, circular partitions included <80% of their home range were unconstrained by neighboring groups in one or more directions, and their home ranges extended into unoccupied habitat. This phenomenon was exaggerated when higher quality habitat (i.e. more characteristics of good quality) existed at or beyond the periphery of the partition but not in proximity to the cavity tree cluster. Likewise, some clusters were bordered on one or more sides by large areas of unsuitable habitat and home ranges typically extended away from such habitat. In these cases, home ranges were often irregular or linear in shape and extended, at least in one direction, well beyond the 800 m partition radius.

Thiessen and circular foraging partition methods included approximately an equal percentage of home range area at smaller radii, but diverged by 5-10% as radius increased. This occurred because, using the thiessen method, partitions were more likely to become truncated by neighboring groups as radius increases, thereby producing smaller partitions. This effect was exaggerated as the density of red-cockaded woodpecker clusters increased. Of course home range included in a circular partition but excluded from a thiessen partition was still protected, but within the partition of a neighboring group. Thus use of thiessen partitions may introduce errors in management at the level of individual groups, but not at the population level.

Not surprisingly, the percentage of the home range protected increased as a function of partition radius. Does this imply that increasing the standard radius would be wise? One might consider larger partitions better since they necessarily include more habitat than smaller partitions. A trade-off exists, however, between partition size and function, because red-cockaded woodpeckers are a central-place foraging species (i.e. they regularly return to the cavity tree cluster), and preferentially select habitat near the cavity tree cluster (Rosenberg and McKelvey 1999). This makes habitat near the cluster center more valuable than habitat further away. Furthermore, in this study, the percentage of better quality habitat decreased as a function of partition radius. Using larger partitions will result in restrictions on use of land that is in reality unsuitable or poorer quality habitat.

The change in habitat quality with partition size may be explained in two ways. First, red-cockaded woodpeckers may select the location of their cavity tree cluster because of the proximity to better quality foraging habitat. See Johnson (1980) for an informative discussion on habitat selection order. Alternatively, that habitat quality decreases as a function of distance from the cluster may be an artifact of past management practices. To a large extent, nesting and foraging habitat have been managed separately, with nesting habitat generally receiving more attention in the form of frequent burning and midstory control. Only recently has it been realized that the features of high quality nesting and foraging habitat are similar, and that growing season fire is essential to foraging, as well as nesting, habitat management (James et al. 1997, James et al. 2001, Walters et al. 2002). Thus the best foraging habitat currently may be habitat that has been managed for nesting in the past, which usually will be in proximity to the cluster center. Whatever the mechanism, larger partitions will provide more area and protect a higher percentage of the home range, but the habitat they provide will be of poorer quality and less available than habitat in smaller partitions.

MANAGEMENT RECOMMENDATIONS

Overall, the habitat partitioning method advocated by the U.S. Fish and Wildlife Service (2003) performed well. I see no reason to change the 800 m standard. An examination of circular partitions revealed that the thiessen partitions protect most of the home range, although not all habitat may be assigned to the correct group. In cases where partitions performed less well, it can be largely attributed to the distribution of neighboring groups and of unsuitable habitat within the partition, because groups often extended their home range in the direction away from neighbors and unsuitable habitat. Applying a larger partition to individual groups whose foraging movement is clearly constrained might minimize the number of cases in which a group's home range is not adequately protected. However, unless home range follows are performed, there will always be uncertainty about the habitat used by individual groups. Land managers should limit the size and scope of practices that decrease foraging habitat quality within the partition and especially within the vicinity of the cluster area.

Furthermore, because home range size and shape are related to the distribution of neighboring groups, it is important that the status of red-cockaded woodpecker clusters and the foraging partitions designed to provide for them are updated on a regular basis. The existence of partitions around abandoned clusters or the omission of a partition around an active cluster may have consequences for the performance of neighboring groups.

LITERATURE CITED

Ammon, G. 2000. Create thiessen polygons (version 2.6) [computer program]. Available: www.esri.com.

Anonymous. 1996. Draft comprehensive long range red-cockaded woodpecker habitat management plan. Marine Corps Base, Camp Lejeune, North Carolina.

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, Texas.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:43-64.

Geographic Information Systems Office of the Business and Logistics Support Department. 2000. Integrated geographic information repository (IGIR). Marine Corps Base Camp Lejeune.

Gese, E. M., D. E. Andersen, and O. J. Rongstad. 1990. Determining home range size of resident coyotes from point and sequential locations. Journal of Wildlife Management 54:501-506.

Gulf Engineers and Consultants Inc, and Dr. J.H. Carter III and Associates Inc. Environmental Consultants. 2000. Final Report. Forest inventory report - Red-cockaded woodpecker foraging habitat inventory. Marine Corps Base, Camp Lejeune, North Carolina.

Hooge, P. N., and B. Eichenlaub. 1997. Animal movement extension to Arcview (version 1.1) [computer program]. Alaska Biological Science Center, USGS, Anchorage, Alaska.

Hooper, R. G., and R. F. Harlow. 1986. Forest stands selected for foraging red-cockaded woodpeckers. Research Paper SE-259, US Forest Service.

James, F. C., C. A. Hess, B. C. Kicklighter, and R. A. Thum. 2001. Ecosystem management and the niche gestalt of the red-cockaded woodpecker in longleaf pine forests. Ecological Applications 11:854-870.

James, F. C., C. A. Hess, and D. Kufrin. 1997. Species-centered environmental analysis: Indirect effects of fire history on red-cockaded woodpeckers. Ecological Applications 7:118-129.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65-71.

Kenward, R. E., and K. H. Hodder. 1996. Ranges V: An analysis system for biological location data [computer program]. Institute of Terrestrial Ecology, Wareham, UK.

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

Rosenberg, D. K., and K. S. McKelvey. 1999. Estimation of habitat selection for central-place foraging animals. Journal of Wildlife Management 63:1028-1038.

Seaman, D. E., J. J. Millspaugh, B. J. Kernohan, G. C. Brundige, K. J. Raedeke, and R. A. Gitzen. 1999. Effects of sample size on kernel home range estimates. Journal of Wildlife Management 63:739-747.

Seaman, D. E., and R. A. Powell. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology 77:2075-2085.

U.S. Fish and Wildlife Service 2003. Recovery plan for the red-cockaded woodpecker (*Picoides borealis*): Second revision. U.S. Fish and Wildlife Service, Atlanta, Georgia.

Walters, J. R. 2003. Unusual dynamics in a rapidly increasing population of red-cockaded woodpeckers on Camp Lejeune, North Carolina. This Volume.

Walters, J. R., S. J. Daniels, J. H. Carter III, and P. D. Doerr. 2002. Defining quality of red-cockaded woodpecker foraging habitat based on habitat selection and fitness. Journal of Wildlife Management In Press.

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home range studies. Ecology 70:164-168.

Worton, B. J. 1995. Using Monte Carlo simulation to evaluate kernel-based home range estimators. Journal of Wildlife Management 59:797-800.

Table 2.1. Characteristics of good quality habitat, as defined in the USFWS 2003 Foraging Habitat Guidelines, and the variables in this study used to evaluate them.

Characteristic	Components	Measured/Analyzed
45 or more stems/ha of pines that are >60 years in age and > 35 cm dbh. Minimum basal area for these pines is 4.6 m2/ha.	▪ # pine stems/ha $\geq$35 cm dbh ▪ Tree age ▪ BA pines/ha $\geq$35 cm dbh	* * *
Basal area of pines 25.4-35 cm dbh is between 0 and 9.2 m^2/ha.	▪ BA pines/ha 25.4-35 cm dbh	*
Basal area of pines <25.4 cm dbh is below 2.3 m^2/ha *and* <50 stems/ha.	▪ BA pines/ha <25.4 cm dbh ▪ # pines stems/ha <25.4 dbh	* *
Basal area of all pines $\geq$25.4 cm dbh $\geq$9.2 m^2/ha.	▪ BA pines/ha $\geq$25.4 cm dbh	*
Groundcovers of native bunchgrass and/or other native, fire-tolerant, fire-dependent herbs total >40% of groundcover and midstory plants and are dense enough to carry growing season fire at least once every 5 years.	▪ % Herbaceous groundcover	*
No hardwood midstory exists, or if a hardwood midstory is present it is sparse and <2.1 m in height.	▪ Hardwood midstory (density) ▪ Hardwood midstory (height)	‘open’ or ‘light’ good; otherwise not *
Canopy hardwoods are absent or <10% of the number of canopy trees in longleaf forests and <30% of the number of canopy trees in loblolly and shortleaf forests.	▪ % canopy hardwoods	*

* same as described in Components

Table 2.2. Percentage of 95% fixed kernel home range encompassed by foraging partitions as a function of partitions radius. Bold represents thiessen foraging partitions; normal case indicates circular partitions. All partitions centered on red-cockaded woodpecker cluster tree centers, calculated as the arithmetic mean of the cavity tree universal transmercator (UTM) coordinates.

	Buffer radius (m)					
	400	500	600	700	800	900
Group	% home range in thiessen and simple partitions					
1	37	**48.4**	**53.9**	**58.6**	**64.1**	**69.1**
2	**73.8**	**84.7**	**86.6**	**86.6**	**86.6**	**86.6**
3	**53.9**	**64**	**69.7**	**74**	**75.2**	**75.2**
4	**48.9**	**56.4**	**57**	**57**	**57**	**57**
7	**42.4**	**55.4**	**63.9**	**64.8**	**64.9**	**64.9**
8	38.1	**51.9**	**59.1**	**66.7**	**74.5**	**78.4**
9	45.2	**62.6**	**72.5**	**78.5**	**83.5**	**86.6**
10	**52.1**	**62.4**	**68.6**	**68.9**	**69.1**	**70.4**
11	**38.4**	**47.8**	**56.4**	**63.4**	**70**	**77.8**
14	42.5	**58.1**	**71.6**	**81.1**	**86**	**86.1**
18	44.7	65.2	84.8	96	100	100
19	48	57.5	63.2	73.2	80.7	88.5
20	43.8	53.2	63.1	70.2	**78**	**86.6**
22	50.7	64.3	77.4	89	**96.9**	**100**
33	35.2	51.6	68.2	84.3	95.2	100
35	26.8	36.4	46.3	54.6	62.6	70.2
39	51.5	**68.6**	**76.7**	**82**	**83.5**	**83.5**
42	58.3	78.1	89.9	94.5	98.4	100
43	**49.9**	**58.6**	**65.8**	**71**	**75**	**77.4**
44	29.6	**41.2**	**51.9**	**62.6**	**71.6**	**76.1**
46	52.7	72.1	88.4	**96.4**	**97.5**	**97.5**
47	**51.6**	**61.8**	**69.5**	**73.8**	**76.6**	**77.1**
48	80.9	94.3	**97.9**	**99.3**	**99.3**	**99.3**
Mean (SE)	47.7 (2.6)	60.6 (2.7)	69.7 (2.8)	75.9 (2.8)	80.3 (2.7)	83.0 (2.6)

Table 2.3. Percentage of 95% fixed kernel home range encompassed by circular foraging partitions as a function of partition radius. Bold represents partitions that overlap with at least one other of the same radius – these also analyzed as thiessen partitions in Table 2.2. All partitions centered on red-cockaded woodpecker cluster tree centers, calculated as the arithmetic mean of the cavity tree universal transmercator (UTM) coordinates.

	Buffer radius (m)					
	400	500	600	700	800	900
Group	% home range in simple partition					
1	37	**52.6**	**66.9**	**74**	**80.3**	**88**
2	**74.7**	**92**	**99.2**	**100**	**100**	**100**
3	**59.9**	**77.5**	**88.5**	**95.8**	**99.6**	**100**
4	**56.4**	**73.7**	**91.5**	**99.1**	**100**	**100**
7	**43.8**	**59.2**	**74.5**	**88.6**	**98.1**	**100**
8	38.1	**52**	**62.3**	**76.1**	**88.2**	**96.3**
9	45.2	**62.8**	**75.9**	**86.1**	**93.4**	**96.4**
10	**69**	**80.3**	**86.5**	**86.8**	**87.4**	**91.6**
11	**40.4**	**50.2**	**59.5**	**67.2**	**75.7**	**84.5**
14	42.5	**58.2**	**71.8**	**83.1**	**92.3**	**97.5**
18	44.7	65.2	84.8	96	100	100
19	48	57.5	63.2	73.2	80.7	88.5
20	43.8	53.2	63.1	70.2	**78**	**86.6**
22	50.7	64.3	77.4	89	**96.9**	**100**
33	35.2	51.6	68.2	84.3	95.2	100
35	26.8	36.4	46.3	54.6	62.6	70.2
39	51.5	**70.4**	**81**	**88.4**	**94.2**	**98.7**
42	58.3	78.1	89.9	94.5	98.4	100
43	**51.1**	**67.3**	**80.2**	**87.6**	**92.3**	**95.6**
44	29.6	**44**	**59.4**	**75**	**87.2**	**94.6**
46	52.7	72.1	88.4	**98.9**	**100**	**100**
47	**54.6**	**71.6**	**84.4**	**91.9**	**98.7**	**100**
48	80.9	94.3	**98.2**	**100**	**100**	**100**
Mean (SE)	49.4 (2.8)	64.5 (3.0)	76.6 (2.9)	85.2 (2.5)	91.3 (2.1)	95.2 (1.5)

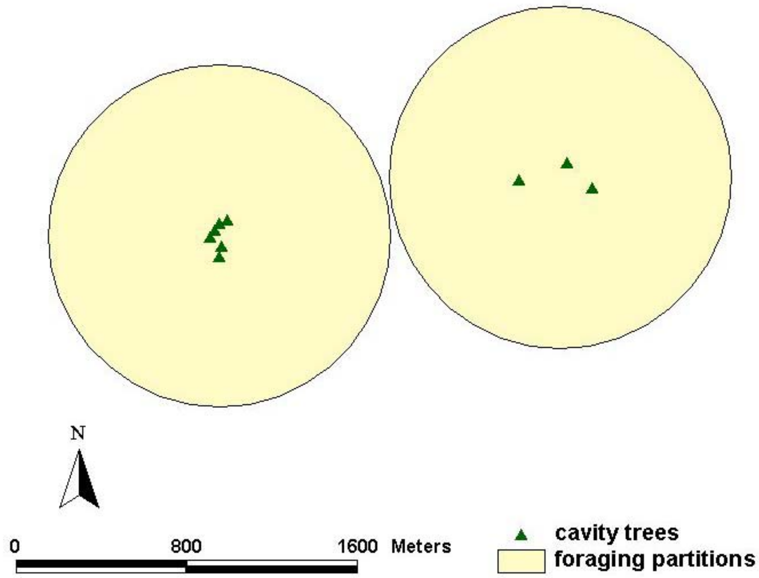

Figure 2.1. Example of two non-overlapping 800 m foraging partitions (i.e. with centers >1.6 km apart). When partitions do not overlap, they are represented by simple circles. Partition centers were calculated as the arithmetic mean of the cavity tree universal transmercator (UTM) coordinates.

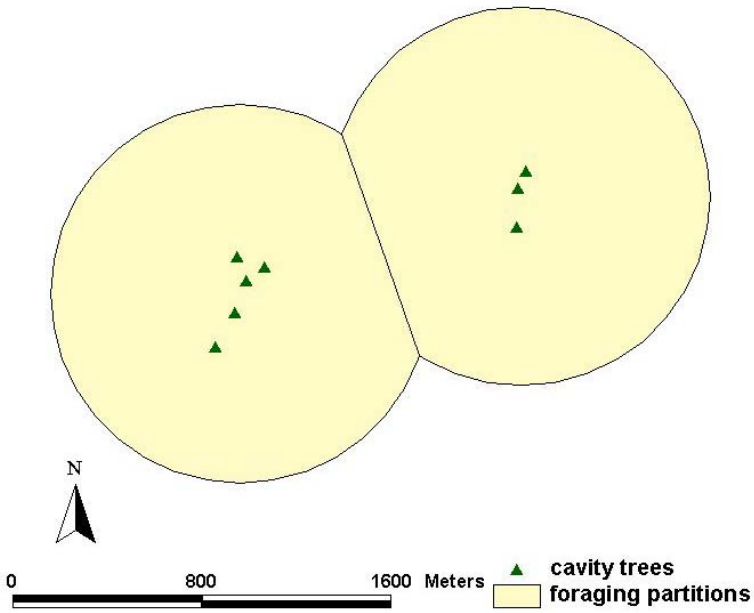

Figure 2.2. Example of two 800 m foraging partitions with centers less with than 1.6 km apart. When partitions would otherwise overlap, thiessen partitions are used to define the area nearest to each cluster center. Partition centers calculated as the arithmetic mean of the cavity tree universal transmercator (UTM) coordinates.

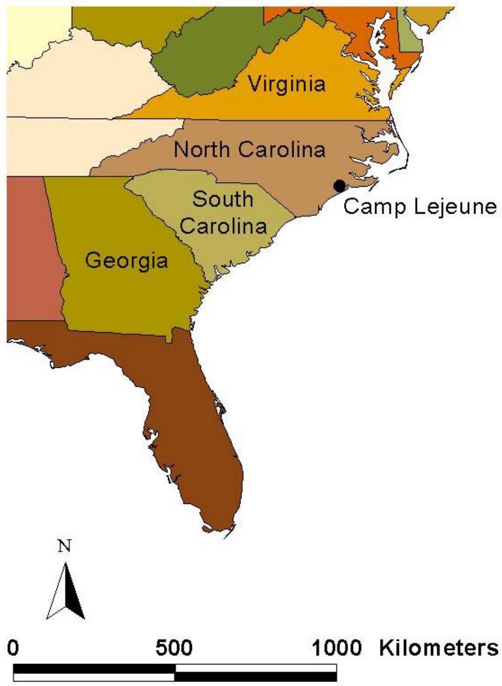

Figure 2.3. Location of Camp Lejeune Marine Base, North Carolina.

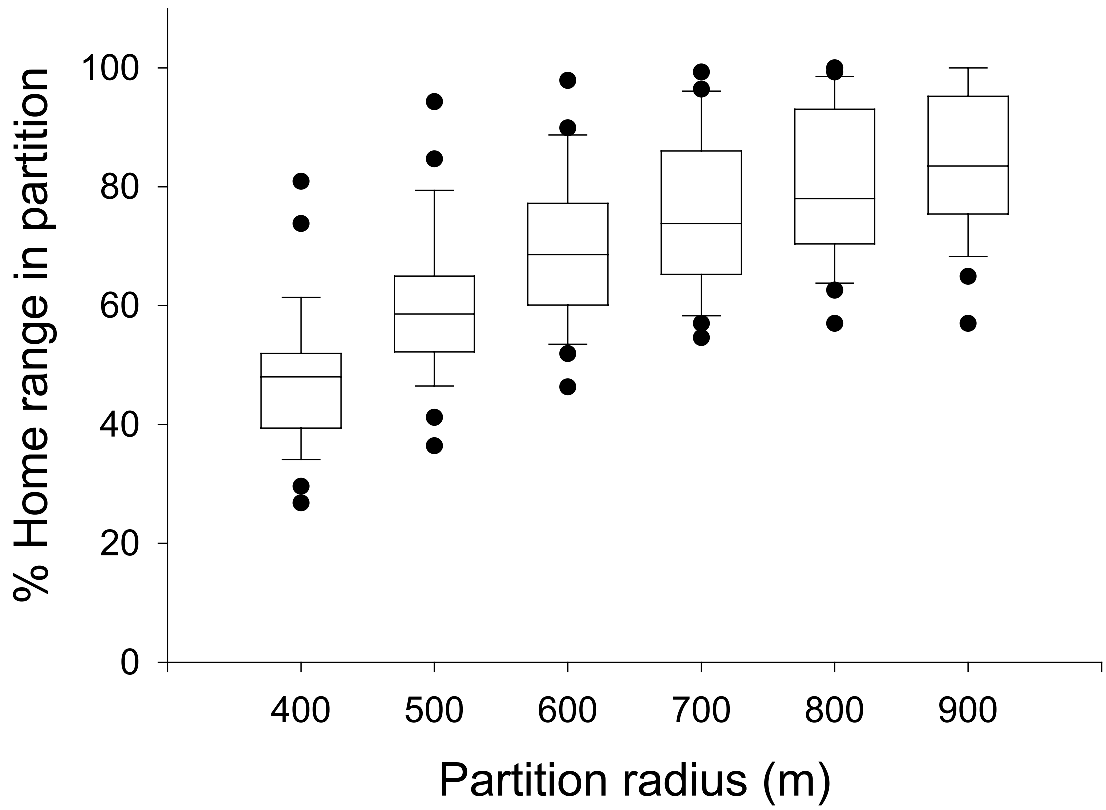

Figure 2.4. Boxplot of percentage of 95% fixed kernel home range in foraging partitions created using the thiessen method as a function of partition radius for 23 study groups at Camp Lejeune, NC. The box represents the median, upper and lower quartiles, the whiskers the 10 and 90 percentiles, and the dots represent extreme observations.

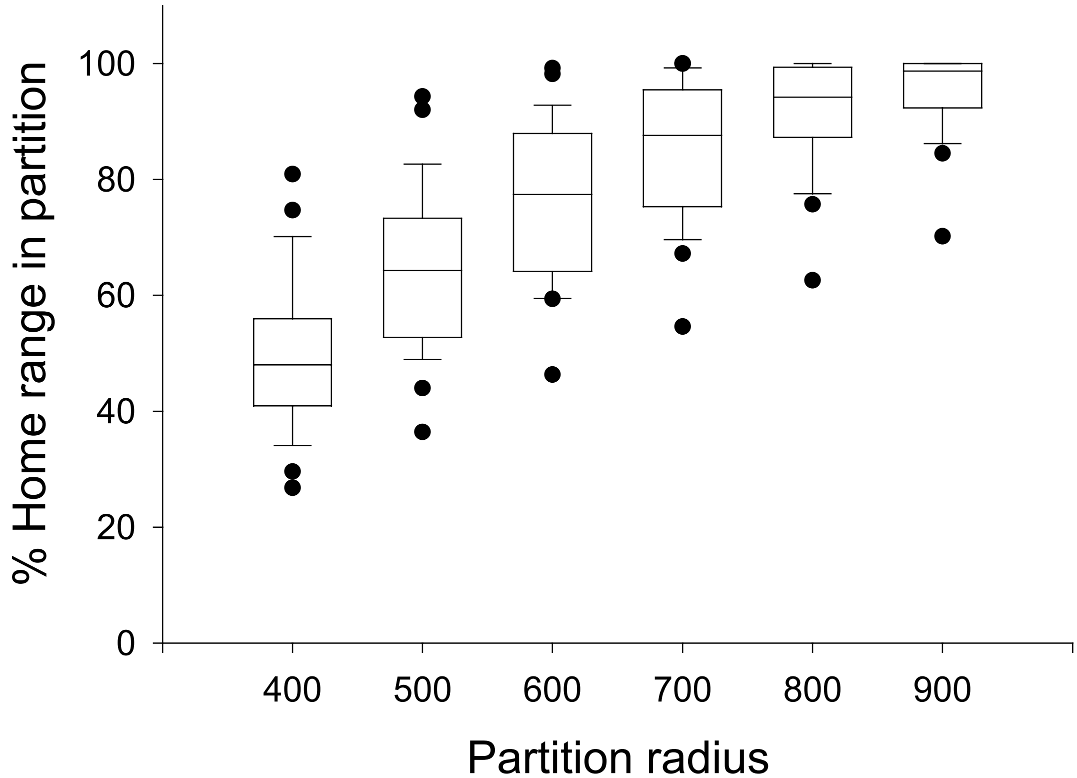

Figure 2.5. Boxplot of percentage of 95% fixed kernel home range in circular foraging partitions as a function of partition radius for 23 study groups at Camp Lejeune. The box represents the median, upper and lower quartiles, the whiskers the 10 and 90 percentiles, and the dots represent extreme observations.

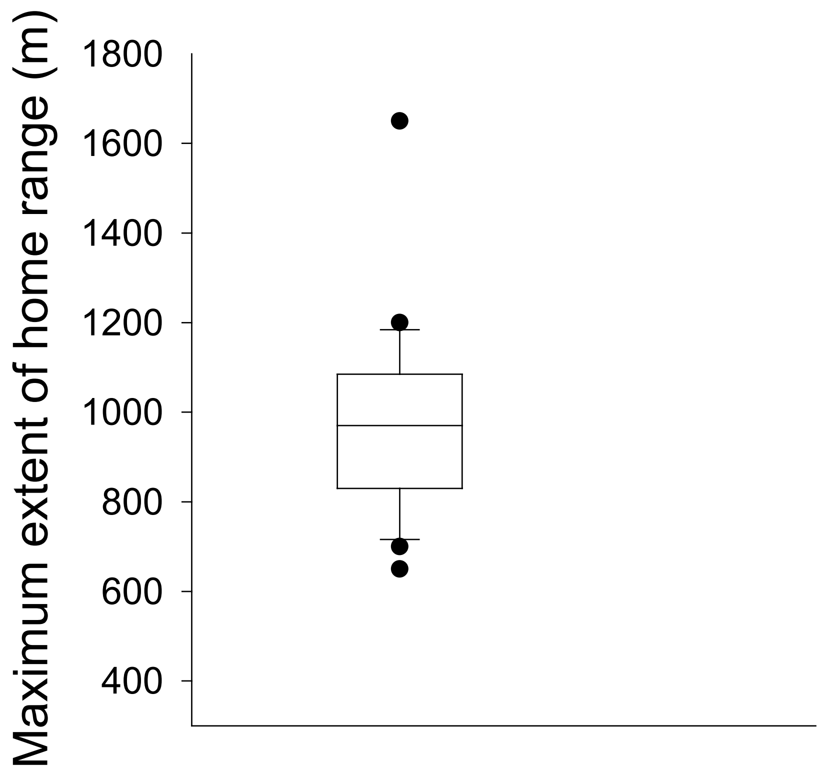

Figure 2.6. Boxplot of the maximum distance the 95% kernel home ranges extended from the cavity tree cluster center for 23 study groups at Camp Lejeune, NC. Mean value 969 m. The box represents the median, upper and lower quartiles, the whiskers the 10th and 90th percentiles, and the dots represent extreme observations. Cluster centers calculated as the arithmetic mean of the cavity tree universal transmercator (UTM) coordinates.

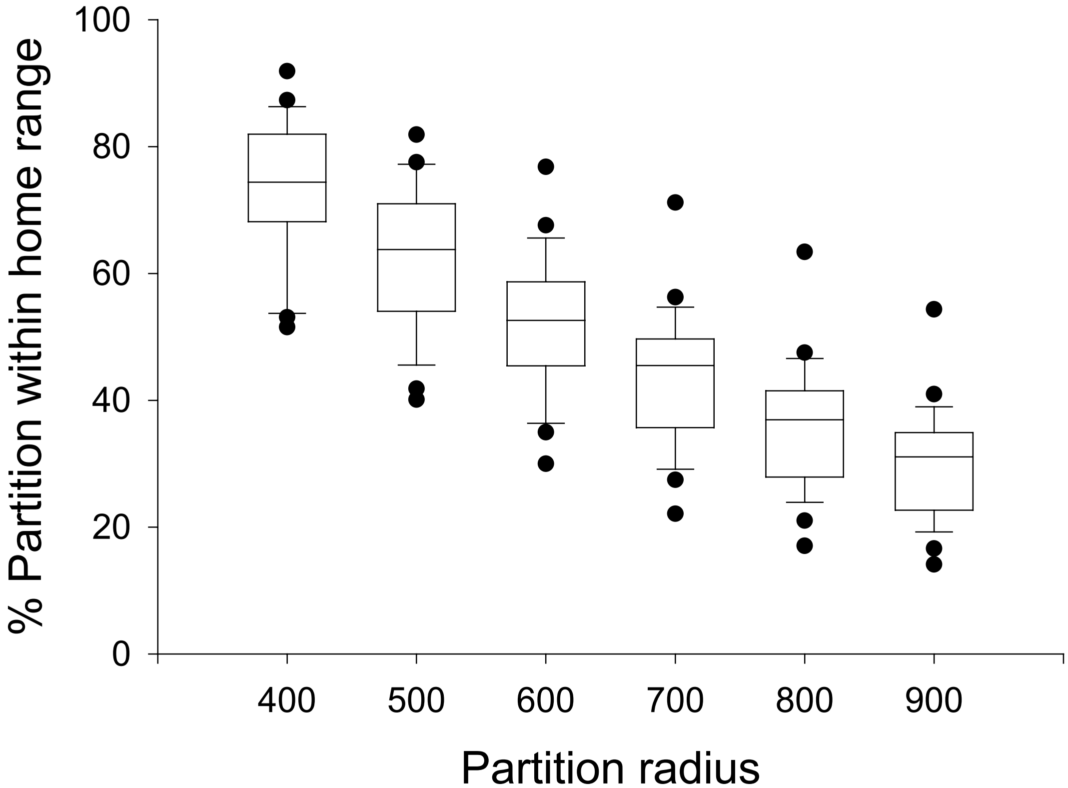

Figure 2.7. Boxplot of percentage of partition area within the 95% fixed kernel home range in circular foraging partitions as a function of partition radius for 23 study groups at Camp Lejeune, NC. The box represents the median, upper and lower quartiles, the whiskers the 10th and 90th percentiles, and the dots represent the extreme observations.

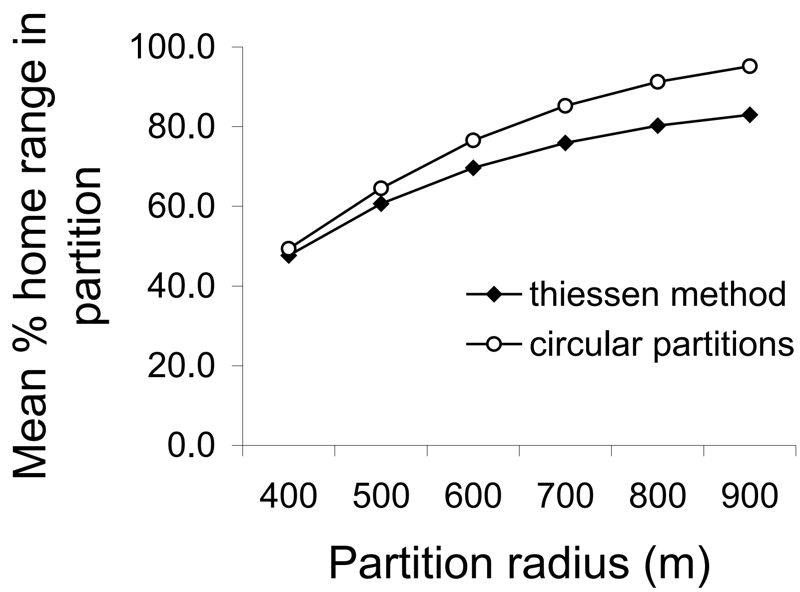

Figure 2.8. Percentage of 95% fixed kernel home range in circular and thiessen foraging partitions as a function of partition radius for 23 study groups at Camp Lejeune, NC.

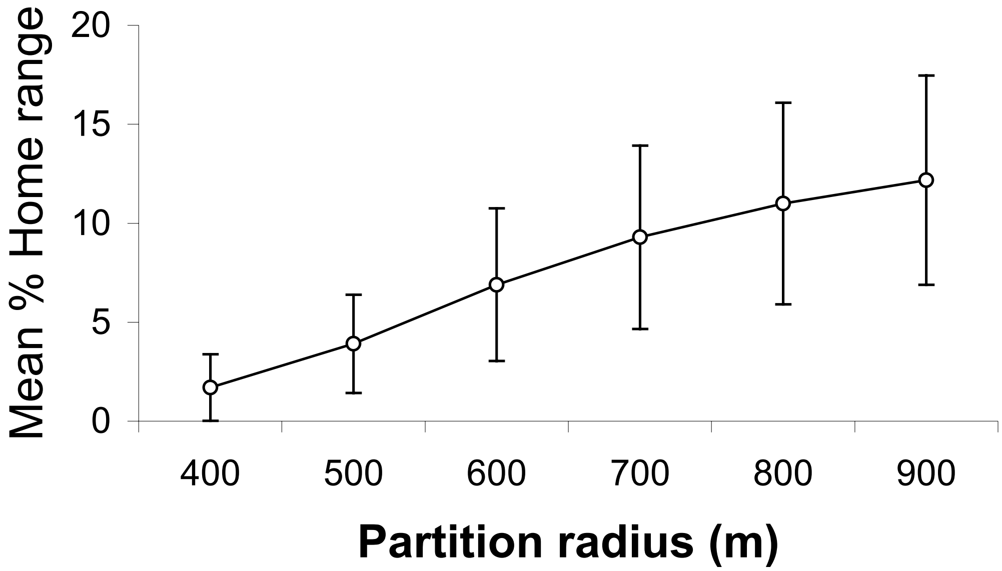

Figure 2.9. Percent of 95% fixed kernel home range within circular but not thiessen partitions for 23 study groups at Camp Lejeune, NC. Vertical bars represent 95% confidence intervals.

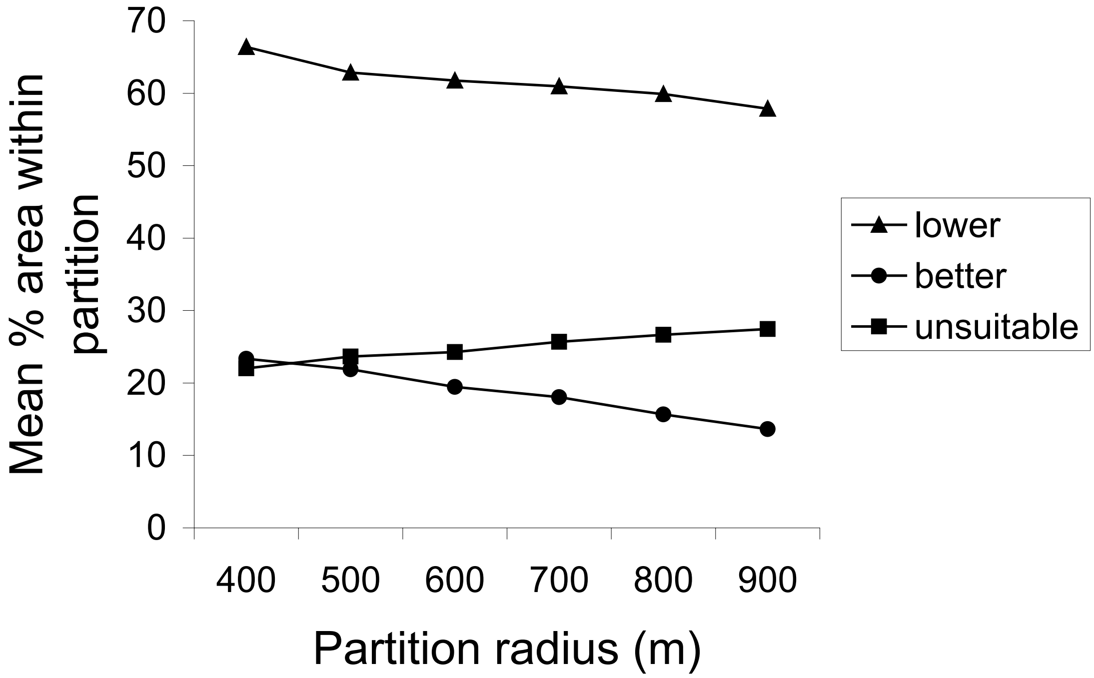

Figure 2.10. Percentage of better quality, lower quality, and unsuitable habitat with respect to partition radius. Better quality habitat met 4-7 characteristics of good quality habitat described in the new Recovery Plan, lower quality habitat 3 or less. Unsuitable habitat included unforested areas, pine/pine-hardwood stands too young (approx <30 yrs) to be sampled in the original forest inventory, forested areas dominated by hardwoods, and pine/pine-hardwood stands with representative age <30 years and representative dbh <17.78 cm (7 inches). Partitions are simple circular buffers centered on red-cockaded woodpecker cluster tree centers.

CURRICULUM VITAE

Ken M. Convery

EDUCATION

VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY   October 2002
M.S. Biology; GPA 4.0
Thesis: Assessing habitat quality for the endangered red-cockaded woodpecker

UNIVERSITY OF CALIFORNIA, SANTA BARBARA   December 1994
B.S. Ecology & Evolutionary Biology. B.A. Environmental Studies.

WORK EXPERIENCE

VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY
Blacksburg, VA
Graduate Research Assistant (Aug 1999-Oct 2002)

US FISH AND WILDLIFE SERVICE
ALASKA PENINSULA/BECHAROF NATIONAL WILDLIFE REFUGE COMPLEX
King Salmon, AK
Crew Leader/Biological Technician (Apr-Aug 1999; Apr-Oct 1998)

THE INSTITUTE FOR BIRD POPULATIONS (IBP)
Point Reyes Station, CA
Biologist/Instructor (Mar-Aug 1996 & 1997)
Biologist Intern (May-Aug 1995)

TULANE UNIVERSITY
New Orleans, LA
Field Assistant (Jan-Mar 1997; Feb 1998)

POINT REYES BIRD OBSERVATORY
Farallon Islands National Wildlife Refuge, CA
Research Assistant (Sept-Nov 1996)
Research Assistant (Dec 1995-Feb 1996)

CALIFORNIA STATE UNIVERSITY, FULLERTON
Research Assistant (Sept-Nov 1995)

UNIVERSITY OF CALIFORNIA, SANTA BARBARA
Research Assistant (Sept 1993-May 1994)
Research Assistant (Sept-Dec 1993)

SEA SHEPHERD CONSERVATION SOCIETY
Malibu, CA
Intern (Jul-Aug 1994)

HONORS and RECOGNITION

Certified Trainer
NORTH AMERICAN BIRD BANDING COUNCIL. (1999-present)

Elected Officer, Social Chair
BIOLOGY GRADUATE STUDENT ASSOCIATION, VIRGINIA TECH. (2000-2001)

"On the Spot" Award for Outstanding Leadership and Technical Expertise.
U.S. FISH & WILDLIFE SERVICE (1998)