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Red-cockaded Woodpecker *Picoides Borealis* Microhabitat Characteristics and Reproductive Success in a Loblolly-Shortleaf Pine Forest

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Abstract: We investigated the relationship between red-cockaded woodpecker (*Picoides borealis*) reproductive success and microhabitat characteristics in a southeastern loblolly (*Pinus taeda*) and shortleaf (*P. echinata*) pine forest. From 1997 to 1999, we recorded reproductive success parameters of 41 red-cockaded woodpecker groups at the Bienville National Forest, Mississippi. Microhabitat characteristics were measured for each group during the nesting season. Logistic regression identified understory vegetation height and small nesting season home range size as predictors of red-cockaded woodpecker nest attempts. Linear regression models identified several variables as predictors of red-cockaded woodpecker reproductive success including group density, reduced hardwood component, small nesting season home range size, and shorter foraging distances. Red-cockaded woodpecker reproductive success was correlated with habitat and behavioral characteristics that emphasize high quality habitat. By providing high quality foraging habitat during the nesting season, red-cockaded woodpeckers can successfully reproduce within small home ranges.

Keywords: Loblolly pine, microhabitat, *Picoides borealis*, red-cockaded woodpecker, reproduction, shortleaf pine.

INTRODUCTION

Red-cockaded woodpeckers (*Picoides borealis*; hereafter RCW) are a federally-endangered species endemic to pine ecosystems of the southeastern United States [1]. Few studies have quantitatively examined RCW microhabitat selection and reproductive success within fragmented loblolly (*Pinus taeda*) and shortleaf (*P. echinata*) pine ecosystems [2,3]. Previous research focused on longleaf pine (*P. palustris*) monocultures or private timber industry lands [4-6]. However, approximately 50% of RCW subpopulations on public lands are located in loblolly, shortleaf, or mixed pine forests [7]. Thus, we examined the relationship between RCW reproductive success and microhabitat characteristics within a fragmented loblolly and shortleaf pine forest.

Although numerous studies examined RCW microhabitat use, few examined the relationship between reproductive success and microhabitat characteristics [2,3,8,9]. The few studies that attempted to determine a causal relationship between RCW reproductive success and microhabitat characteristics produced conflicting results. RCW reproductive success was not related to the amount of suitable foraging habitat or degree of habitat fragmentation in a Florida longleaf pine forest [8]. RCW reproductive success was not related to the amount of foraging habitat provided by the RCW recovery plan [8,10]. Similarly, others were unable to detect a relationship between RCW reproductive success and microhabitat variables (i.e., stem size, frequency of large pine stems, pine basal area, or stand suitability) on private lands [5]. Conversely, others developed a successful discriminant function that linked the number of RCW fledglings with three microhabitat variables (i.e., number of cavities, dbh of overstory pine trees, and understory height) [11]. In Texas, RCWs had lower partial brood loss in clusters where hardwood midstory was minimal [3]. RCW foraging behavior also exhibited a preference for habitat with less hardwood midstory [2].

Our objective was to test the relationship between RCW reproductive success and microhabitat characteristics in a loblolly-shortleaf pine forest in central Mississippi. We tested the null hypotheses that microhabitat and behavioral characteristics did not influence RCW reproductive success parameters such as percent of RCW groups that attempted nesting, clutch size, number of eggs hatched, and number of young fledged per nest.

MATERIALS AND METHODOLOGY

Study Area

Bienville National Forest encompassed 72,216 ha of loblolly-shortleaf pine forest in Jasper, Newton, Scott, and Smith counties in central Mississippi. RCW areas included pine, pine-hardwood, and hardwood stands of varying age classes in a highly fragmented landscape [12]. Dominant pine species included loblolly and shortleaf pine with smaller quantities of longleaf and slash pine (*P. elliotii*). Hardwood species such as white oak (*Quercus alba*), water oak (*Q. nigra*), willow oak (*Q. phellos*), southern red oak (*Q. falcata*), mockernut hickory (*Carya tomentosa*), and sweetgum (*Liquidambar styraciflua*) were also present but in lower densities and in riparian areas. With a range of 94–107 active RCW groups, Bienville National Forest contained the largest subpopulation of RCWs in Mississippi [12].

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Methods

We randomly selected, without replacement, a subsample of all RCW groups at Bienville National Forest each year for visual observations (1997 [*n* = 15], 1998 [*n* = 14]), 1999 [*n* = 12] [11]. Five-hr visual observation periods were performed on selected groups for one year beginning in January and concluding in December annually [8]. Visual observation periods were performed sequentially by group throughout the year to approximate equal effort [10]. Visual observation periods began at first light and concluded five hrs after RCWs were first observed. Each visual observation period was subdivided into 6-min periods which consisted of a 1-min observation period followed by a 5-min waiting period [13]. We used a 6-min period to ensure that all habitat types used by RCWs were detected. We defined the group as the sampling unit and selected one RCW from the group during the visual observation period and recorded all locations of that individual RCW during the 1-min observation period [14].

We quantified microhabitat characteristics of RCW foraging locations using a modified bird-centered location method [15,16]. Plots were centered on trees selected by RCWs during visual observation periods. For each RCW group, we sub-sampled for microhabitat variables at every fifth location throughout the year. Vegetation plots were categorized as nesting depending upon nest initiation and fledging dates for each group. Microhabitat characteristics were quantified inside vegetation sampling plots [17-19, 10] (Table **1**).

We recorded whether nesting was attempted, clutch size, number of eggs hatched, and number of young fledged per nest for each RCW group. We used a Treetop Peeper Scope (Sandpiper Technologies Inc., Manteca, California), to obtain data on presence/absence of an incubating adult, clutch size, and number of eggs hatched. We counted fledglings at the time they left the nest cavity.

For the nesting attempted model, the response variable was binomial (attempted or not attempted), therefore we performed logistic regression using PROC LOGISTIC [20]. For other reproductive parameter models, response variables were continuous; therefore we performed linear regression using PROC REG [20]. For all models, multicollinearity was detected by diagnostic procedures [20]. Therefore, we specified the STEPWISE model selection option which provided reduced models for regression analyses. Multicollinearity problems were not detected in the reduced models during subsequent regression analyses. Following model selection, we ran separate regressions for each nest stage parameter (alpha = 0.10).

RESULTS

Reproductive Success and Microhabitat Characteristics

Seventy percent of RCW groups attempted nesting. RCWs averaged 3.2 eggs/nest, 2.8 eggs hatched/nest, and 2.0 young fledged/nest. Table **2** includes mean values ± standard errors for nesting season microhabitat variables and other behavioral variables.

Table 1. Microhabitat and behavioral variables sampled at Red-cockaded Woodpecker foraging locations at Bienville National Forest, Mississippi 1997–1999.

Variable	Definition
DENSIOT	Mean percent canopy cover at tree resolution
DENSIOF	Mean percent canopy cover at stand resolution
B1	Mean percent horizontal obstruction (2.0–2.5 m)
B2	Mean percent horizontal obstruction (1.5–2.0 m)
B3	Mean percent horizontal obstruction (1.0–1.5 m)
B4	Mean percent horizontal obstruction (0.5–1.0 m)
GROUND	Mean percent horizontal obstruction (0.0–0.5 m)
MIDHGT	Mean mid-story canopy height (m)
CANHGT	Mean dominant canopy height (m)
TOTSTEMS	Mean number of stems/ha
PSTEMS	Mean number of pine stems/ha
HSTEMS	Mean number of hardwood stems/ha
P35HA	Mean number of pine stems 7.6–12.7 cm/ha
P610HA	Mean number of pine stems 15.2–25.4 cm/ha
P11HA	Mean number of pine stems $\geq$27.9 cm/ha
H35HA	Mean number of hardwood stems 7.6–12.7 cm/ha
H610HA	Mean number of hardwood stems 15.2–24.5 cm/ha
H11HA	Mean number of hardwood stems $\geq$27.9 cm/ha
PSNAG	Mean number of pine snags/ha
HSNAG	Mean number of hardwood snags/ha
BAP35	Mean basal area of pine stems 7.6–12.7 cm (m^2/ha)
BAP610	Mean basal area of pine stems 15.2–25.4 cm (m^2/ha)
BAP11	Mean basal area of pine stems $\geq$27.9 cm (m^2/ha)
BAH35	Mean basal area of hardwood stems 7.6–12.7 cm (m^2/ha)
BAH610	Mean basal area of hardwood stems 15.2–24.4 cm (m^2/ha)
BAH11	Mean basal area of hardwood stems $\geq$27.9 cm (m^2/ha)
MID	Mean number of mid-story stems/ha
CAN	Mean number of dominant canopy stems/ha
TOTSNG	Mean number of snags/ha
HRA	Mean annual home range size (ha)
HRNN	Mean non-nesting season home range size (ha)
HRN	Mean nesting season home range size (ha)
BURN	Growing seasons since last prescribed burn (yrs)
DENSITY	Rank of RCW group density (1 = low; 2 = medium; 3 = high)
FODISTA	Farthest foraging location from brood tree annually (m)
FODISTNN	Farthest foraging location from brood tree (non-nesting season) (m)
FODISTN	Farthest foraging location from brood tree (nesting season) (m)

Table 2. Descriptive statistics of microhabitat and behavioral variables measured at Red-cockaded Woodpecker foraging locations at Bienville National Forest, Mississippi (1997–1999).

Variable	Mean	SE	Range
DENSIOT	93.6	0.4	87–97
DENSIOF	86.6	0.9	68–93
B1	49.8	3.0	12–82
B2	55.4	3.2	12–86
B3	62.8	3.3	13–92
B4	70.9	3.1	17–96
GROUND	84.3	2.0	46–99
MIDHGT	10.6	0.5	22–64
CANHGT	26.4	0.2	68–95
TOTSTEMS	364.5	17.5	155–890
PHA	228.1	11.3	128–470
HHA	143.6	10.4	27–420
P35HA	67.4	8.7	5–280
P610HA	42.7	3.8	2–109
P11HA	118.1	4.4	75–184
H35HA	84.9	6.9	13–280
H610HA	45.4	3.9	10–115
H11HA	12.2	2.0	0–70
PSNAG	6.4	0.8	0–19
HSNAG	28.3	4.2	2–99
BAP35	4.7	1.2	0–35
BAP610	7.7	1.6	0–59
BAP11	154.8	15.5	53–632
BAH35	6.5	2.1	0–69
BAH610	6.9	1.0	0–24
BAH11	4.6	1.6	0–61
MID	227.2	16.6	35–665
CAN	140.1	6.0	75–225
TOT	35.5	4.2	5–107
BURN	4.7	0.7	1–8
HRA	54.6	6.0	14–97
HRNN	42.9	6.4	10–94
HRN	24.0	3.0	7–45
DENSITY	2.1	0.2	1–3
FODISTA	783.2	57.9	280–1224
FODISTNN	739.1	62.9	400–1224
FODISTN	518.0	54.3	280–942

Nest Attempts

Mean percentage horizontal obstruction (2.0–2.5 m) (χ_1^2 = 4.47, P = 0.04) and mean nesting season home range were retained in the final logistic regression model (χ_1^2 = 2.86, P = 0.09). The model correctly classified 87% (33 of 38) of RCW nest attempts; however, the model only correctly classified 33% (1 of 3) of RCW groups that did not attempt nesting. Nest attempts were associated positively with mean percentage horizontal obstruction (2.0–2.5 m) (Coefficient = 0.136, SE = 0.07) and negatively associated with mean nesting season home range (Coefficient = -0.113, SE = 0.07).

Clutch Size

A five variable model (mean percentage canopy cover at tree resolution, mean percentage horizontal obstruction [2.0–2.5 m], mean mid-story canopy height**,** rank of RCW group density, and farthest foraging location from the brood tree annually) explained more variation than a model with no variables (i.e., intercept only) ($F_{5, 22}$ = 5.35, P < 0.001; R^2_{adj} = 0.44). Model selection procedures removed one variable, mean mid-story canopy height, from the final regression model (t_{22} = 1.69, P = 0.11). After model selection (Table **3**), four variables remained in the final regression model including: mean percentage canopy cover at tree resolution (t_{22} = 2.45, P = 0.02), mean percentage horizontal obstruction (2.0–2.5 m) (t_{22} = 2.19, P = 0.04), rank of RCW group density (t_{22} = 4.25, P < 0.001), and farthest foraging location from the brood tree annually (t_{22} = -2.34, P = 0.03).

Number Hatched

Six variables were entered into the regression model ($F_{6, 25}$ = 6.94, P < 0.001; R^2_{adj} = 0.54). All variables remained in the final regression model (Table **3**) including: mean number of hardwood stems $\geq$27.9 cm/ha (t_{22} = -3.40, P < 0.001), mean basal area of hardwood stems 15.2-24.4 cm m^2/ha (t_{22} = -3.82, P < 0.001), mean annual home range size (t_{22} = -2.65, P = 0.01), rank of RCW group density (t_{22} = 3.17, P < 0.001), farthest foraging location from brood tree [nesting season] (t_{22} = -2.94, P = 0.01) and mean non-nesting season home range size (t_{22} = -1.95, P = 0.06).

Number Fledged

Five variables were entered into the regression model (rank of RCW group density, mean nesting season home range size, mean number of midstory stems/ha, mean number of hardwood snags/ha, and mean percentage horizontal obstruction [1.0–1.5 m]) ($F_{5, 31}$ = 4.53, P < 0.001; R^2_{adj} = 0.33). Model selection procedures dropped two variables, mean nesting season home range size (t_{22} = -1.69, P = 0.11) and mean percentage horizontal obstruction (1.0–1.5 m) (t_{22} = -1.58, P = 0.13) from the final model. Three variables remained in the final regression model (Table **3**), mean number of midstory stems/ha (t_{22} = -2.33, P = 0.03), mean number of hardwood snags/ha (t_{22} = -2.36, P = 0.03), and rank of RCW group density (t_{22} = 1.89, P = 0.07).

Table 3. Coefficients ± standard errors (SE) associated with significant variables from linear regression models of Red-cockaded Woodpecker microhabitat and behavioral characteristics compared to reproductive success parameters at Bienville National Forest, Mississippi 1997–1999.

Reproductive Parameter	Variable	Coefficient	±SE
Clutch size			
	Intercept	-12.4	5.97
	DENSITY	+0.514	0.12
	B1	+0.012	0.01
	FODISTA	-0.001	<0.001
	DENSIOT	+0.142	0.06
Number hatched			
	Intercept	+2.61	0.27
	H11HA	-0.02	0.01
	BAH610	-0.03	0.01
	HRA	+0.012	0.01
	DENSITY	+0.297	0.09
	FODISTN	-0.001	<0.001
	HRNN	-0.013	0.01
Number fledged			
	Intercept	+3.54	0.7
	DENSITY	+0.226	0.12
	MID	-0.003	<0.001
	HSNAG	-0.014	0.01

DISCUSSION

Nest Attempts

Two variables, mean percentage horizontal obstruction (2.0–2.5 m) and mean nesting season home range were useful in predicting RCW nest attempts. RCW nest attempts were related positively with increased values of horizontal obstruction (i.e., understory vegetation density). Understory vegetation at the Bienville NF consisted mainly of herbaceous vegetation, vines, and hardwood shrubs and saplings [12]. Other researchers suggested that height of understory vegetation may affect production of insect prey used by foraging RCWs [5]. Although we did not sample potential prey availability and their habitat associations, several studies have examined RCW prey selection. In South Carolina, adult RCWs provisioned chicks with several insect species associated with understory habitats [21]. Similarly, other researchers determined that a significant proportion of the macroarthropod biomass available to foraging RCWs originate in the soil and vegetative litter on the forest floor [22]. Therefore, the structure and composition of the understory may have a significant impact on RCW fitness [23,24].

RCW nest attempts were negatively associated with RCW nesting season home range size. Thus, RCW groups that did not attempt nesting had larger mean nesting season home ranges than RCW groups that did nest. This suggests that RCW groups located in areas with better habitat quality have smaller home ranges than RCW groups in poor quality habitats with larger home ranges [12]. RCW groups that fly shorter distances to obtain food for nestlings would retain a competitive advantage over groups that fly longer distances to obtain the same resources [9,25].

Clutch Size

RCW clutch size was positively associated with understory vegetation height and increasing RCW group density. The strong positive relationship of canopy cover reflects the presence of a high stocking density of mature pines in the cluster areas. No relationship between RCW group density and provisioning rates of nestlings was reported in a Texas RCW subpopulation; however, clutch size was not included as a dependent variable [26]. Conversely, RCW clutch size was related inversely with farthest foraging distance from the brood tree (i.e., RCW groups with larger clutch sizes foraged closer to the brood tree than RCW groups with smaller clutch sizes). This result suggests that RCW groups with smaller annual foraging ranges were able to lay larger clutches [9,25]. In Louisiana, other researchers reported mean seasonal foraging distances for RCW groups in Louisiana; however, they did not attempt to relate measures of RCW reproductive success with foraging distance [27].

Number Hatched

The number of hatchlings was positively related to increasing RCW group density. The negative relationship with presence of hardwood stem density and basal area was similar to other studies of RCW habitat selection [25,27,28]. The inclusion of mean annual and non-nesting season home range size suggests that hatching success may be related to habitat quality and group density. In areas with increased RCW group densities, RCW home ranges should be smaller than RCW groups in areas of decreased group density due to territoriality and competition. This also suggests that RCW groups occupying better habitats require less space to meet the energetic requirements of nestlings and adults. The negative relationship with foraging distance in the model supports this hypothesis. This relationship has been documented in paruline warblers [29], belted kingfisher (*Megaceryle alcyon*) [30], and Lapland longspurs (*Calcarius lapponicus*) [31].

Number Fledged

The number of fledglings was positively associated with increasing RCW group density [26,32]. However, RCW fledgling production was negatively associated with mean number of midstory stems/ha and hardwood snags/ha. This result suggested that fledgling numbers increased with decreasing hardwood stem densities. On private timber lands, no relationship between number of fledglings/nest and hardwood stem densities or basal area within 400–800 m of RCW brood trees was detected [5]. In a mixed pine forest in Louisiana, RCWs selected foraging sites with low hardwood basal areas during the nesting and non-nesting season, although they did not relate microhabitat selection with RCW reproductive success [27]. Similarly, others reported that RCWs selected foraging stands with low hardwood stem densities and high pine densities, but did not relate habitat selection to reproductive success [8]. In Arkansas, RCWs selected foraging sites with fewer hardwoods (<22.9 cm), but no attempt was made to relate habitat components with reproductive success [25]. Other studies have examined RCW microhabitat selection and fledgling production; however hardwood components were not included in analysis [4,11].

Microhabitat and Reproductive Success

Numerous descriptive studies have examined RCW microhabitat selection [33-38], although none of those studies examined the role of microhabitat selection and RCW fitness measures. Several studies examined RCW reproductive success and microhabitat selection; however, these studies produced conflicting results. In southwestern Georgia, RCWs in old-growth longleaf pine forest demonstrated greater reproductive success, than RCWs in modified landscapes with lower habitat quality [39]. Others reported a relationship between RCW reproductive success and indicators of habitat quality (i.e., microhabitat variables) including number of cavities present, understory height, and dbh of overstory pine trees in North Carolina [11]. Using microhabitat variables, a discriminant function was developed that was 80% successful at classifying successful and unsuccessful RCW groups [11]. In a Florida longleaf pine forest, a positive relationship between RCW reproductive success measures and microhabitat variables was reported [32]. The number of RCW fledglings produced was inversely related to density of pine trees >25 cm dbh and pine basal area (i.e., increased densities of large pine stems and large pine basal areas had a negative impact on RCW reproductive success) [32].

Conversely, several studies reported insignificant relationships between RCW reproductive success and microhabitat variables. In a Florida longleaf pine forest, researchers were unable to link RCW reproductive success with microhabitat variables associated with RCW foraging habitat management guidelines [4]. On private timber lands in Louisiana, no relationship between microhabitat variables and the presence of eggs or fledglings produced was detected in univariate analyses or included in predictive models [5].

RCW reproductive success was correlated with habitat and behavioral characteristics that emphasize high quality habitat. By providing high quality foraging habitat during the nesting season, RCWs can successfully reproduce within small home ranges (i.e., increase group density). This would allow more RCWs to make greater contributions to population recruitment and species recovery.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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PATIENT'S CONSENT

Declared none.

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