GOLDEN-CHEEKED WARBLER (*DENDROICA CHRYSOPARIA: PARULIDAE*) TERRITORY AND NON-TERRITORY HABITAT CHOICE IN FRAGMENTED ASHE JUNIPER PATCHES ON THE KERR WILDLIFE MANAGEMENT AREA

THESIS

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TABLE OF CONTENTS

PAGE

LIST OF TABLES

LIST OF FIGURES

FIGURE **PAGE**

ABSTRACT

GOLDEN-CHEEKED WARBLER (*DENDROICA CHRYSOPARIA: PARULIDAE*)

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Golden-cheeked Warblers (*Dendroica chrysoparia*) use a variety of cues for selecting appropriate habitat. This study examined habitat variables associated with Golden-cheeked Warbler habitat choice in territories and non-territory areas in fragmented Ashe juniper (*Juniperus ashei*) patches on the Kerr Wildlife Management Area. The point-centered quarter method was used to gather vegetational data. Woody vegetational characteristics in both the canopy ($\geq$ 1.5 m) and understory (< 1.5 m) in

territory ($n = 25$) and non-territory ($n = 25$) areas were analyzed through stepwise (backwards) logistic regression. The normal approximation to the Mann-Whitney U test was used to examine differences between territory and non-territory areas. Canopy and understory statistics were handled separately. Differences in territory and non-territory areas were found to be a combination of woody plant structure and species composition. Territory areas had greater patch size, less total density of all plants, greater mean area per plant, and greater mean canopy coverage per plant in both the canopy and understory. Canopy in territories had fewer individual plants, a greater point-to-plant distance, less mean total canopy coverage for all species, and less mean total density than non-territory areas while territory understories had a greater number of plants, relatively equal point-to-plant distance, greater mean total canopy coverage for all species, and less mean total density than non-territory areas. The logistic regression model was tested for discrimination and calibration by ROC analysis and the Hosmer and Lemeshow goodness-of-fit test.

INTRODUCTION

Wood warblers (family Parulidae), as their name suggests, are typically found in woodlands, forests, or dense brush. Parulid warblers vary in their degree of habitat specialization, some being very specialized, with specific components of the habitat critical for survival and reproductive success. (Dunn and Garrett 1997). For example, the Kirtland's Warbler (*Dendroica kirtlandii*) requires brushy young jack pines (*Pinus banksiana*) which are the result of fire stimulating the germination of seeds from mature growth forest and creating patchy new growth.

The Golden-cheeked Warbler, *Dendroica chrysoparia* (GCW hereafter), an endangered, insectivorous songbird of the family Parulidae, is also a habitat specialist. This species is the only endemic breeding bird of Texas closely associated with mature Ashe juniper (*Juniperus ashei*) - mixed oak (*Quercus* spp.) woodlands and forests on the Edwards Plateau, Lampasas Cut Plains, and Llano Uplift regions (Pulich 1976, Keddy-Hector 1992). This species is highly dependent on mature Ashe juniper for their specialized nest building in which the shredding bark of mature Ashe juniper is primarily used in nest construction.

Due to significant population declines in recent years, loss of nesting habitat, and reduction in the overall range, a federal endangered status for the species was established by an emergency ruling (55 FR 18844) on 4 May 1990. A permanent listing of the GCW under the Endangered Species Act occurred on 27 December 1990 (FR 55 53153) and listing as an endangered species for the state of Texas by Texas Parks and Wildlife on 19 February 1991 (Executive Order No. 91-001) (Keddy-Hector 1992). Currently, the most serious threats to the viability of the GCW in the northern, spring-summer distribution include loss and fragmentation of breeding habitat mainly because of urbanization, agriculture, and range management practices and nest parasitism by the Brown-headed Cowbird (*Molothrus ater*).

Habitat of the Golden-cheeked Warbler

The typical central Texas breeding habitat for GCWs can be generalized as old-growth woodlands containing a significant portion of Ashe juniper mixed with various species of oak. Specifically, GCWs prefer areas with a moderate to high density of older trees and dense foliage in the upper canopy. Mature Ashe junipers (20 to 40 years old) with loose, stripping bark provide GCWs material for nest construction, as well as singing perches (Pulich 1976, Kroll 1980, Shaw 1989, Wahl et al.1990, Dunn and Garrett 1997) while oaks provide foraging substrate (Wahl et al. 1990, Pulich 1976). Preferred habitat is usually somewhat mesic, such as that associated with steep canyons and slopes along creeks and draws. There is usually a large percentage (50-100%) of continuous canopy coverage.

Background of This Study

Attwater in 1892 first reported GCWs in Kerr County, Texas (Attwater 1892, Pulich 1976). Today almost all of Kerr County has GCW habitat wherever sufficient amounts of Ashe juniper exist (Pulich 1976). One of the more western localities in the distribution of GCWs is the Kerr Wildlife Management Area (KWMA hereafter) located near Hunt, Kerr County, Texas on the headwaters of the North Fork of the Guadalupe River. The landscape of the KWMA is characteristic of the Edwards Plateau (Hill Country) of Texas with gentle hills, fresh water springs, dense Ashe juniper brakes, and live oak-shin oak thickets (Texas Parks and Wildlife 1986). In the 1960s, range improvement practices on the KWMA resulted in the removal of a large portion of the Ashe juniper. Selected patches of mature Ashe juniper stands were retained for historical GCW habitat and as cover for wildlife in Spring Pasture, Spring Trap and along watersheds.

Texas Parks and Wildlife Department (hereafter TPWD) and U. S. Fish and Wildlife Service (hereafter USFWS) have established management guidelines for landowners by describing habitat where GCWs are expected to occur, where they may occur, and where they are not expected to occur (Campbell 1995). Thirty year old Ashe juniper patches maintained on the KWMA now meet the size requirements for GCW breeding habitat (shredding bark, $\geq$ 4.6 m tall), but with a questionable mix of hardwoods, these areas have habitat classified as habitat which may be used by warblers. However, field surveys suggest that the assemblage of GCWs on the KWMA is increasing and spreading to these Ashe juniper patches. In 1984 (Ladd 1985), 18 territories were found with 15 in Spring Pasture and Spring Trap, and three in River Pasture. Ladd (1985) observed GCWs again in 1985 in Spring Pasture and Spring Trap where they were expected to occur and in Buck Pasture, in habitat classified as where warblers may occur. In 1992, 22 GCWs were banded on the KWMA and observed in Ashe juniper patches in Bobcat, Buck, Fawn, and Love pastures in habitat classified as where GCWs may occur. A more intense survey of the entire KWMA occurred in 1998.

GCWs were found in areas with previous documentation, new locations within these pastures, and in additional pastures.

Definition of "Patch"

The definition of "patch" used in this paper is: a particular unit with identifiable boundaries which differs from its surroundings in one or more ways. These can be a function of plant composition, structure, age or some combination of the three. In this study, the vegetational structure of the KWMA was modified through mechanical fragmentation in the 1960's creating visually and structurally defined fragmented Ashe juniper patches. Wiens (1976) stated that from an ecological perspective, patches are dynamic and represent relatively discrete areas (spatial domain) or periods (temporal domain) of relatively homogeneous environmental conditions where the patch boundaries are distinguished by discontinuities in environmental character states from their surroundings of magnitudes that are perceived by or relevant to the organism or ecological phenomenon under consideration. From a strictly organism-centered view, patches may be defined as environmental units between which fitness prospects, or "quality", differ (Wiens 1976).

Purpose of This Study

Several studies have characterized optimal GCW habitat and use by GCWs, yet little is known about the use of less than optimal habitat, especially in fragmented Ashe juniper patches. No studies in the same area have focused on the contrasting characteristics of habitat where GCWs have territories and habitats without GCWs. This study will provide information on GCW habitat choice relative to the characteristics of the woody vegetation. In addition, this study will add to the knowledge of patch use by GCWs and help to define the understory structure in breeding/non-breeding habitat. These parameters were identified as information and research needs in the Golden-cheeked Warbler Population and Habitat Viability Assessment Report (USFWS 1996). This study will also provide insight on active land management practices that affect this species and will aid landowners in creating or maintaining GCW habitat.

Data recorded for the 1998 field season (March to July, when GCWs are present on the KWMA) were used to answer the following questions:

1. What is the distribution of GCWs on the KWMA?
2. What is the extent of Ashe juniper patch use by GCWs on the KWMA?
3. What is the density of GCWs per patch?

The bulk of this paper, however, is dedicated to the following questions:

4. What canopy and understory features of the woody vegetation characterize the habitat where GCWs are expected / not expected to occur? Is there a difference in woody vegetation between GCW territories and other areas in patches of Ashe juniper? Can a model be generated which would explain these differences, if they do exist?

MATERIALS AND METHODS

Study Area

The KWMA is located in Kerr County, Texas, 19.3 km northwest of Hunt, Texas. It was purchased under the Pittman-Robertson Act using Federal Aid in Wildlife Restoration Program funds in 1950. Today the 2,628-ha KWMA is managed by TPWD as a wildlife management, research, and demonstration area for the Edwards Plateau ecoregion (Texas Parks and Wildlife 1998).

Topography of the KWMA is gently rolling to hilly with occasional draws and small canyons. Rocky and shallow soils cover a layer of limestone. Elevation ranges from 585 m – 661 m. The average annual rainfall is 64.8 cm with most occurring during April-June and August-October.

The flora of the landscape varies from grassland to mixed woodlands. Dominant tree species include oaks (*Quercus* spp.) and Ashe Juniper. Ashe juniper patches ranging in size from 0.40 ha to 258.60 ha occur in 23 pastures (Fig. 1). Common grasses are Texas wintergrass (*Stipa leucotricha*), little bluestem (*Schizachyrium scoparium*), curlymesquite (*Hilaria bleangeri*), and sideoats grama (*Bouteloua curtipendula*). Perennial forbs are increasing in abundance and diversity due to improved range conditions. Numerous wildlife species are also present such as white-tailed deer (*Odocoileus virginianus*), Rio Grande Turkey (*Meleagris gallopavo intermedia*), Black-tailed jackrabbits (*Lepus californicus*), and Northern Bobwhite (*Colinus virginianus*)

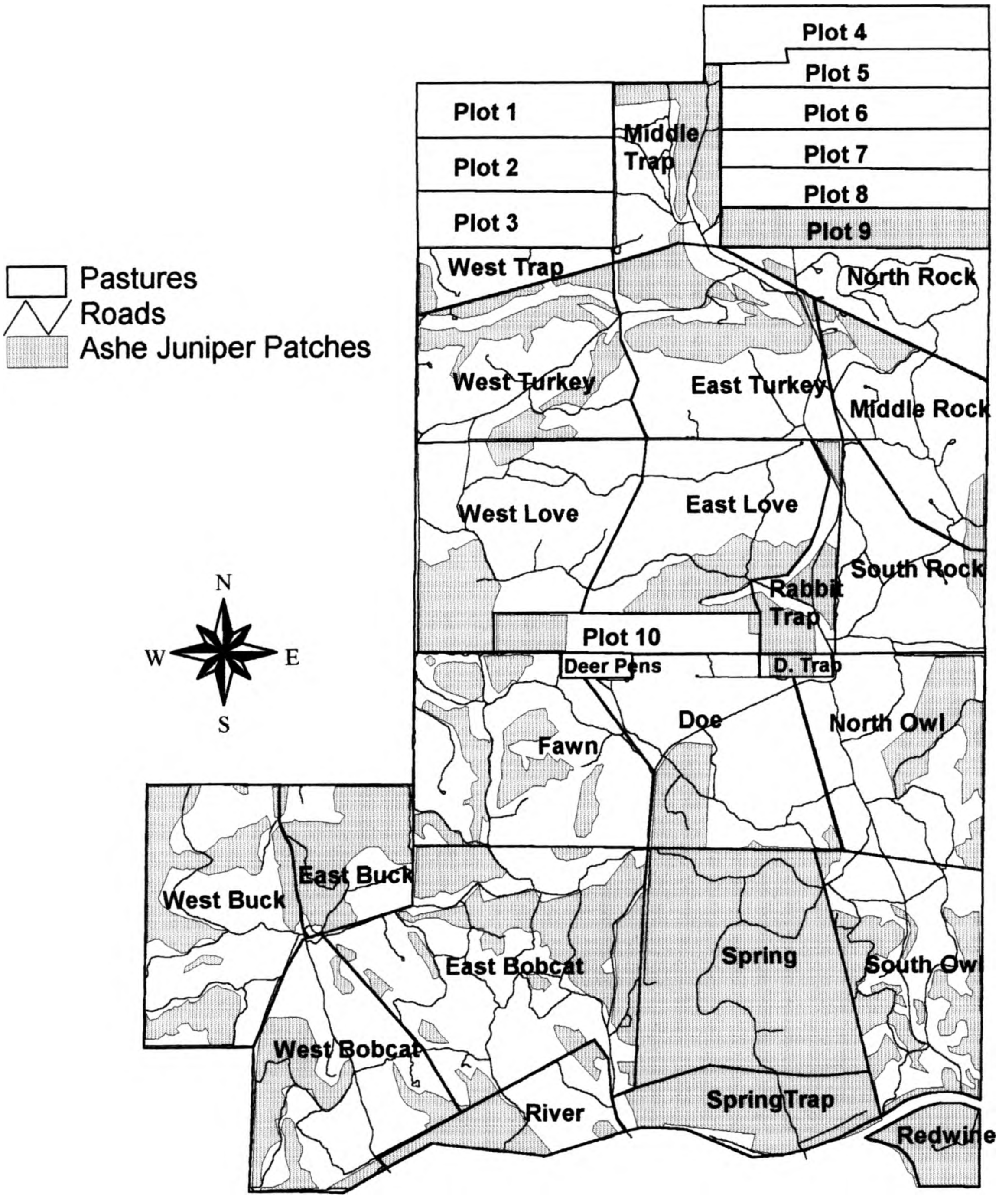

Fig. 1. The location of Ashe juniper patches and roads on the Kerr Wildlife Management Area.

(Texas Parks and Wildlife 1998). GCWs are present on the KWMA from March through July.

Intensive land and wildlife management techniques practiced at the KWMA include managed hunts, livestock rotational grazing, prescribed burns, brush management and cowbird trapping (Texas Parks and Wildlife 1986, Texas Parks and Wildlife 1998).

Data Collection

Searching for Territories

During March to July 1998, intensive surveys for GCWs were conducted in pastures with Ashe juniper patches on the KWMA. Based on data from previous surveys and habitat composition, pastures surveyed included those where GCWs were expected to occur, those in which they may occur, and those where they were not expected to occur. Searching began at dawn and continued into the late afternoon early in the season, but only dawn to early afternoon later in the season as days got hotter and singing ceased earlier in the day. Roads that bordered Ashe juniper patches were surveyed on foot or by vehicle (Fig. 1). If a patch had a width > 250 m perpendicular to the road, the area was explored further on foot. Whether surveying by car or on foot, a minimum of one to four hours was spent searching in each patch depending on the size. If no birds were heard, the patch was visited 3-5 days later. This was repeated until the patch was surveyed at least five times. Any observations of GCWs were recorded, and the location was given a number and flagged. A territory was recognized based on a minimum of three different sightings of a singing male in the same area or a male with a companion female. "Same area" was defined as falling within the average territory size (17,400 m^2) for GCWs

(Pulich 1976). The locations of territories were based on the estimated center of activity and recorded with a GPS unit. This information was recorded in ArcView 3.0a (ESRI, Inc. 1992-1997, Redlands, California).

Nest and Fledgling Searching

Although reproductive success was not the primary focus of this study, I did search for nests when incidental behavioral or audio cues were detected. Cues included females carrying nesting materials, adults carrying food, nestlings begging for food, and females vocalizing a distinct high-pitched chip. Searches for fledglings were conducted using the same cues as for nests. Locations of both nests and fledglings were flagged, their locations entered into a GPS unit, and the points recorded in ArcView.

Habitat Analysis

In 1998, habitat analysis was completed on 25 known territories, and on 25 other areas where warblers were not found, but where the visual characteristics of the woody vegetation suggested they might occur (mature Ashe junipers along with mixed oaks and various hardwoods; Fig. 2). This study included pastures where GCWs were expected to occur, where they may occur and where they were not expected to occur. The point-centered quarter method (Cottam and Curtis 1956) was used with 100 m intersecting sampling lines extended in the cardinal directions. Ten randomly chosen sample points were used to document woody vegetation on each line. The starting point was the estimated center of each territory, and a randomly chosen point in areas where GCWs did not occur. Woody plant species, point-to-plant distance (not exceeding 10 m) and canopy length and width were recorded. A height of 1.5 m was used as the separation for "canopy" and "understory" variables. This height was chosen to correspond with an

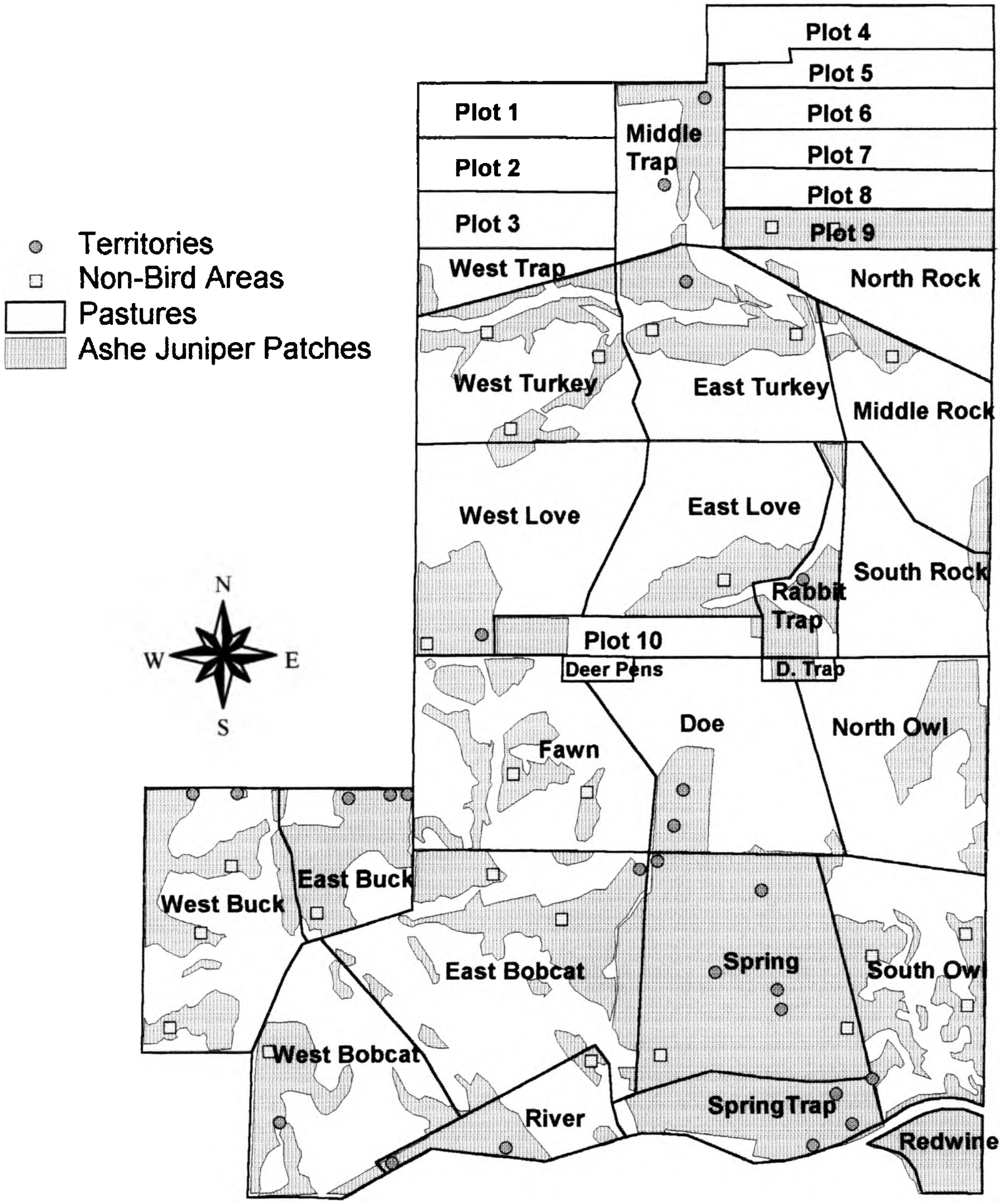

Fig. 2. The location of territory and non-territory areas used in vegetational analysis on the Kerr Wildlife Management Area in 1998.

approximate white-tailed deer browse line. "Canopy" was woody vegetation ≥ 1.5 m; "understory" was woody vegetation < 1.5 m.

Statistical Analysis

Hypothesis

The null hypothesis for all statistical tests was that any difference in the characteristics of woody vegetation between territory and non-territory areas was due to random sampling error.

Habitat Analysis

All data were first entered into a Microsoft Excel 97 (Microsoft Corp., 1997, Redmond, Washington) spreadsheet for evaluation. For each point the following were calculated for both canopy and understory in both territories and non-bird areas: mean point-to-plant distance, mean area per plant, density of all plants, mean canopy area per species, importance values of each species, absolute and relative density, dominance, and frequency for each species. Canopy and understory statistics were analyzed separately. I used SPSS for Windows Version 10.0.5 (SPSS Inc., 1999, Chicago, Illinois) for the statistical analysis.

Logistic Regression

A model to explain GCWs presence based on vegetational characteristics was obtained by binary logistic regression using backwards elimination based on the probability of the likelihood-ratio statistic, which is based on the maximum partial likelihood estimates. With backward elimination, there is less risk of failing to find a relationship when one exists (Menard 1995). With this method, all chosen variables are in the model at the onset of analysis. Then variables are eliminated one by one based on their inability to improve the model's correct classification of sites with GCWs (Menard 1995). This is done by looking at the change in –2 log-likelihood when each variable is deleted. The likelihood ratio statistic is called the "deviance" by some authors, and plays a significant role in assessing goodness-of-fit of the model (Hosmer and Lemeshow 1989). This method is useful in the analysis of relationships between a response (dependent) variable and one or more explanatory variables (independent variables) (Hosmer and Lemeshow 1989). The dependent variable in this study was binary (absence or presence of GCWs) and the independent variables were the 10 woody species with the greatest densities for each canopy and understory, various parameters of the woody vegetation compiled from the data, as well as patch size. The probability for stepwise was 0.05 for entry and 0.10 for removal. Classification cutoff was 0.50.

The models for both Canopy and Understory that correctly classified the largest number of sites are reported. For the best-fit model for canopy, the density variables were: ASHEJUN (Ashe juniper), TEXOAK (Texas oak, *Quercus buckleyi*), SHINOAK (shin oak, *Quercus sinuata*), LIVEOAK (live oak, *Quercus virginiana*), LACEYOAK (Lacey oak, *Quercus glaucoides*), HACKBERR (hackberry, *Celtis laevigata*), CEDARELM (cedar elm, *Ulmus crassifolia*), PERSIMMO (persimmon, *Diospyros virginiana*), RIVWALNU (river walnut, *Juglans microcarpa*), and REDBUD (redbud, *Cercis canadensis*). Also used in the analysis were PATCHHA (patch size in hectares), TOTALDEN (total density of all species), MEANAREA (mean area occupied per plant), and MEANCANO (mean canopy area per plant).

The best-fit model for understory density variables were: ASHEJUN (Ashe juniper), TEXOAK (Texas oak), SHINOAK (shin oak), LIVEOAK (live oak), LACEYOAK (Lacey oak), HACKBERR (hackberry), PERSIMMO (persimmon), AGARITA (agarita, *Mahonia trifoliolata*), RIVWALNU (river walnut), and FRAGMIMO (fragrant mimosa, *Mimosa borealis*). PATCHHA (patch size in hectares), TOTALDEN (total density of all species), MEANAREA (mean area occupied per plant), and MEANCANO (mean understory [< 1.5m] canopy area of all species).

Model Calibration and Discrimination

Evaluating the predictive performance of a model is a vital step in model development (Pearce and Ferrier 2000b). Two criteria of evaluation were used with each logistic regression model: model calibration/reliability and model discrimination. Model calibration tells how closely the observed and predicted probabilities match (Norusis 1999, Pearce and Ferrier 2000b). The Hosmer and Lemeshow goodness-of-fit test was used to evaluate this criteria ($p < 0.05$). Model discrimination, or the ability of the model to distinguish between cases in the two groups was done by receiver operating characteristic (ROC) analysis. The area under the ROC curve (AUC) is reported. Values for the AUC can range from 0.5 for models with no discrimination ability, to 1.0 for models with perfect discrimination ability.

Mann-Whitney U

Preliminary tests for normality of the data were conducted on the same variables used in the logistic regression. The tests included histograms, stem and leaf plots, normal and normal detrended probability (normal Q-Q) plots, and box and whisker plots. Many of the variables did not appear to be normally distributed, so not to violate an assumption of the independent samples *t*-test, the normal approximation to the Mann-Whitney *U* test was chosen to examine whether differences existed in vegetational characteristics between sites with and without GCWs. Variables used were the same for the logistic regression canopy and understory models, respectively, with the addition of MEANDIST (mean point to woody plant distance), and TOTCANOP (sum of canopy coverage of all species in m^2/ha) to both sets. *P* values < 0.05 were considered statistically significant.

RESULTS

GCW Distribution on the KWMA

Fifty-seven male GCWs and three females were found on the KWMA (Fig. 3). Forty of the 57 males were sighted three or more times, seven twice, and 10 were sighted once (Table 1). No GCWs were found in Plot 9, North Rock, West Turkey, or North Owl pastures. Spring pasture had the most sightings with 10. Three birds were sighted one time each on the border between two pastures: East Love / Rabbit Trap, Middle Rock / South Rock, and Fawn / Plot 10. Two other pastures, Rabbit Trap and Redwine, also had just one sighting. The 40 birds that were sighted three or more times in the same general area were assumed to have established a territory (Fig. 4). Ten territories were found in Spring Pasture, which had the most, while South Owl, West Bobcat, West Love, East Love / Rabbit Trap, and Rabbit Trap had just one territory each (Table 2).

Ashe Juniper Patch Use by GCWs on the KWMA

The first observation of a GCW on the KWMA in 1998 was on 18 March. Various Ashe juniper patches on the KWMA were used by GCWs for establishing territories, defending territories, foraging, nest building, and raising young. Not all behaviors were observed in all patches. In 1998, two nests were found in two different Ashe juniper patches (Doe, East Bobcat; Fig. 5). The nest in Doe pasture was active with three chicks. Only one fledgling from this nest was seen on a later date. The other chicks may have fledged but this cannot be confirmed. The other nest (East Bobcat) was not

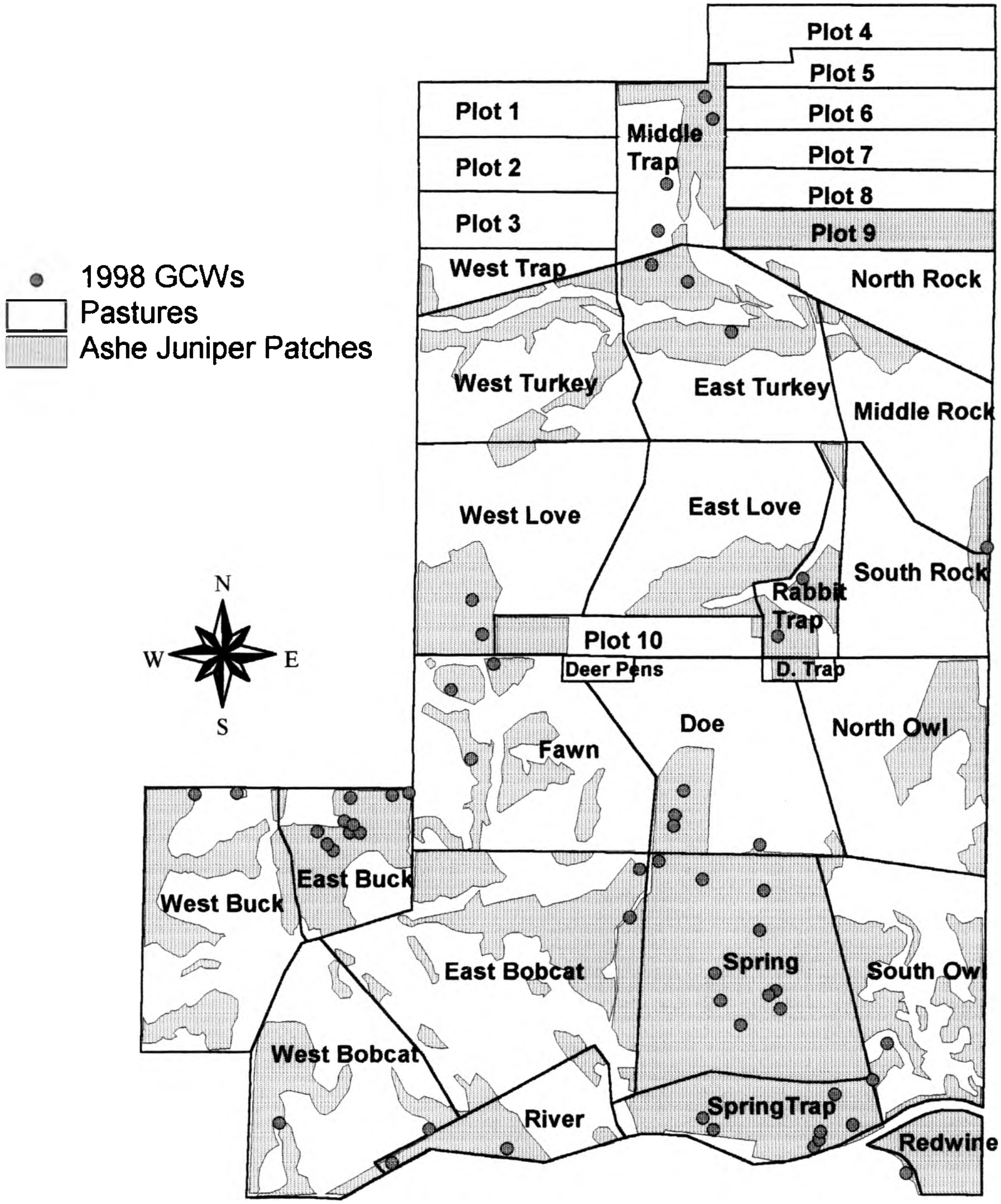

Fig. 3. The locations of all male Golden-cheeked Warbler observations for 1998 on the Kerr Wildlife Management Area.

Table 1. The number of sightings per Golden-cheeked Warbler for all male Golden-cheeked Warblers observed on the Kerr Wildlife Management Area in 1998.

	Number Sightings/Bird			
Pasture	**= 1**	**= 2**	**≥ 3**	**Total**
Spring			10	10
East Buck	4	2	3	9
Spring Trap	1		6	7
Doe	1		4	5
Middle Trap			4	4
East Turkey		1	2	3
East Bobcat			2	2
River			2	2
South Owl		1	1	2
West Bobcat	1		1	2
West Buck			2	2
West Love		1	1	2
Fawn	1	1		2
East Love / Rabbit Trap			1	1
Fawn / Plot 10	1			1
Middle Rock / South Rock	1			1
Rabbit Trap			1	1
Redwine		1		1
TOTAL	**10**	**7**	**40**	**57**

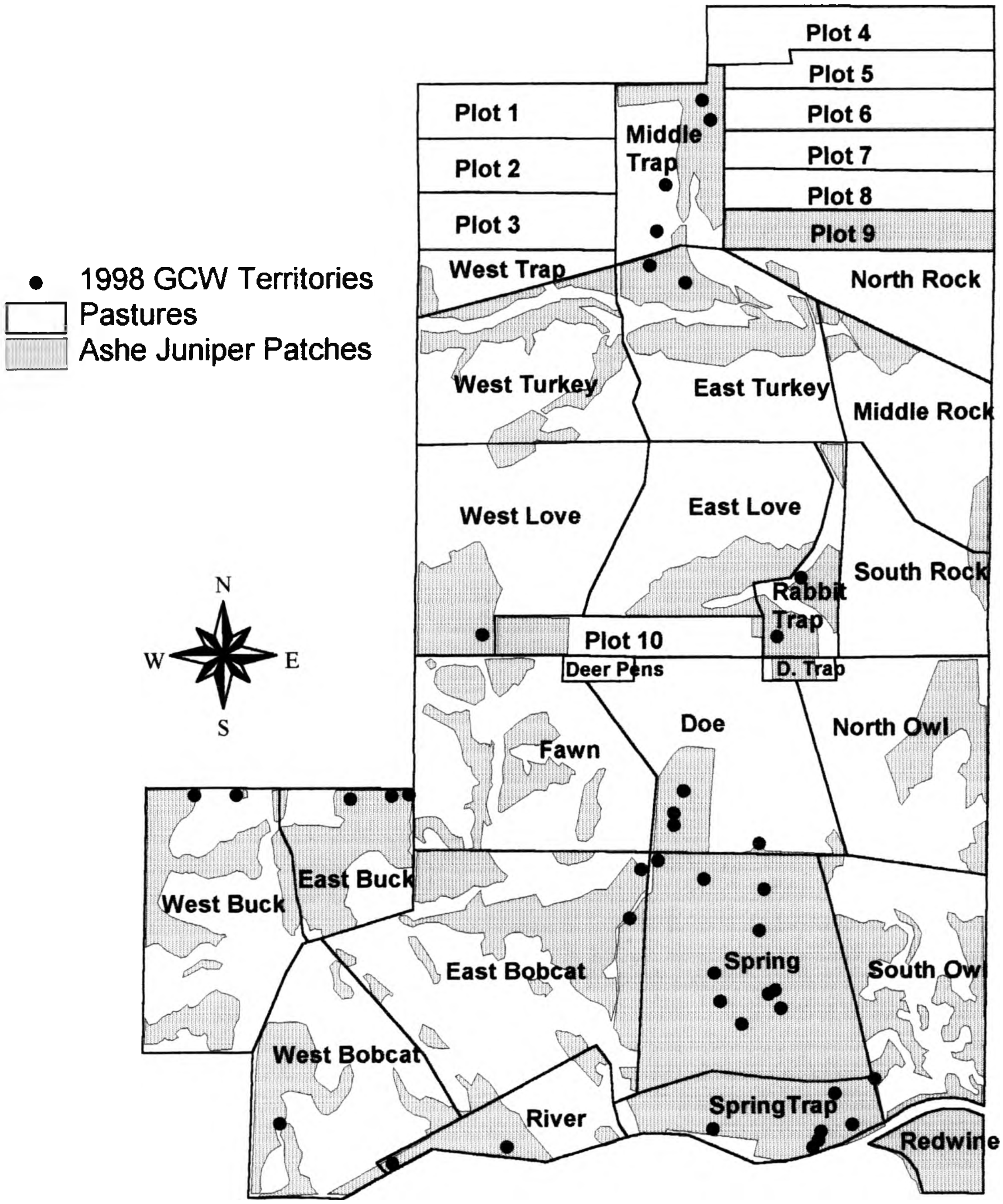

Fig. 4. The locations of all Golden-cheeked Warbler territories for 1998 on the Kerr Wildlife Management Area.

Table 2. The number of Golden-cheeked Warbler territories by pasture on the Kerr Wildlife Management Area, 1998.

Pasture	**Territories**
Spring	10
East Buck	3
Spring Trap	6
Doe	4
Middle Trap	4
East Turkey	2
East Bobcat	2
River	2
South Owl	1
West Bobcat	1
West Buck	2
West Love	1
Fawn	0
East Love / Rabbit Trap	1
Fawn / Plot 10	0
Middle Rock / South Rock	0
Rabbit Trap	1
Redwine	0
TOTAL	**40**

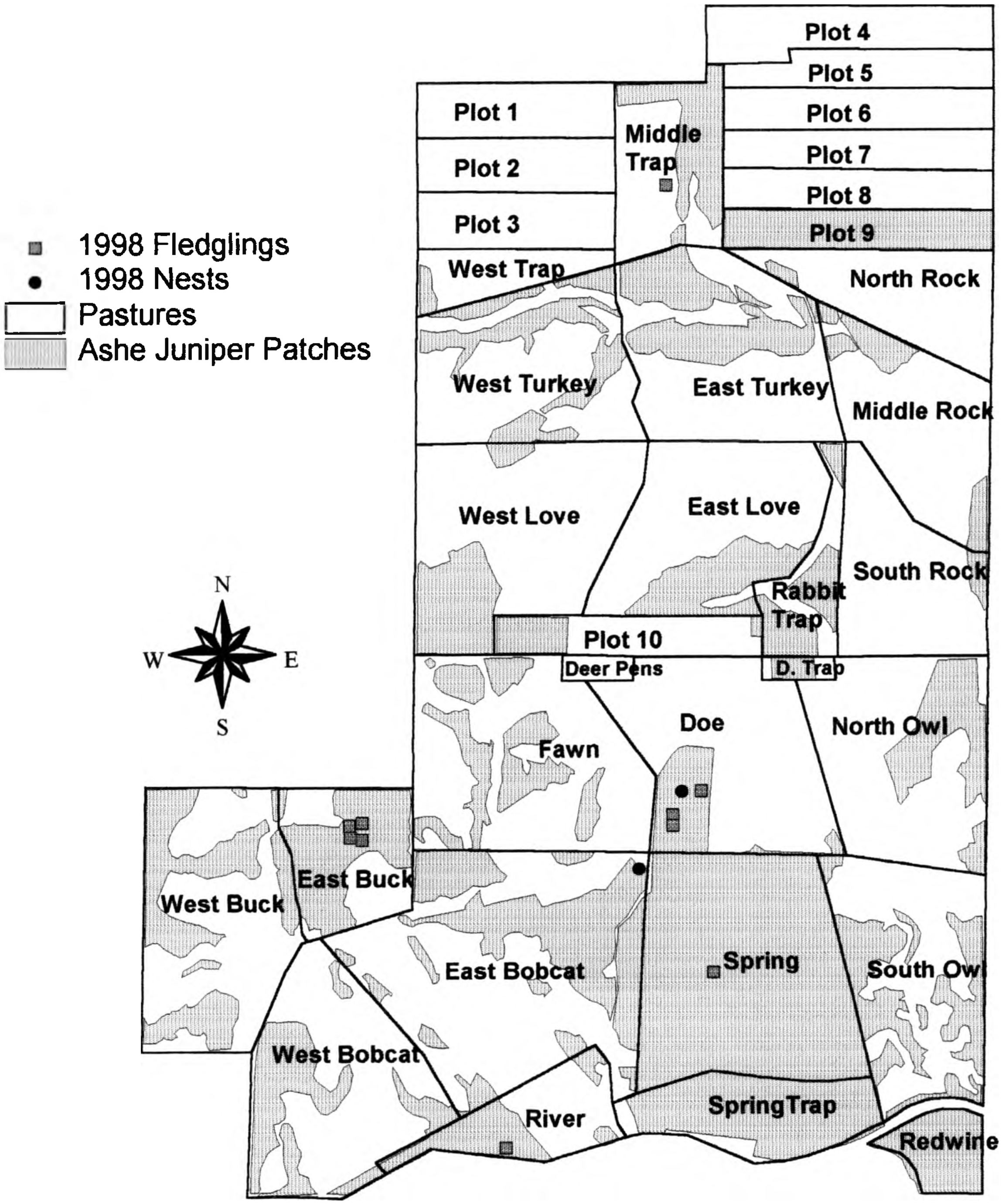

Fig. 5. The locations of nests and fledglings observed on the Kerr Wildlife Management Area in 1998.

observed in an active state, so it was uncertain whether it was from this field season or a previous one. A total of 10 fledglings were observed in the 1998 field season in 5 pastures in 4 different Ashe juniper patches (Fig. 5). The majority of fledglings were observed with the male or alone (Table 3). The last GCW was seen/heard on 23 June.

Density and Patch Size

The density of GCWs (per 100 ha pasture) and estimated territory size can be seen in Table 4. The smallest Ashe juniper patch containing a GCW territory and completely within the boundaries of the KWMA was 17.4 ha, while the largest was 258.6 ha. Mean patch size that contained a territory for all observed territories was 126.3 ha ($n = 40$). Mean territory patch size used in the statistical analysis was 111.2 ha ($n = 25$). Mean non-territory patch size was 52.6 ha ($n = 25$). The largest estimated territory size was 40.47 ha in Rabbit Trap pasture, while the smallest was 4.76 ha in Doe Pasture. The mean territory size was 1 territory / 15.14 ha ($n = 40$) for all observed territories and 1 territory / 22.42 ha ($n = 25$) for those territories used in the statistical analysis. Territory size estimates were based on the number of birds per Ashe juniper patch and not actual measurements.

Canopy and Understory Woody Vegetation Features of GCW Habitat on the KWMA

In 1998, the following woody plant species were identified through habitat analysis of the canopy and understory on the KWMA: post oak (*Quercus stellata*), Ashe juniper, live oak, shin oak, Lacey oak, Texas oak, shin-Vasey oak hybrid (*Quercus sinuata x Quercus pungens)*, hackberry, bumelia (*Bumelia lanuginosa)*, fragrant mimosa, kidneywood (*Eysenhardtia texana*), cedar elm, river walnut, redbud, persimmon, agarita,

Table 3. The number of Golden-cheeked Warbler fledglings observed in territories in pastures on the Kerr Wildlife Management Area, March to July 1998.

GCW ID	Pasture	Date sighted	Number of fledglings	Sighted with male or female
5	Doe	6 Jun	1	Male
6	Doe	2 Jun	1	Male
9	Doe	13 May	1	Male
56	East Buck	23 Jun	1	Male
60	East Buck	3 Jun	3	Both
26	River	3 Jun	1	Male
43	Spring	11 Jun	1	Alone
23	Middle Trap	23 Jun	1	Alone

Table 4. Density of Golden-cheeked Warblers per 100 hectares and territory size (ha) of Golden-cheeked Warbler pairs per patch at the Kerr Wildlife Management Area, 1998.

Pasture	Size (ha)	n	Density	Territory size[a]
Spring[b]	258.60	10	6.57	15.21
Spring Trap[b]	258.60	6	6.57	15.21
South Owl[b]	258.60	1	6.57	15.21
Doe	19.02	4	21.03	4.76
East Buck	42.90	3	6.99	14.30
Middle Trap	25.50	4	15.68	6.38
East Turkey	17.40	2	11.49	8.70
West Bobcat	29.54	1	3.39	29.54
West Buck[c, d]	0.40	1	250.00	0.40
West Buck	29.54	1	3.39	29.54
West Love	27.11	1	3.68	27.11
East Bobcat	41.68	2	4.79	20.84
River	28.33	2	7.06	14.17
Rabbit Trap/East Love	45.32	1	2.21	45.32
Rabbit Trap	40.47	1	2.47	40.47

[a]Territory sizes are estimates based on the number of birds per patch, not actual measurements.

[b]Spring, Spring Trap, and South Owl are different sections of the same 258.60 ha Ashe juniper patch.

[c]West Buck had two territories in two different Ashe juniper patches.

[d]This patch continued beyond the KWMA fence onto adjacent ranchland, density listed is an over-estimation.

escarpment black cherry (*Prunus serotina*), elbowbush (*Forestiera pubescens*), flameleaf sumac (*Rhus copallina*), skunkbush (*Rhus trilobata*), and mesquite (*Prosopsis glandulosa*). Initially, territory and non-territory areas appeared similar in plant composition for both canopy and understory (Fig. 6). However, upon closer inspection, differences were noted. Population and community structure of these species for canopy and understory for both territory and non-territory points are detailed in Table 5 and Table 6, respectively.

Territory canopies had greater densities of Texas oak, hybrid oak (shin x Vasey oak), hackberry, cedar elm, persimmon, bumelia, escarpment black cherry, and mesquite than non-territory points. Non-territory canopy points had greater densities of Ashe juniper, shin oak, live oak, post oak, Lacey oak, agarita, walnut, redbud, kidneywood, fragrant mimosa, and elbow bush. Bumelia and hybrid oaks were not found in non-territory canopies, while agarita, fragrant mimosa, and elbow bush were not found in territory canopies. Ashe juniper and Texas oak had the greatest dominance in territory canopy points, while Ashe juniper and shin oak had the greatest dominance in non-territory canopy areas.

Territory understories had greater densities of Texas oak, hackberry, cedar elm, persimmon, escarpment black cherry, redbud, mesquite, kidneywood, fragnant mimosa, elbowbush, skunk bush, and flame-leaf sumac than non-territory areas. Non-territory understories had greater densities of Ashe juniper, shin oak, live oak, Lacey oak, agarita, bumelia, and walnut. Escarpment black cherry, mesquite, elbowbush, and flame-leaf sumac were all found in territory understories but not in non-territory understories. There were no unique species present in understory non-territory areas that were not found in

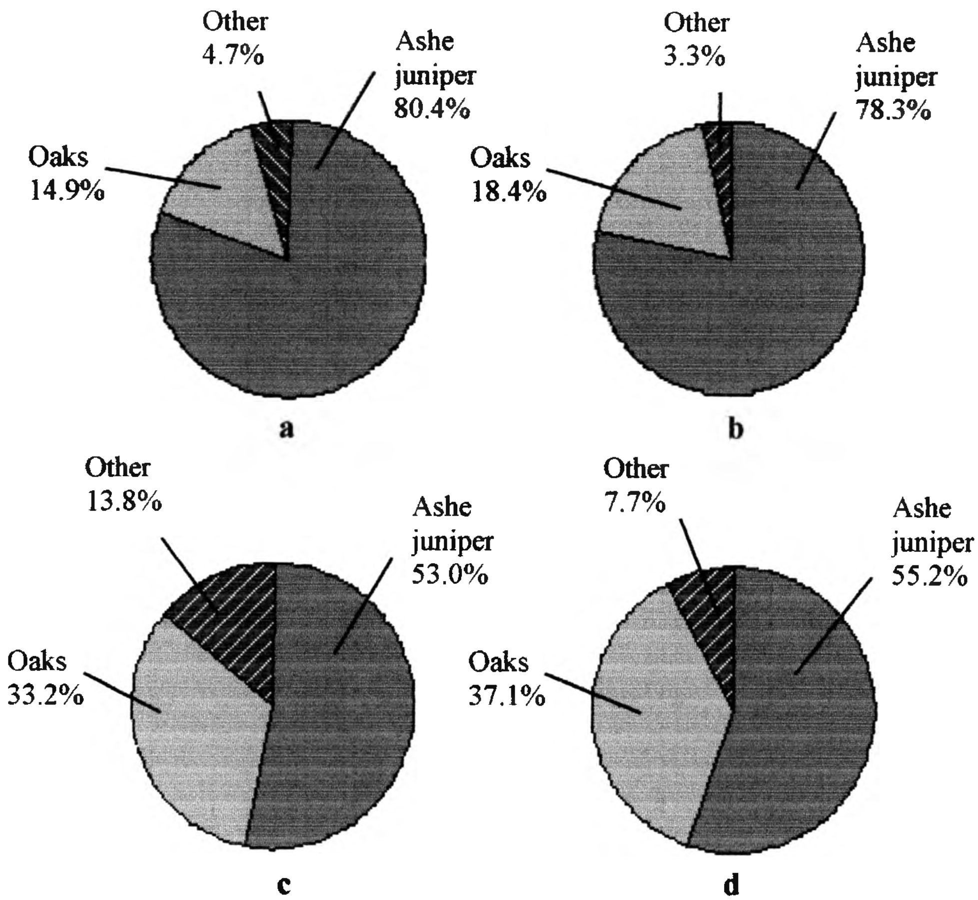

Figure 6. Plant composition of (a) canopy territory sites ($n = 25$), (b) canopy non-territory sites ($n = 25$), (c) understory territory sites ($n = 25$), and (d) understory non-territory sites ($n = 25$) at the Kerr Wildlife Management Area, 1998.

Table 5. Community structure of woody vegetation of known Golden-cheeked Warbler territories for both canopy and understory at the Kerr Wildlife Management Area, 1998.

Territory	Density		Dominance (m^2/ha)		Frequency		Importance
canopy species	Absolute	% Relative	Absolute	% Relative	Absolute	% Relative	Value
Ashe juniper	424.9	80.4	6766.0	73.8	91.4	62.2	72.1
Texas oak	18.2	3.4	739.3	8.1	8.6	5.9	5.8
Shin oak	25.7	4.9	441.2	4.8	13.6	9.3	6.3
Live oak	30.1	5.7	488.9	5.3	16.8	11.4	7.5
Post oak	0.3	0.1	3.8	0.0004	0.2	0.1	0.1
Lacey oak	3.5	0.7	165.4	1.8	1.8	1.2	1.2
Shin x Vasey oak	1.2	0.2	26.9	0.3	0.2	0.1	0.2
Hackberry	5.2	1.0	36.4	0.4	3.0	2.0	1.1
Cedar elm	6.9	1.3	421.5	4.6	3.8	2.6	2.8
Persimmon	2.6	0.5	7.5	0.1	1.6	1.1	0.6
Bumelia	0.9	0.2	1.9	0.0002	0.6	0.4	0.2
Walnut	4.9	0.9	26.8	0.3	2.6	1.8	1.0
Esc. Black cherry	1.2	0.2	17.0	0.2	0.8	0.5	0.3
Redbud	1.2	0.2	8.7	0.1	0.8	0.5	0.3
Mesquite	1.4	0.3	14.6	0.2	0.8	0.5	0.3
Kidneywood	0.6	0.1	0.6	0.00006	0.4	0.3	0.1

Table 5. Cont.

Territory understory species	Density Absolute	Density % Relative	Dominance (m^2/ha) Absolute	Dominance (m^2/ha) % Relative	Frequency Absolute	Frequency % Relative	Importance value
Ashe juniper	374.7	53.0	139.7	59.4	76.0	39.3	50.5
Texas oak	74.5	10.5	4.6	1.9	24.4	12.6	8.4
Shin oak	88.7	12.5	28.2	12.0	30.8	15.9	13.5
Live oak	66.1	9.4	13.5	5.7	22.4	11.6	8.9
Post oak	0.4	0.1	0.02	0.00008	0.2	0.1	0.1
Lacey oak	5.5	0.8	0.6	0.3	2.0	1.0	0.7
Hackberry	11.1	1.6	2.6	1.1	4.6	2.4	1.7
Cedar elm	18.2	2.6	11.7	5.0	5.0	2.6	3.4
Persimmon	17.8	2.5	9.0	3.8	7.0	3.6	3.3
Agarita	7.9	1.1	11.6	4.9	3.6	1.9	2.6
Bumelia	4.4	0.6	0.5	0.2	1.8	0.9	0.6
Walnut	10.3	1.5	3.5	1.5	3.8	2.0	1.6
Esc. Black cherry	1.2	0.2	0.1	0.0005	0.6	0.3	0.2
Redbud	7.1	1.0	0.9	0.4	3.2	1.7	1.0
Mesquite	2.8	0.4	1.1	0.5	0.8	0.4	0.4
Kidneywood	2.8	0.4	1.4	0.6	1.2	0.6	0.5
Fragrant mimosa	11.1	1.6	5.1	2.2	5.0	2.6	2.1
Elbow bush	1.2	0.2	0.2	0.1	0.6	0.3	0.2
Skunk bush	1.2	0.2	0.6	0.3	0.4	0.2	0.2
Flame-leaf sumac	0.4	0.1	0.1	0.1	0.2	0.1	0.1

Table 6. Community structure of woody vegetation of known Golden-cheeked Warbler non-territory areas for both canopy and understory at the Kerr Wildlife Management Area, 1998.

Non-GCW areas	**Density**		**Dominance (m^2/ha)**		**Frequency**		**Importance**
canopy species	**Absolute**	**% Relative**	**Absolute**	**% Relative**	**Absolute**	**% Relative**	**Value**
Ashe juniper	592.9	78.3	7904.3	76.2	97.4	62.9	72.5
Texas oak	13.3	1.8	363.7	3.5	8.6	5.6	3.6
Shin oak	60.4	8.0	976.1	9.4	20.0	12.9	10.1
Live oak	48.7	6.4	457.4	4.4	13.6	8.8	6.5
Post oak	0.8	0.1	5.1	0.0005	0.2	0.1	0.1
Lacey oak	16.1	2.1	531.9	5.1	5.0	3.2	3.5
Hackberry	4.7	0.6	23.4	0.2	2.2	1.4	0.8
Cedar elm	2.7	0.4	26.2	0.3	1.0	0.6	0.4
Persimmon	2.0	0.3	7.0	0.1	0.8	0.5	0.3
Agarita	1.2	0.2	11.4	0.1	0.6	0.4	0.2
Walnut	7.8	1.0	50.8	0.5	2.8	1.8	1.1
Esc. Black cherry	0.4	0.1	3.6	0.0003	0.2	0.1	0.1
Redbud	2.0	0.3	2.7	0.0003	0.6	0.4	0.2
Mesquite	0.8	0.1	0.3	0.00003	0.4	0.3	0.1
Kidneywood	0.8	0.1	1.7	0.0002	0.4	0.3	0.1
Fragrant mimosa	1.2	0.2	5.1	0.0005	0.6	0.4	0.2
Elbow bush	1.2	0.2	3.0	0.0003	0.4	0.3	0.1

Table 6. Cont.

Non-GCW areas understory species	**Density**		**Dominance (m^2/ha)**		**Frequency**		**Importance**
	Absolute	**% Relative**	**Absolute**	**% Relative**	**Absolute**	**% Relative**	**Value**
Ashe juniper	393.5	55.2	58.3	44.7	81.2	45.0	48.3
Texas oak	34.0	4.8	1.7	1.3	11.0	6.1	4.1
Shin oak	131.3	18.4	31.3	23.9	37.0	20.5	21.0
Live oak	85.6	12.0	13.0	9.9	21.6	12.0	11.3
Post oak	0.4	0.1	0.1	0.1	0.2	0.1	0.1
Lacey oak	13.4	1.9	0.8	0.6	5.2	2.9	1.8
Hackberry	4.2	0.6	0.2	0.1	2.0	1.1	0.6
Cedar elm	0.8	0.1	0.02	0.0001	0.2	0.1	0.1
Persimmon	13.0	1.8	7.7	5.9	5.0	2.8	3.5
Agarita	12.6	1.8	11.4	8.7	5.0	2.8	4.4
Bumelia	4.6	0.6	0.9	0.7	1.4	0.8	0.7
Walnut	11.3	1.6	1.5	1.2	4.0	2.2	1.7
Redbud	3.8	0.5	0.6	0.4	1.6	0.9	0.6
Kidneywood	2.5	0.4	2.8	2.2	4.2	2.3	1.6
Fragrant mimosa	1.3	0.2	0.4	0.3	0.6	0.3	0.3
Skunk bush	0.8	0.1	0.0001	0.00001	0.2	0.1	0.1

understory territories. Ashe juniper and shin oak were the most dominant species for both territory and non-territory understory points.

The mean total density of all woody plants in territory canopies (528.78 plants / ha) was less than that in non-territory areas (757.29 plants / ha). The understory mean total density for territories (707.34 plants / ha) was similar to the non-territory areas mean total density (713.19 plants / ha) but slightly less. The canopy mean point-to-plant distance between plants was greater for territories (4.35 m) than for non-territory areas (3.63 m, $n = 25$). For understory, the mean point-to-plant distance between plants was similar (3.76 m for territories, 3.74 m for understory in non-territory areas; $n = 25$). For canopy, the average area of ground surface on which one plant occurs (mean area per plant) was greater (18.91 m^2, $n = 25$) in territories than in non-territory (13.20 m^2, $n = 25$). For understory, the mean area per plant was similar in territory and non-territory areas (14.14 m^2 and 14.02 m^2, respectively, $n = 25$) but slightly greater in territories. The mean canopy coverage per woody plant in territories was greater (17.34 m^2/ ha, $n = 25$) than in non-territory areas (13.71 m^2 / ha, $n = 25$) while the mean total woody plant canopy coverage for all species in territories was less (9,166.53 m^2 / ha) than in non-territory areas (10,379.12 m^2/ ha). Mean understory coverage per woody plant was greater in territories (0.33 m^2, $n = 25$) than in non-territories (0.18 m^2, $n = 25$) as was mean total woody plant understory coverage for all species (235.12 m^2/ ha, 130.56 m^2 / ha in non-territory areas, $n = 25$) . Non-territory areas had a greater number of individual canopy plants (1,929) than territory areas (1,828). Territory understories had a slightly greater number of individual plants (1,786) than non-territory understories (1,700).

Statistical Analysis

Logistic Regression

From the logistic regression analysis, the variables that best explained the presence of GCWs based on canopy features were: greater patch size (PATCHHA, p = 0.11), less total density of all plants (TOTALDEN, p = 0.01), greater mean area per plant (MEANAREA, p = 0.01), greater mean canopy coverage per plant (MEANCANO, p = 0.01), less shin oak density (SHINOAK, p = 0.08), less live oak density (LIVEOAK, p = 0.14), less lacey oak density (LACEYOAK, p = 0.01), greater cedar elm density (CEDARELM, p = 0.03), and less river walnut density (RIVWALNU, p = 0.02) (Table 7). The probability of occurrence of GCWs on the Kerr Wildlife Management Area based on canopy features is: $P = 1 / (1 + e^{-z})$, where z = -81.55 + 0.10 (PATCHHA) + 0.05 (TOTALDEN) + 2.12 (MEANAREA) + 1.13 (MEANCANO) – 0.02 (SHINOAK) – 0.02 (LIVEOAK) – 0.14 (LACEYOAK) + 0.26 (CEDARELM) – 0.36 (RIVWALNU). This model correctly classified 90.0% of 50 sites (45 cases) as to presence or absence of GCWs (Table 8). The cases correctly and incorrectly identified are expressed in a histogram of estimated probabilities (Fig. 7). The logistic regression variables that best explained the presence of GCWs based on understory features were: less total density of all plants (TOTLDEN, p = 0.09), greater mean area per plant (MEANAREA, p = 0.10), greater mean understory canopy coverage area per plant (MEANCANO, p = 0.02), greater density of Texas oak (TEXOAK, p = 0.04), less density of shin oak (SHINOAK, p = 0.04), greater density of hackberry (HACKBERR, p = 0.02), greater density of persimmon (PERSIMMO, p = 0.07), less density of agarita (AGARITA, p = 0.02), and greater density of fragrant mimosa (FRAGMIMO, p = 0.02) (Table 9). The probability

Table 7. Canopy variables[a] used in the logistic regression analysis of Golden-cheeked Warbler habitat at the Kerr Wildlife Management Area, 1998.

							95.0% C.I.for EXP(B)	
Variable	**B[b]**	**S.E.**	**Wald[c]**	**df**	**Sig.**	**Exp(B)**	**Lower**	**Upper**
PATCHHA	0.01	0.01	2.57	1	0.11	1.01	1.00	1.02
TOTALDEN	0.05	0.02	6.44	1	0.01	1.05	1.01	1.09
MEANAREA	2.12	0.81	6.76	1	0.01	8.32	1.69	41.10
MEANCANO	1.13	0.46	6.14	1	0.01	3.10	1.27	7.58
SHINOAK	-0.02	0.01	3.01	1	0.08	0.98	0.95	1.00
LIVEOAK	-0.02	0.02	2.16	1	0.14	0.98	0.95	1.01
LACEYOAK	-0.14	0.05	6.09	1	0.01	0.87	0.78	0.97
CEDARELM	0.26	0.12	4.86	1	0.03	1.30	1.03	1.64
RIVWALNU	-0.36	0.16	5.13	1	0.02	0.70	0.51	0.95
Constant	-81.55	31.69	6.62	1	0.01	0.00		

[a]Variables entered on step 1: PATCHHA, TOTALDEN, MEANAREA, MEANCANO, ASHEJUN, TEXOAK, SHINOAK, LIVEOAK, LACEYOAK, HACKBERR, CEDARELM, PERSIMMO, RIVWALNU, REDBUD

[b]Estimated coefficient

[c]Wald statistic ($W = B'V^{-1}B$, where B is the vector of maximum likelihood estimates for the coefficients of the categorical variable and V^{-1} is the inverse of the asymptotic variance covariance matrix of the coefficients)

Table 8. Classification table[a] from logistic regression analysis on canopy woody plant characteristics at the Kerr Wildlife Management Area, 1998.

		Predicted present		**Percentage**
Step	**Observed present**	no	yes	**correct**
1	no	22	3	88
	yes	1	24	96
	Overall Percentage			92
2	no	22	3	88
	yes	1	24	96
	Overall Percentage			92
3	no	22	3	88
	yes	1	24	96
	Overall Percentage			92
4	no	22	3	88
	yes	1	24	96
	Overall Percentage			92
5	no	22	3	88
	yes	1	24	96
	Overall Percentage			92
6	no	21	4	84
	yes	1	24	96
	Overall Percentage			90

[a]Cutoff value is 0.50

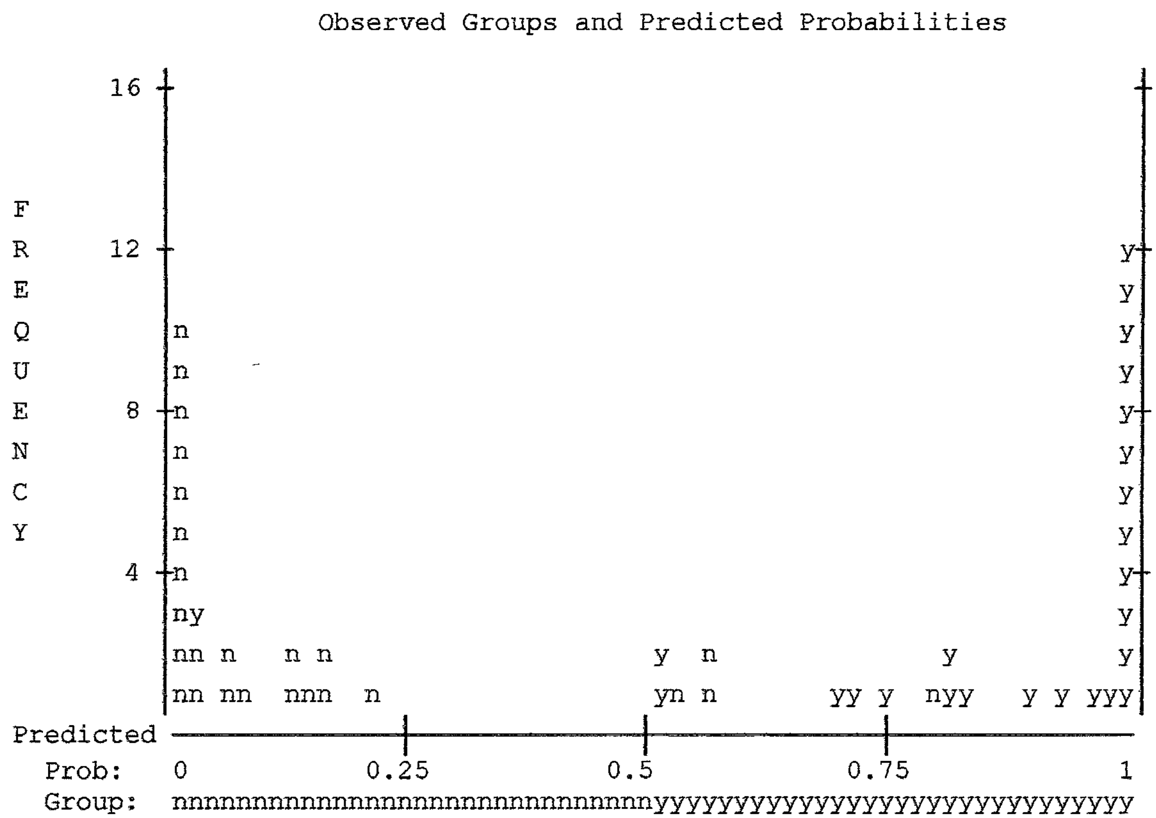

Fig. 7. Histogram of predicted probabilities for Golden-cheeked Warbler presence/absence in habitat on the Kerr Wildlife Management Area according to canopy vegetational variables. The cut value is 0.50. Symbols: n – absent, y – present. Each symbol represents 1 case.

Table 9. Understory variables[a] used in the logistic regression analysis of Golden-cheeked Warbler habitat at the Kerr Wildlife Management Area, 1998.

							95.0% C.I.for EXP(B)	
Variable	**B[b]**	**S.E.**	**Wald[c]**	**df**	**Sig.**	**Exp(B)**	**Lower**	**Upper**
TOTALDEN	0.01	0.00	2.92	1	0.09	1.01	1.00	1.01
MEANAREA	0.25	0.15	2.68	1	0.10	1.28	0.95	1.73
MEANCANO	28.40	11.84	5.75	1	0.02	2.16E+12	178.88	2.61E+22
TEXOAK	0.02	0.01	4.36	1	0.04	1.02	1.00	1.03
SHINOAK	-0.01	0.01	4.42	1	0.04	0.99	0.98	1.00
HACKBERR	0.11	0.05	5.57	1	0.02	1.12	1.02	1.23
PERSIMMO	0.06	0.03	3.25	1	0.07	1.06	1.00	1.12
AGARITA	-0.32	0.13	5.53	1	0.02	0.73	0.56	0.95
FRAGMIMO	0.53	0.23	5.41	1	0.02	1.69	1.09	2.64
Constant	-13.93	6.63	4.42	1	0.04	8.89E-07		

[a]Variables entered on step 1: PATCHHA, TOTALDEN, MEANAREA, MEANCANO, ASHEJUN, TEXOAK, SHINOAK, LIVEOAK, LACEYOAK, HACKBERR, PERSIMMO, AGARITA, RIVWALNU, FRAGMIM

[b]Estimated coefficient

[c]Wald statistic ($W = B'V^{-1}B$, where B is the vector of maximum likelihood estimates for the coefficients of the categorical variable and V^{-1} is the inverse of the asymptotic variance covariance matrix of the coefficients)

of occurrence of GCWs on the Kerr Wildlife Management Area based on understory features is: $P = 1 / (1 + e^{-Z})$. $Z = -13.93 + 0.01$ (TOTALDEN) + 0.25 (MEANAREA) + 28.40 (MEANCANO) + 0.02 (TEXOAK) – 0.01 (SHINOAK) + 0.11 (HACKBERR) + 0.06 (PERSIMMO) – 0.32 (AGARITA) + 0.53 (FRAGMIMO). This model correctly classified 96.0% of 50 sites (48 cases) as to presence or absence of GCWs based on understory features (Table 10). The cases correctly and incorrectly identified are expressed in a histogram of estimated probabilities (Fig. 8).

Hosmer and Lemeshow Goodness-of-fit

The Hosmer and Lemeshow Goodness-of-fit statistic for both the canopy ($\chi^2 = 1.95$, df = 8, $p = 0.98$) and understory ($\chi^2 = 3.67$, df = 8, $p = 0.89$) regression models was > 0.05 (Table 11). Therefore, I could not reject the null hypothesis that there is no difference between the observed and predicted values of the dependent variable. This means that the model predicts values, which are very similar, to what they should be (the observed values) implying that the model's estimates fit the data at an acceptable level (Hosmer and Lemeshow 1989). This indicates that both models fit well.

ROC analysis

The area under the ROC curve (AUC) (Fig. 9) generated by analysis on the logistic regression model for "canopy" was 0.96 (Table 12). This means that in 96% of all possible pairs of cases, the logistic regression model assigned a higher probability of GCWS being present when they actually were. The AUC for the ROC curve (Fig. 10) analysis on the "understory" logistic model was 0.968 (Table 12). In this case the model assigned a higher probability to true positive cases 97% of the time. The test has no

Table 10. Classification table[a] from logistic regression analysis on understory woody plant characteristics at the Kerr Wildlife Management Area, 1998.

Step	Observed present	Predicted present		Percentage
		no	yes	correct
1	no	24	1	96
	yes	1	24	96
	Overall Percentage			96
2	no	24	1	96
	yes	1	24	96
	Overall Percentage			96
3	no	24	1	96
	yes	1	24	96
	Overall Percentage			96
4	no	24	1	96
	yes	1	24	96
	Overall Percentage			96
5	no	24	1	96
	yes	1	24	96
	Overall Percentage			96
6	no	25	0	100
	yes	2	23	92
	Overall Percentage			96

[a]Cutoff value is 0.50

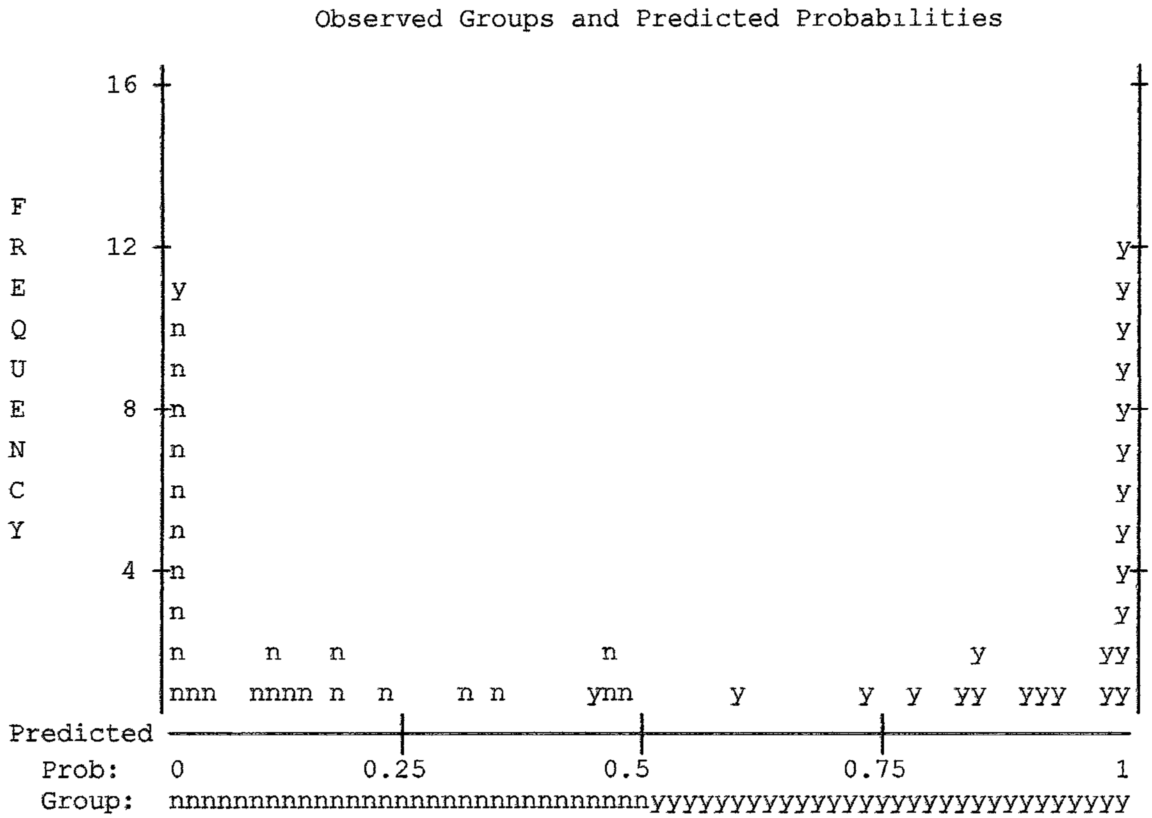

Fig. 8. Histogram of predicted probabilities for Golden-cheeked Warbler presence/absence in habitat on the Kerr Wildlife Management Area according to understory vegetational variables. The cut value is 0.50. Symbols: n – absent, y – present. Each symbol represents 1 case.

Table 11. Hosmer and Lemeshow goodness-of-fit statistics for canopy and understory woody vegetation in Golden-cheeked Warbler habitat on the Kerr Wildlife Management Area, 1998.

Canopy				**Understory**			
Step	**Chi-square**	**df**	**Sig.**	**Step**	**Chi-square**	**df**	**Sig.**
1	3.29	8	0.91	1	46.00	8	2.4E-07
2	17.91	8	0.02	2	9.37	8	0.31
3	17.61	8	0.02	3	2.95	8	0.94
4	18.56	8	0.02	4	2.82	8	0.94
5	2.30	8	0.97	5	3.62	8	0.89
6	1.95	8	0.98	6	3.67	8	0.89

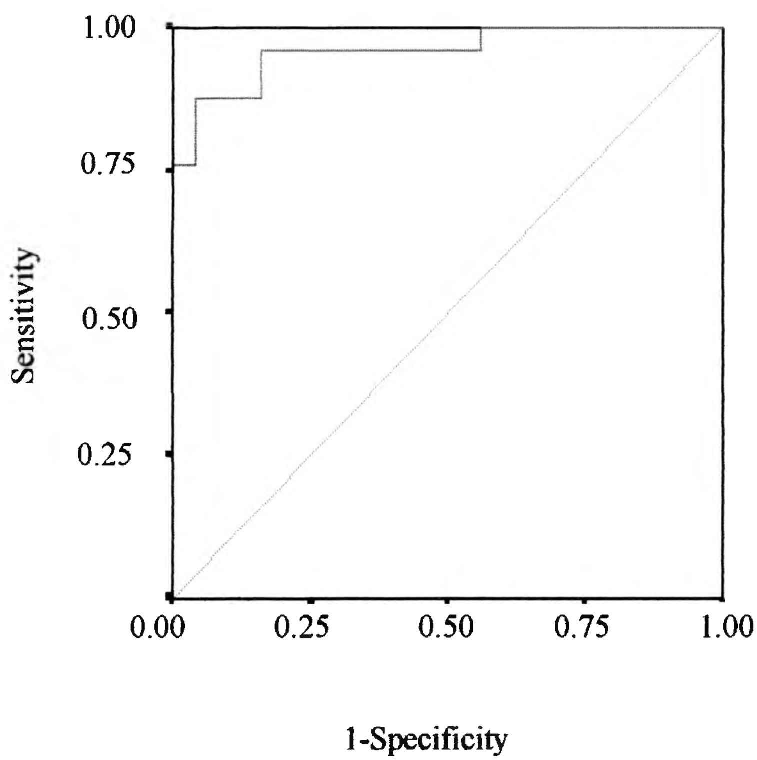

Fig. 9. ROC curve for canopy logistic regression model

Table 12. Area Under the Curve (AUC) from ROC curves for both canopy and understory woody vegetation in Golden-cheeked Warbler habitat on the Kerr Wildlife Management Area, 1998.

		Std.	Asymptotic	Asymptotic 95% Confidence Interval	
	Area	**Error**	**Sig.**	**Lower Bound**	**Upper Bound**
Canopy	0.96	0.03	2.43E-08	0.91	1.01
Understory	0.97	0.03	1.39E-08	0.91	1.02

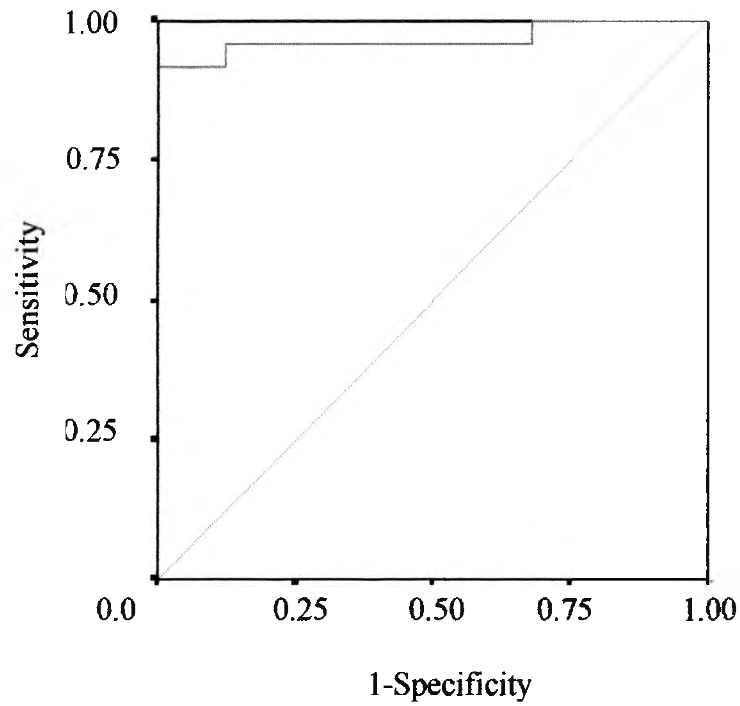

Fig 10. ROC curve for understory logistic regression model

discriminatory power if the total area under the curve is 0.5 or less, low accuracy from 0.5 - 0.7, limited utility from 0.7 - 0.9, and high accuracy > 0.9. Both the above cases show high accuracy.

Mann-Whitney U

By using the normal approximation to the Mann-Whitney test, it was found that woody vegetation > 1.5 m, the size of the patch (ha; greater in territories), total woody plant density (# plants / ha; greater in non-territories), mean area per plant (m^2; greater in territories), mean point-to-plant distance (m; greater in territories), mean canopy area per plant (m^2; greater in territories), and mean total canopy coverage (m^2 / ha; greater in non-territories) were significantly different in sites with and without GCWs (Mann-Whitney *U*-test: patch size, P [$Z_{0.05(2), 25, 25} \leq -2.56$] = 0.01; total woody plant density, P [$Z_{0.05(2), 25, 25} \leq -2.13$] = 0.03; mean area per plant, P [$Z_{0.05(2), 25, 25} \leq -2.13$] = 0.03; mean point-to-plant distance, P [$Z_{0.05(2), 25, 25} \leq -2.11$] = 0.03; mean canopy area per plant, P [$Z_{0.05(2), 25, 25} \leq -2.22$] = 0.03; mean total canopy, P [$Z_{0.05(2), 25, 25} \leq -2.22$] = 0.03) (Table13).

For woody plant understory (< 1.5m), patch size (ha; greater in territories), mean canopy area per plant (m^2; greater in territories), the densities of Texas oak and fragrant mimosa (# / ha; both greater in territories), and mean total canopy coverage (m^2 / ha; greater in territories) were significantly different in sites with and without GCWs (Mann-Whitney *U*-test: patch size, P [$Z_{0.05(2), 25, 25} \leq -2.56$] = 0.01; mean canopy area per plant, P [$Z_{0.05(2), 25, 25} \leq -2.35$] = 0.02; density of Texas oak, P [$Z_{0.05(2), 25, 25} \leq$

Table13. Mann-Whitney *U* test statistics for canopy woody vegetation in Golden cheeked Warbler habitat on the Kerr Wildlife Management Area, 1998.

Canopy Variable	**Mann-Whitney *U***	***Z***	**Asymp. Sig. (2-tailed)**
PATCHHA	181.5	-2.56	0.01
TOTALDEN	203.0	-2.12	0.03
MEANAREA	203.0	-2.12	0.03
MEANCANO	198.0	-2.22	0.03
MEANDIST	203.5	-2.12	0.03
TOTCANOP	198.0	-2.22	0.03
ASHEJUN	237.0	-1.46	0.14
TEXOAK	239.5	-1.56	0.19
SHINOAK	257.5	-1.08	0.28
LIVEOAK	295.0	-0.34	0.73
LACEYOAK	298.5	-0.39	0.70
HACKBERR	299.5	-0.33	0.74
CEDARELM	303.0	-0.35	0.72
PERSIMMO	303.0	-0.31	0.76
RIVWALNU	297.0	-0.41	0.68
REDBUD	302.0	-0.39	0.70

2.37] = 0.02; density of fragrant mimosa, P [$Z_{0.05(2), 25, 25} \leq -3.38$] = 0.001; mean total canopy, P [$Z_{0.05(2), 25, 25} \leq -2.36$] = 0.02) (Table14).

Table 14. Mann-Whitney *U* test statistics for understory woody vegetation in Golden-cheeked Warbler habitat on the Kerr Wildlife Management Area, 1998.

Understory variable	Mann-Whitney *U*	*Z*	Asymp. Sig. (2-tailed)
PATCHHA	181.5	-2.56	0.01
TOTALDEN	300.0	-0.24	0.8
MEANAREA	300.0	-0.24	0.8
MEANCANO	191.5	-2.35	0.02
TOTCANOP	191.0	-2.35	0.02
ASHEJUN	307.0	-0.11	0.92
TEXOAK	193.5	-2.36	0.02
SHINOAK	275.0	-0.73	0.47
LIVEOAK	248.5	-1.24	0.21
LACEYOAK	310.0	-0.07	0.94
HACKBERR	293.0	-0.47	0.64
AGARITA	279.5	-0.75	0.46
PERSIMMO	291.5	-0.46	0.65
RIVWALNU	299.0	-0.74	0.46
FRAGMIMO	178.0	-3.38	0.001

DISCUSSION

Overview of Findings on the KWMA

Distribution

The GCW appears to be increasing its presence on the KWMA, both in abundance and geographical distribution. Historically, Spring Pasture and Spring Trap had the greatest number of GCW territories on the KWMA. This trend continued for the 1998 season. However, areas which were once thought as less than optimal GCW habitat are now being used by GCWs for territories. Whether or not these territories are successful (acquiring a mate, breeding, and fledglings) was only marginally examined in this study. Intraspecific population pressure can cause some avian species to occupy a broader range of habitats, and breed in less suitable habitats in years of higher population density (Cody 1985). Fretwell's Theory (Fretwell 1972) states that a species should initially select only the best habitat, but as its density increases, it should spread out to equalize the return generated by all used patch types.

The 17 birds that were sighted ≤ 2 times were believed to be transients, or birds wandering from their territories. Pulich (1976) noted that male GCWs may cross the boundaries of their territory for prenuptial wanderings or for water supply areas.

No GCWs were found in Plot 9, North Rock, West Turkey, or North Owl pastures. A large part of Plot 9 (especially in the western and central portions) exists as a solid Ashe juniper brake and used as a demonstration area to show management implications. However, the woody plant species composition becomes more diverse with oaks and other hardwoods as one moves east in this pasture. Still, this dense Ashe juniper brake may be a factor in discouraging GCWs in this area. North Rock Pasture contains one small (1.62 ha) Ashe juniper patch. In close proximity to this patch is a cabin which houses students and other visitors throughout the year. Both size of patch and human activity may be factors discouraging GCWs here. West Turkey Pasture and North Owl Pasture both appear to have habitats that may be used by warblers based on TPWD guidelines. It is difficult to establish a cause for the perceived absence of warblers in this area without further research, but possible explanations could be researcher error (failing to find GCWs when they were actually there), the influence of another variable (slope, water proximity, etc.) other than an aspect of the woody vegetation, or too few GCWs to fill suitable habitat. In North Owl pasture, researcher error is highly likely since two GCW territories were found here during the following 1999 field season (Hunt 1999).

Reproductive Success in Ashe Juniper Patches

Nesting productivity is a measure of habitat quality (Gass 1996, Simons et al. 1999). Only two nests and 10 fledglings were observed in 1998. This number is probably not an accurate representation of the true reproductive success of GCWs for that year. These numbers were based mostly on incidental observations, as most field time was dedicated to searching for territories and habitat analysis. Active searching for fledglings in the following year yielded much higher results, 32 fledglings (Hunt 1999).

Density

GCW density ranged from 2.21 pair/100 ha to 21.03 pair/100 ha (Table 4). Pulich (1976) based density estimates on three categories of habitat: excellent (12.5 pair/100 ha), average (5 pair/100 ha), and marginal (3 pair/100 ha). Using this density estimate criteria, territories on the KWMA in 1998 ranged approximately from below marginal to beyond excellent. It appears that Pulich's criteria would have to be adjusted for the KWMA as Spring Pasture and Spring Trap, the historical home of the GCW, would only be considered average, while Middle Trap and East Turkey, thought to be marginal/areas where GCWs may occur, would be considered excellent. The true and potential density would also have to be considered, since marginal habitat would have a lower carrying capacity than good habitat. An Ashe juniper patch in West Buck (0.40 ha) is not accurately represented as having 250 pairs/100 ha. This patch continues beyond the KWMA fence into adjacent ranchland. The area on the KWMA is most likely just the southern tip of this bird's entire territory. It is unlikely, based on data from the rest of the KWMA, that this density would be maintained if the area of the patch located on the KWMA was ≥ 100 ha.

Ladd (1985) found Spring Pasture and Spring Trap had 15 territories with an average rate of occurrence for these pastures of 1 territory/14.8 ha. Similarly, in 1998 there were 17 territories in Spring Pasture and Spring Trap with an average rate of occurrence of 1 territory/15.21 ha. Pulich (1976) found that the average rate of occurrence was one pair / 12.15 ha.

Patch Size and Distribution

Patch size was significant for canopy in both the logistic regression analysis and Mann-Whitney *U* test. Understory patch size was significant in Mann-Whitney *U* test. This is somewhat redundant since in a patch with a mix of canopy and understory, canopy is really what determines the patch size. Therefore if patch size is significant with regard to canopy, patch size with regard to understory must also be significant. Patches containing territories ranged in size from 17.4 ha to 258.6 ha, with a mean patch size of 126.3 ha ($n = 40$). One territory found in West Buck Pasture was in a small patch (0.4 ha), but as mentioned above, this patch continued to the north beyond the KWMA fence line and was most likely just the southern tip of this bird's territory, and therefore not a true representation of the entire territory.

Wahl et al. (1990) stated that core areas (where territorial birds have persisted for at least 10 years) should be at least 250 acres (101.2 ha). On the KWMA, Spring Pasture and Spring Trap fit this definition of a core area (258.6 ha). Small patches of habitat (< 5.1 ha) that are associated with or within 944.9 m (0.94 km) of core areas, or other small patches farther than 944.9 m from core areas, also constitute suitable habitat (USFWS 1996). Most patches in the middle and southern portion of the KWMA are within 944.9 m from Spring Pasture and Spring Trap. Middle Trap, the farthest pasture from the core area in which a territory was found, was approximately 3.22 km (3,218.7 m) away.

In regard to a species' fitness, there can be detrimental effects relative to size and location of habitat. The risk of elimination from patches of suitable habitat increases as the size of a patch decreases, and/or as the distance between habitat patches increases, and/or as the distance of patches from a core area increases (MacArthur and Wilson

1967). The context within which patches occur also affects their suitability for GCWs. Robbins et al. (1989) suggested that several forest patches of 50 ha or greater may be functionally equivalent to a larger patch for area-dependent species if the distance between each smaller patch is not great. However, the isolation of patches increases the likelihood that displaying males will not attract females, that fledglings will not disperse successfully, and that disturbance events (both within and surrounding patches) may inhibit successful reproduction (USFWS 1996). Maas (1998) found that fragmented areas had significantly less GCW reproductive output than unfragmented areas. She attributed this to predation, which has been theorized to occur with greater frequency at a fragment's edge. On the KWMA in 1998, the majority of fledglings, and both nests were found in close proximity to Spring Pasture and Spring Trap. In the northern KWMA pastures, which are the greatest distance from the core area, only one fledgling was found in 1998 (Middle Trap), and none were observed in 1999 (Hunt 1999). The fledgling from 1998 was sighted alone late in the season (23 June) and may have been from another area. Pulich (1976) notes that once the fledgling's independence is established, the young birds may wander around in the Ashe juniper brakes without the restriction of having to remain in the territory. Therefore, it's impossible to know if this fledgling was actually from the closest territory in Middle Trap. Fretwell (1972) suggested in his ideal–despotic distribution theory, that lower success of breeding birds in secondary habitat would indicate that territoriality is acting to limit density because resources in the preferred habitat would be underutilized. Thus, if this theory is operative, fitness (i.e., breeding success) should be higher in primary habitat and lower in secondary habitat.

More intensive studies focusing on reproductive success would have to be done in all pastures to assess the individual fitness of birds.

Habitat Choice

According to Cody (1985) habitat selection theory is really a branch of optimal foraging theory. The approach states that habitats occur as patches and that organisms make choices about how to allocate their time among those patches. Selection of an optimum habitat provides conditions for survival and reproduction and insures a better chance of a longer life than a random choice. This selection is apparently an example of innate behavior that can be modified by early learning experiences (Bolen and Robinson 1995). Habitat choice may involve many different criteria, such as food resources, nesting sites, and shelter, hierarchically ordered as a sequence of choices. If habitat selection does proceed in a stepwise fashion, with the evaluation of different criteria at different stages, with differing temporal components at each stage, the differences often reported in correlations of particular species with particular features of their habitat can be understood. However, the correlation alone does not tell us what characteristic of the structural variable causes a bird's response (Cody 1985).

Warblers are sensitive to a variety of factors associated with vegetational characteristics, such as forest type and successional stage. The population density of warblers may not always correlate closely with vegetational density, indicating that birds do not always respond directly to simple quantitative parameters, e.g., canopy volume (Cody 1985).

Importance of Texas oak

In 1998 on the KWMA, Texas oak was the only oak species with a greater density in territory as opposed to non-territory areas. The canopy in territories was dominated by Ashe juniper and Texas oak (Table 5). This concurred with a number of other observations. Ladd (1985) found that in addition to Ashe juniper, Texas oak was also very important particularly in the central part of the GCWs range in Travis, Hays, Comal, Kendall, and Blanco counties. In these areas the two most common trees at 10 GCW sites (in order of frequency of occurrence or "relative dominance") were Ashe juniper and Texas oak. In a study of 17 areas by Wahl et al. (1990), the most common canopy dominants in 15 stands sampled were also Ashe juniper and Texas oak. A greater density of Texas oak in territories was significant for understory in both the logistic regression analysis and Mann-Whitney U test. More intensive studies focusing on the use of oaks by GCWs should be done to understand what exactly the importance of this species is in the biology/ecology of the GCW.

Comparison of Vegetation in Good/Poor habitats

Woody vegetation at the KWMA was very similar at sites with and without GCWs (Fig. 6). Kroll (1980) noticed that to the casual observer, good and poor GCW habitat seems quite similar, but upon closer examination there are considerable differences. If the vegetational characteristics are present (composition, height, and stem density), other variables such as slope may not be a factor in GCW habitat choice (USFWS 1996). Various studies have focused on differences in the aspects of GCWs habitat to make better management judgements.

In Meridian State Park (Bosque County), GCW habitat had less Ashe juniper and more shin oak than poor habitat (Kroll 1980). This was true for Ashe juniper but not shin oak in both canopy and understory in territories on the KWMA in 1998. Juniper-oak ratios for good and poor habitats in Meridian State Park were 1.35:1 and 2.27:1, respectively. Understory ratios on the KWMA were1.59:1 for territories, and 1.48:1 for unoccupied areas. For canopy this ratio was much higher: 5.38:1 in territories, and 4.3:1 in unoccupied areas. Stepwise discriminant analysis applied to Kroll's (1980) measurements of woody vegetation suggested that presence of shin oak and Ashe juniper, greater distances between trees, greater densities of shin oak, less densities of Ashe juniper, and lower height of the stand were the most important variables associated with the presence of GCWs. Kroll (1980) also suggested that GCW nesting habitat contained older Ashe junipers and that scrubby forms of species such as Texas oak and live oak were also important. Wahl et al. (1990) created a regression model which suggested that greater variability in tree heights, greater density of deciduous oaks, and greater average tree height were associated with higher densities of warblers. In the same study, the total cover at maximum canopy and the density of Texas oak had a weak positive correlation with warbler density.

In territory and non-territory areas examined on the KWMA in 1998, the data suggest that hardwood species other than Ashe juniper and various oaks may play an important role in GCW habitat choice, especially in the understory. Canopy and understory in both territory and non-territory areas were comprised of Ashe juniper, oaks, and other hardwoods. However, territories had less Ashe juniper and oaks and greater amounts of other woody plants in both the canopy and understory than non-territory areas. Shin oak, live oak, and Lacey oak were all significant in the canopy logistic regression analysis, but all had greater densities in non-territory canopy areas. GCWs utilize both the canopy and understory when foraging, moving downward into the understory as the breeding season continues (Beardmore 1994). When looking at the understory, woody species other than Ashe juniper and oaks (except Texas oak) seem to play an important role. This is especially interesting considering that many plants with higher densities in territory understory such as hackberry, kidneywood, flame-leaf sumac, and cedar elm are favored white-tailed deer browse. Agarita and walnut were both denser in understory non-territory areas. Agarita is an undesirable white-tailed deer browse plant and walnut, although palatable, is not a preferred food. This suggests that territory areas may not be as overbrowsed as non-territory areas, especially since the territory understory also had greater mean understory coverage, which was statistically significant.

Through logistic regression analysis and Mann-Whitney U tests, I concluded that structural characteristics of the patch in addition to species composition are important factors for GCW choice of habitat. Most small birds apparently distinguish habitats on the basis of structural characteristics (Cody1985). On the KWMA in 1998, territories had less total density, but a greater mean area per plant and mean canopy coverage per plant. This suggests that in territories, the vegetation is larger, therefore possibly older. The mean point-to-plant distance was greater for territories in the canopy (4.35 m, 3.63 m for canopy in non-territory areas) and similar in the understory (3.76 m, 3.74 m for understory in non-territory areas). This, together with less total density at both levels suggests that the GCWs are choosing quality of habitat over quantity.

In summary, GCW territories as opposed to non-territory areas on the KWMA were characterized by the following structural characteristics of the canopy: greater patch size, fewer numbers of individual woody plants, less mean total density, greater mean area per plant, less mean total canopy area, greater mean canopy coverage per plant, and greater mean distance between plants. Structural characteristics of the understory were: greater patch size, greater number of individual woody plants, less mean total density, greater mean area per plant, greater mean total understory canopy, greater mean understory canopy per plant, and greater mean distance between plants.

The Logistic Regression Model

With a range of approaches available for modelling, it is potentially difficult for practicing ecologists to choose appropriate methods. In addition, methods for comparing model performance are also evolving (Manel et al. 1999). Regression methods are useful in the analysis of relationships between a response variable and one or more explanatory variables (Hosmer and Lemeshow 1989, Norusis 1999). Logistic regression, which falls within the framework of Generalized Linear Models (GLM), can predict the probability of occurrence of a species as a function of environmental variables (Peeters and Gardeniers 1998). This has important implications as it allows us to make informed decisions about the management of a species. Logistic regression is being used increasingly to develop regional-scale predictive models of species distributions for use in regional conservational planning (Pearce and Ferrier 2000a). Examples of how logistic regression has been used in recent presence/absence habitat studies with various avian and other species follows. Hershey et al. (1998) used logistic regression to determine if forest structure at Northern Spotted Owl (*Strix occidentalis*, a threatened species) nest sites differed from forest structure of other older forest found in home ranges of spotted owls. Habitat variables associated with occupancy by Henslow's Sparrow (*Ammodramus henslowii*) on silvicultural lands in the core of its winter range in the Gulf Coastal Plain were identified by Plentovich et al. (1999) with logistic regression. Peeters and Gardeniers (1998) applied logistic regression to two species of macroinvertebrates (*Gammarus pulex* and *Gammarus fossarum*) as a tool to define their habitat requirements. Miller et al. (2000) examined four habitat selection models using logistic regression for Eastern Wild Turkeys (*Meleagris gallopavo silvestris*) in central Mississippi. Habitat selection of Swainson's Warblers (*Limnothlypis swainsonii*) in southern Missouri was examined using logistic regression (Thomas et al. 1996). Perkins et al. (2000) used logistic regression to find which habitat characteristics explained use of lowland agricultural grassland by birds in the United Kingdom during winter. Berry and Bock (1998) analyzed patterns of habitat use by songbirds in northern Colorado by logistic regression.

Predicting the distribution of endangered species from habitat data is frequently perceived to be a useful technique. The habitat-association approach to ecology has been used for a variety of purposes, including conservation and ecological management (Fielding and Bell 1997). Discrimination of wildlife habitat models that predict the presence or absence of a species is normally judged by the number of prediction errors, i.e., the agreement between predictions and actual observations. These may be two types: false positives (FP) and false negatives (FN) and are usually presented in a 2x2 classification table, or confusion/error matrix. Morrison et al. (1992) refer to FP errors as Type I and FN errors as Type II. A species is predicted to be present or absent at a site based on whether the predicted probability for the site is higher or lower than a specified threshold probability value. The table can be used to calculate four indices describing predictive performance of models. Two of these indices – sensitivity (the true positive fraction) and specificity (the true negative fraction) – measure the proportion of sites at which the observations and predictions agree. Using these indices, the accuracy (the total fraction of the sample that is correctly predicted by the model) can be calculated (Pearce and Ferrier 2000b, Murtaugh 1996). Prediction errors can arise due to limitations imposed by the classification algorithm and the data gathering process ('algorithmic'errors), or directly from the organism's ecology ('biotic'errors) such as unsaturated habitat and species interactions. Consequently, if prediction errors are not placed in an ecological context the results of the model may be misleading. The simplest and most widely used measure of prediction accuracy is the number of correctly classified cases (Fielding and Bell 1997). However, accuracy judged only by the number of false classifications is misleading and of limited diagnostic performance when dealing with rare species. Metz (1978) stated that "one can be very accurate simply by ignoring all evidence and calling all cases negative."

ROC Analysis

A number of commonly used discrimination indices, including those traditionally employed in wildlife studies, depend on species rarity and/or the choice of a threshold probability, making them unsuitable as an unbiased measure of accuracy (Fielding and Bell 1997). One index does meet the requirements of an unbiased discrimination index, providing a pure index of accuracy over the complete spectrum of thresholds (i.e., decision level, decision criteria, or "cut-off" value). This index is derived from the area under a relative operating characteristic (ROC) curve (Pearce and Ferrier 2000b). A ROC curve is obtained by plotting all sensitivity values (true positive fraction) on the y axis against their equivalent (1-specificity) values (false positive fraction) for all available thresholds on the x axis. ROC analysis is independent of both species prevalence and decision threshold effects. The ROC curve describes the compromises that are made between the sensitivity and false positive fractions as the decision threshold is varied (Pearce and Ferrier 2000b). ROC plots provide a view of this whole spectrum of sensitivities and specificities because all possible sensitivity/specificity pairs for a particular test are graphed. The ROC plot provides a comprehensive picture of the ability of a test to make the distinction being examined over all decision thresholds (Zweig and Campbell 1993). In summation, a ROC plot of a logistic regression model is simple, graphical, and easily appreciated visually. It is a comprehensive representation of pure accuracy, or discriminating ability, over the entire range of the test, and it does not require selection of a particular decision threshold because the whole spectrum of possible decision thresholds is included (Zweig and Campbell 1993). In addition, the ROC approach is nonparametric, which makes it free of assumptions about the mathematical relationship between response and indicator (Murtaugh 1996).

Cost of False Positive and False Negative Errors

Two elements are required to identify the appropriate threshold in ROC plots (Zweig and Campbell 1993). These are the cost of FP and FN errors and the prevalence of positive cases (p). When making management decisions with rare species such as the GCW especially in regard to habitat, there is a greater danger in making false negative errors (predicting absence when they actually present), than false positive errors (predicting presence when they are absent). In this case the threshold can be adjusted to decrease the FN rate at the expense of an increased FP error rate (Fielding and Bell 1997). Since the cost of a FN error is "costlier" than a FP error, the decision threshold should favor sensitivity. Based on the histogram of estimated probabilities for canopy (Fig. 7), the threshold for the logistic regression analysis could be adjusted from 0.5 to ~ 0.8 to eliminate the probability of false positives but this may increase the number of false negatives. With understory variables (Fig. 8), the threshold could be adjusted to ~ 0.3 to eliminate at least one of the false negatives, and left at 0.5 if false positives were of concern. Since the ROC curves generated from both the canopy and understory are stepped non-parametric curves, to find which sensitivity/specificity pair corresponds to this desired threshold, a line with slope $m = (FPC/FNC) \times ([1-p])/p)$ must be calculated. The line is moved from the top left of the graph until it intersects the ROC curve. This point corresponds to the optimal sensitivity/specificity pair based on relative costs (Zweig and Campbell 1993).

Discrimination Ability

Good discrimination ability implies that a model can differentiate between occupied and unoccupied sites and that predictions from the model thereby act as a good index of likely species occurrence even if the actual predicted values do not represent true probability of occurrence (Pearce and Ferrier 2000b). For both the canopy and understory logistic regression models, the ROC curve was much closer to the upper left-hand corner of the graph than to the 45° line. Qualitatively, the closer the plot is to the upper left corner, the higher the overall accuracy of the test (Zweig and Campbell 1993). A model that has no discrimination ability will generate a ROC curve that follows the 45° line.

That is, for all decision threshold values, the sensitivity equals the false positive fraction. Perfect discrimination is indicated when the ROC curve follows the left hand and top axes of the graph. That is, for all threshold values, the true positive fraction equals one and the false positive fraction equals zero (Pearce and Ferrier 2000b).

Area Under the Curve (AUC)

Swets (1986) concluded that the best discrimination index in a range of indications appears to be the area under the ROC curve expressed as a proportion of the total area of the unit square defined by the false positive and true positive axes. Both the canopy and understory models had AUCs close to 1 (0.96 and 0.968, respectively). Rates higher than 0.9 indicate very good discrimination because the sensitivity rate is high relative to the false positive rate (Swets 1988).

Hosmer and Lemeshow Goodness-of-Fit

Model calibration tells how closely the observed and predicted probabilities match. The cases are divided into 10 approximately equal groups based on the estimated probability of the event occurring. Then the observed and expected events are compared (Norusis 1999). If $p \leq 0.05$, we would reject the null hypothesis that there is no difference between the observed and predicted values generated by the model, i.e., the model predicts values significantly different from what they should be. In both the canopy and understory goodness-of-fit tests (Table 10), the significance was > 0.05, so we fail to reject the null hypothesis, which means the model's estimates fit the data well (Garson 2000).

Limitations of This Study

The KWMA is an intensively managed wildlife area. Although a great deal of what was found in this study about GCW habitat choice concurs with what others have found, there may be some findings that are unique to the KWMA due to the management implications. If one chooses to use logistic regression analysis similar to how it was used in this study, a unique model for that particular area should be generated, using the variables from this study as guidelines.

The method of gathering vegetation data used in this study (PCQ) was time, labor, and data intensive, and although appropriate to this study, may not be the best choice in all areas, especially if time is a factor.

Recommendations for Further Research

Seasonal monitoring of GCWs on the KWMA should focus on surveying of territories and reproductive success. More intensive searching for territories should be conducted in pastures where few to no GCWs have been observed in the last few years (West Turkey, West Love, and Owl). Greater efforts should be made to collect reproductive success data, especially in the northern pastures. Because the GCWs are not banded on the KWMA, we have to assume that we are hearing/seeing the same bird in the same territory every time. Due to the nature of the territoriality of the GCW, this is not a far-fetched assumption. However color banding would definitely confirm our assumptions, and also allow us to possibly age the birds to see if those occupying "less than optimal" habitat are only young or inexperienced birds.

The habitat analysis should be repeated on the KWMA and the data generated used to test the logistic regression model from this study. Testing should be done in known areas of good/poor habitat. The role of Texas oak in GCW habitat should be examined more thoroughly to see what role it plays in the GCW's biology/ecology. It is assumed that GCWs choose territory based on canopy vegetation characteristics, however this study has shown that vegetation variables in the understory may be important to habitat choice as well. The importance of the understory in GCW habitat choice should be further examined.

Conclusion

In GCW habitat choice, a variety of cues are used to determine appropriate habitat. Differences in territory and non-territory areas were found to be a combination of woody plant structure and species composition. GCWs appear to be choosing habitat based on these characteristics. The data suggests that canopy and understory both play an important role in habitat choice and that GCWs are choosing quality of habitat over quantity of habitat, although there are certain lower limitations as to the appropriate size of habitat areas.

The models generated by the logistic regression analysis can be used as guidelines to predict GCW habitat, although modifications may be needed to suit a particular area. It is important for managers and landowners to take into consideration plant species and structure in both the canopy and understory when judging habitat.

LITERATURE CITED

Attwater, H. P. 1892. List of birds observed in the vicinity of San Antonio, Bexar County, Texas. Auk 9:337-345.

Beardmore, C. J. 1994. Habitat use of Golden-cheeked Warblers in Travis County, Texas. M. S. Thesis, Texas A&M University, College Station, Texas.

Berry, M. E., and C. E. Bock. 1998. Effects of habitat landscape characteristics on avian breeding distributions in Colorado foothills shrub. The Southwestern Naturalist 43:453-461.

Bolen, E. G., and W. L. Robinson. 1995. Wildlife ecology and management. Prentice Hall, Inc., Englewood Cliffs, New Jersey.

Campbell, L. G. 1995. Management guidelines for the Golden-cheeked Warbler. Pp 23-37 *in* L.G. Campbell, editor. Endangered and threatened animals of Texas: their life history and management. Texas Parks and Wildlife Department, Austin, Texas.

Cody, M. L. 1985. Habitat selection in birds. Academic Press, Inc., New York, New York.

Cottam, G., and J. Curtis. 1956. The use of distance measurements in phytosociological sampling. Ecology 37:451-460.

Dunn, J., and K. Garrett. 1997. A field guide to warblers of North America. Houghton Mifflin Company, Boston, Massachusetts.

Fielding, A. H., and J. F. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation 24:38-49.

Fretwell, S. D. 1972. Populations in a seasonal environment. Princeton University Press, Princeton, New Jersey.

Garson, G. D. 2000. Logistic Regression. 02-15-00.

Gass, L. R. 1996. Nesting behavior of Golden-cheeked warblers in Travis County, Texas. M. S. Thesis, Southwest Texas State University, San Marcos, Texas.

Hershey, K. T., E. C. Meslow, and F. L. Ramsey. 1998. Characteristics of forests at spotted owl nest sites in the Pacific Northwest. Journal of Wildlife Management 62:1398-1410.

Hosmer, D. W., and S. Lemeshow. 1989. Applied logistic regression. John Wiley and Sons, New York, New York.

Hunt, B. 1999. Use of fragmented Ashe juniper woodland patches by Golden-cheeked Warblers on the Kerr Wildlife Management Area. Unpublished performance report.

Keddy-Hector, D. P 1992. Golden-cheeked Warbler recovery plan. USFWS-Ecological Services, Austin, Texas.

Kroll, J. C. 1980. Habitat requirements of the Golden-cheeked Warbler: management implications. Journal of Range Management 33:60-65.

Ladd, C. G. 1985. Nesting habitat requirements of the Golden-cheeked Warbler. M. S. Thesis, Southwest Texas State University, San Marcos, Texas.

Maas, D. S. 1998. Factors influencing demographics of Golden-cheeked Warblers (*Dendroica chrysoparia*) at Fort Hood Military Reservation, Texas. M. S. Thesis, University of Oklahoma, Norman, Oklahoma.

MacArthur, R. H., and E. O. Wilson. 1967. The theory of island biogeography. Princeton University Press, New Jersey.

Manel, S., J. Dias, and S. J. Ormerod. 1999. Comparing discriminant analysis, neural networks and logistic regression for predicting species distributions: a case study with a Himalayan River bird. Ecological Modelling 120:337-347.

Menard, S. 1995. Applied logistic regression analysis. SAGE Publications, Thousand Oaks, California.

Metz, C. E. 1978. Basic principals of ROC analysis. Seminars in Nuclear Medicine 8:283-298.

Miller, D. A., B. D. Leopold, G. A. Hurst, and P. D. Gerard. 2000. Habitat selection models for eastern wild turkeys in central Mississippi. Journal of Wildlife Management 64:765-776.

Morrison, M. L., I. C. Timoss, and K. A. With. 1987. Development and testing linear regression models predicting bird-habitat relationships. Journal of Wildlife Management 51:247-253.

Murtaugh, P. A. 1996. The statistical evaluation of ecological indicators. Ecological Applications 6:132-139.

Norusis, M. J. 1999. SPSS regression models 10.0. SPSS Inc., Chicago, Illinois.

Pearce, J., and S. Ferrier. 2000a. An evaluation of alternative algorithms for fitting species distribution models using logistic regression. Ecological Modelling 128:127-147.

__________. 2000b. Evaluating the predictive performance of habitat models developed using logistic regression. Ecological Modelling 133:225-245.

Peeters, E. T. H. M., and J .J. P. Gardeniers. 1998. Logistic regression as a tool for defining habitat requirements of two common gammarids. Freshwater Biology 39:605-615.

Perkins, A. J., M. J. Whittingham, R. B. Bradbury, J. D. Wilson, A. J. Morris, and P. R. Barnett. 2000. Habitat characteristics affecting use of lowland agricultural grassland by birds in winter. Biological Conservation 95:279-294.

Plentovich, S., R. H. Holler, and G. E. Hill. 1999. Habitat requirements of Henslow's Sparrows wintering in silvicultural lands of the Gulf Coastal Plain. Auk 116:109-115.

Pulich, W. M. 1976. The Golden-cheeked Warbler: a bioecological study. Texas Parks and Wildlife Department, Austin, Texas.

Robbins, C. S., D. K. Dawson, and B. A. Dowell. 1989. Habitat area requirements of breeding forest birds of the middle Atlantic states. Wildlife Monographs 103:1-34.

Shaw, D. M. 1989. Applications of GIS and remote sensing for the characterization of habitat for threatened and endangered species. Unpublished Ph. D. Thesis, University of North Texas, Denton, Texas.

Simons, T., K. Rabenold, and D. Buehler. 1999. The role of indicator species: Neotropical migratory song birds. Pp 187-208 *in* J.D. Peine, editor. Ecosystem management for sustainability: principles and practices illustrated by a regional biosphere reserve cooperative. CRC Press, Boca Raton, Florida.

Swets, J. A. 1986. Indices of discrimination or diagnostic accuracy: their ROCs and implied models. Psychological Bulletin 99:100-117.

__________. 1988. Measuring the accuracy of diagnostic systems. Science 240:1285-1293.

Texas Parks and Wildlife Department. 1986. Kerr Wildlife Management Area driving tour. Texas Parks and Wildlife Department, Austin, Texas.

__________. 1998. Wildlife management areas, Kerr Wildlife Management Area. 10-22-98.

Thomas, B. G., E. P. Wiggers, and R. L. Clawson. 1996. Habitat selection and breeding status of Swainson's Warblers in southern Missouri. Journal of Wildlife Management 60:611-616.

U.S. Fish and Wildlife Service. 1996. Golden-cheeked Warbler population and habitat viability assessment report. Compiled and edited by Carol Beardmore, Jeff Hatfield, and Jim Lewis in conjunction with workshop participants. Report of a August 21-24, 1995 workshop arranged by the U.S. Fish and Wildlife Service in partial fulfillment of U.S. National Biological Service Grant No. 80333-1423. Austin, Texas. xii + 48 pp. + Apendix.

Wahl, R., D. D. Diamond, and D. Shaw. 1990. The Golden-cheeked Warbler: a status review. U.S. Fish and Wildlife Service, Fort Worth, Texas.

Wiens, J. A. 1976. Population responses to patchy environments. Annual Review of Ecology and Systematics 7:81-120.

Zweig, M. H., and G. Campbell. 1993. Receiver-operating characteristic (ROC) plots: a fundamental evaluation tool in clinical medicine. Clinical Chemistry 39:561-577.

Vita

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