



Characterization of golden-cheeked warbler *Dendroica chrysoparia* habitat at Fort Hood, Texas, USA

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ABSTRACT: The golden-cheeked warbler *Dendroica chrysoparia* is a federally endangered, neotropical-nearctic migrant songbird that breeds in central Texas, USA, and prefers mature, closed canopy oak–Ashe juniper woodlands for nesting and foraging. Fort Hood is an 87 890 ha military reservation located in central Texas in Bell and Coryell Counties on the eastern edge of the Edwards Plateau ecoregion. We surveyed for golden-cheeked warblers and measured habitat variables at 95 separate locations in a 56.6 km² research area that supports a golden-cheeked warbler breeding population. We detected golden-cheeked warblers on 34 of 95 (36%) point count locations. Principal component analysis was used to reduce the 27 habitat variables to a set of uncorrelated variables. This analysis resulted in the identification of 4 principal components that accounted for 52% of the variance. Logistic regression identified one principal component (ratio of Ashe juniper to other woody species) that was strongly related to golden-cheeked warbler occurrence. Our data indicate that a 4:1 ratio of Ashe juniper to other woody species is an important feature of occupied golden-cheeked-warbler habitat, particularly in the mid- to upper canopy at Fort Hood.

KEY WORDS: Golden-cheeked warbler · Ashe juniper · Habitat · Military training

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INTRODUCTION

The golden-cheeked warbler *Dendroica chrysoparia* is a federally endangered, neotropical-nearctic migrant songbird that breeds in central Texas, USA. The males have bright yellow cheeks interrupted by a black line through each eye, a white lower breast and belly, and are black except for white bars and edging on the wings. The females' cheeks are duller yellow, with more white on the underside, and dark olive green backs. Pulich (1976) estimated that golden-cheeked warblers had a breeding population of less than 15 000 individuals. The United States Fish and Wildlife Service (USFWS) listed golden-cheeked warblers as federally endangered in 1990 (USFWS 1992). The major cause identified for their decline was the loss of breeding habitat due to urban development and conversion of land to agriculture (USFWS 1992, Anders & Dearborn

2004). Habitat fragmentation and nest parasitism by brown-headed cowbirds *Molothrus ater* are other threats to golden-cheeked warblers (USFWS 1992)

The range of breeding habitat for golden-cheeked warblers coincides closely with the distribution of Ashe juniper *Juniperus ashei* (Pulich 1976). Golden-cheeked warblers prefer mature, closed canopy oak–Ashe juniper woodlands for nesting and foraging (Ladd 1985, USFWS 1992, Lockwood 1996, Jetté et al. 1998, Magness et al. 2006). Ashe juniper is the most important component in golden-cheeked warbler habitat, with several species of oak playing an important role in foraging (Kroll 1980, Ladd 1985). Nests frequently occur within Ashe juniper trees between a height of 3 and 7 m, but are occasionally found in other species in close proximity (Ladd 1985, USFWS 1992). Ashe juniper bark begins to peel once it reaches maturity, and female golden-cheeked warblers use strips of

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mature Ashe juniper bark for construction of their nests. In addition, males have been observed offering Ashe juniper bark as part of the courtship ritual (Lockwood 1996). R. Wahl et al. (unpubl.) characterized golden-cheeked warbler habitat as closed canopy with a moderate to high density of trees and dense foliage, usually at higher levels in the canopy. However, habitat studies conducted across the range of the species have produced inconsistent results (USFWS 1992).

Although it is generally recognized that mature, closed canopy oak–Ashe juniper woodlands provide habitat for golden-cheeked warblers, there is still considerable variability in habitat composition and structure among the sites. Therefore, an assessment of the habitat composition and structure among Ashe juniper–oak woodland patches where golden-cheeked warblers are found may help identify critical habitat features necessary for conservation and the development of management and recovery plans for this species.

Our study objective was to identify habitat variables that differed between locations occupied by golden-cheeked warblers and those not occupied within mature oak–Ashe juniper woodlands at Fort Hood, Texas. This study was part of a larger research effort to identify potentially important habitat variables that could be identified through remote sensing and used to parameterize a landscape level habitat model for golden-cheeked warblers.

MATERIALS AND METHODS

Study area. Fort Hood is an 87 890 ha military reservation located in central Texas in Bell and Coryell Counties on the eastern edge of the Edward's Plateau ecoregion (Hayden et al. 2001). It is the largest active duty armored post in the United States, supporting 2 full armored divisions (First Cavalry Division and 4th Infantry Division) and numerous smaller military units and organizations. Fort Hood lies in the Lampasas Cutplains physiographic province, which is characterized by broad valleys, rolling hills, and wide stream divides. Soils in the region developed from underlying limestone parent material and range from the shallow and rocky Inceptisols on the slopes to the deep, organic-matter rich Mollisols in the valleys and flats (Tazik et al. 1993). Long hot summers and short, mild winters typify the climate of the Fort Hood region. The average low temperature in January is 1°C, and the average high temperature in August is 36°C. The average annual rainfall is 87 cm, with the largest amount occurring in May. Vegetation consists of a mix of woodlands and grasslands. Common trees

found at Fort Hood include Texas oak *Quercus texana* and Ashe juniper, with a variety of other oaks intermingled throughout. Because of heavy grazing and military activity, the grasslands of Fort Hood are dominated by Texas winter grass *Stipa leucotrichia* and prairie dropseed *Sporobolus asper* (Tazik et al. 1993). Fort Hood contains the largest breeding population of golden-cheeked warblers managed by a single landowner, and long-term data indicate that the population is increasing (Anders & Dearborn 2004).

Field data collection. We selected a 56.6 km² research area in the western portion of Fort Hood that supports a golden-cheeked warbler breeding population (Fig. 1). The research area is subjected to landscape disturbances from military maneuver exercises, which has resulted in a fragmented landscape with a complex matrix of deforested areas, edge vegetation, and mature mixed deciduous–Ashe juniper woodlands. We developed a general land cover map from multi-spectral imagery that identified potential golden-cheeked warbler habitat (i.e. mature, mixed deciduous–Ashe juniper woodlands). Within potential woodland habitat identified, we randomly allocated points that would serve as the basis for both the habi-

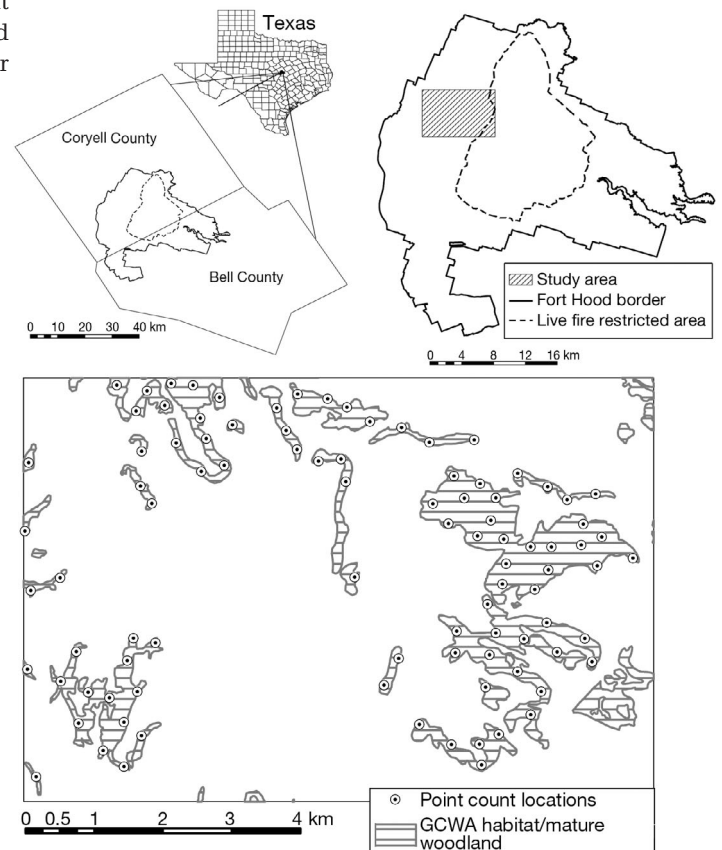


Fig. 1. *Dendroica chrysoparia*. Golden-cheeked warbler (GCWA) study area Fort Hood, Texas, USA

tat assessment and avian survey. Avian survey techniques followed the guidelines established by Ralph et al. (1995a). To avoid double counting, we allocated points using a minimum distance of 250 m between each point, which is the standard technique for the region (Ralph et al. 1995b). Although golden-cheeked warblers can be found in woodland edge, this species is not edge dependent as it is frequently found in dense woodland vegetation away from natural or man-made edges (Tazik et al. 1992). Therefore, to avoid edge effects during the avian survey, we buffered each point 50 m from the edge to ensure that all points were well within woodlands identified as potential habitat. A total of 95 point count stations were allocated and visited from 3 to 14 April 2004, with each station visited on 2 separate occasions by different observers (Ralph et al. 1995b). The point count duration was 6 min with a variable radius to 50 m following a previously established protocol for sampling golden-cheeked warblers at Fort Hood (Anders & Dearborn 2004). We placed each avian observation into 1 of the following distance classes: 1: 0–10 m, 2: 10–20 m, 3: 20–30 m, 4: 30–40 m, and 5: 40–50 m.

At each point, we collected habitat variables in an 11.3 m radius circular plot. Within the plot, we tallied and identified all woody species whose main stem was greater than 10 cm in diameter at breast height (dbh) and placed each individual into 1 of 4 canopy position classes. Canopy classes were as follows: (1) emergent, crowns clearly higher than surrounding canopy with significant exposure of lateral crown; (2) dominant, top of crown and portion of lateral crown exposed to direct sunlight; (3) subdominant, only top of crown exposed to sunlight; and (4) suppressed, crown completely overtopped by other species. We measured total canopy closure at the plot center using a concave spherical stand densiometer. Vegetative cover for each species in the plot was visually estimated using a modified Braun-Blanquet cover abundance scale (+: 0–1%; 1: 1–5%; 2: 5–25%; 3: 25–50%; 4: 50–75%; 5: 75–95%; 6: 95–100%) in the following height strata: A, 0–2 m; B, 2–4 m; C, 4–6 m; D, 6–8 m; and E, 8+ m (Mueller-Dombois & Ellenberg 1974). We also estimated total cover of leaf litter, herbaceous species, graminoids, and bare ground/rock within the plot using the same Braun-Blanquet cover abundance scale.

Data analysis. The patchy nature of habitats in the study area caused many of the avian point counts to cross habitat types. Furthermore, the density of woody vegetation limited the ability of the point count observers to identify general habitat conditions at a distance of >30 m. Therefore, we only used avian point count data from a 20 m radius from the plot center to ensure that the golden-cheeked warbler detection data corresponded to the habitat variables we measured.

If golden-cheeked warblers were detected on either of the 2 visits within 20 m of the plot center, we counted the species as present at that location. We summarized raw habitat data in the following manner: (1) density m^{-2} of all woody species; (2) mean dbh of dominant and emergent Ashe juniper; (3) total aerial vegetative cover of Ashe juniper; (4) ratio of total cover of Ashe juniper to total cover of all other woody species; (5) Ashe juniper cover by height strata; and (6) ratio of Ashe juniper vegetative cover to all other species by height strata. The data summarizations resulted in 27 variables that we used to investigate golden-cheeked warbler occurrence and habitat (Table 1). Because many of the habitat variables were correlated, we used principal component analysis (PCA) to reduce the original 27 habitat variables to a set of uncorrelated variables. The principal components (PCs) derived from the PCA were rotated using Varimax (SYSTAT Software). We used the habitat PCs derived from the PCA as independent variables and the golden-cheeked warbler occurrence data as the dependent variables. We subsequently used a multiple stepwise logistic regression (forward selection) analysis to examine the strength of the relationship between habitat variables derived from PCA and occurrence of golden-cheeked warblers. All analyses were performed in SYSTAT 11.0 (SYSTAT Software).

RESULTS

We detected golden-cheeked warblers within a 20 m radius of the plot center on 34 of 95 (36%) point count locations. Golden-cheeked warblers generally occurred in habitats that were higher in total Ashe juniper cover (128% compared to 112% for unoccupied habitat) and had a higher ratio of Ashe juniper to hardwoods (Table 1). However, total vegetative cover was higher in unoccupied habitats.

The results of PCA showed that there were 8 PCs with eigenvalues >1. Using a scree criterion, we determined that only the first 4 PCs were readily interpretable and biologically meaningful. Each of these PCs consisted of a set of original habitat variables that were ecologically related and explained 52% of the total variance (Table 2). The first habitat PC (PC-1) represented a gradient in stand composition in terms of the ratio of Ashe juniper to hardwoods and total hardwood cover. Habitats that had a higher ratio of Ashe juniper to hardwoods were positively related to PC-1 (Table 2). The second PC (PC-2) was related to total vegetative cover and the cover of Ashe juniper in the upper canopy. Habitats with higher total cover and higher juniper cover in the upper canopy were positively associated with PC-2. PC-3 was associated with

Table 1. *Dendroica chrysoparia*. Mean and SE of habitat variables measured at Fort Hood, Texas, USA, between habitats where golden-cheeked warblers were and were not detected. Dbh: diameter at breast height. See 'Materials and methods' for definitions of the height strata

Habitat variable	Occupied			Unoccupied		
	Mean	SE	N	Mean	SE	N
Juniper density m ⁻²	0.031	0.01	34	0.02	0.01	61
Juniper dbh	17.27	1.13	34	16.29	1.01	61
Dbh all species	17.42	0.83	34	16.84	0.78	61
Juniper total cover (%)	127.75	10.39	34	112.85	8.45	61
Other woody species total % vegetative cover	60.80	8.07	34	94.21	9.41	61
Ratio juniper/other woody species	4.14	0.79	34	3.04	0.81	58
Juniper cover (%)						
Stratum A	26.02	3.16	34	23.48	2.54	61
Stratum B	37.5	3.37	34	31.88	2.50	61
Stratum C	40.66	3.69	34	34.14	2.83	61
Stratum D	21.56	3.20	34	20.78	2.49	61
Stratum E	2.00	0.72	34	2.54	0.81	61
Ratio juniper/other woody species						
Stratum A	5.56	1.57	34	3.83	0.95	61
Stratum B	6.90	2.25	34	6.82	1.87	61
Stratum C	7.49	1.42	34	4.38	1.36	61
Stratum D	4.87	2.24	34	1.88	0.44	61
Stratum E	0.22	0.15	34	0.19	0.10	60
Total vegetative cover (%)						
Stratum A	45.23	3.99	34	48.54	3.19	61
Stratum B	51.41	3.52	34	54.50	3.33	61
Stratum C	51.22	3.96	34	55.21	3.24	61
Stratum D	31.95	4.57	34	38.51	3.72	61
Stratum E	8.73	2.64	34	10.29	2.14	61
Total vegetative cover (%)	188.55	11.26	34	207.06	10.63	61
Canopy closure (%)	77.42	4.08	34	75.49	3.31	61
Herbaceous cover (%)	6.54	3.15	34	5.01	1.03	61
Graminoid cover (%)	11.05	2.44	34	13.82	2.37	61
Litter cover (%)	68.10	4.90	34	67.87	3.17	61
Bare ground-rock cover (%)	16.61	3.36	34	16.41	2.53	61

the cover of Ashe juniper and total cover in the lower canopy. PC-4 described a difference in the age and size of the Ashe juniper that comprised the habitat.

We used logistic regression to analyze the strength of the relationship between habitat variables (PCs) and golden-cheeked warbler occurrence. Of the 4 PCs, only PC-1 (gradient in stand composition) showed a significant relationship between golden-cheeked warbler occurrence and habitat ($p < 0.05$, estimate 0.43, odds ratio 1.54). These results indicated that the odds of golden-cheeked warbler detection significantly increased as the ratio of Ashe juniper to other species increased (i.e. PC-1).

DISCUSSION

In general, the habitat where we detected golden-cheeked warblers at Fort Hood was consistent with other habitat descriptions for the species. Most references to golden-cheeked warbler habitat state that they are restricted to mature Ashe juniper–oak wood-

land habitat (e.g. Lockwood 1996, Jetté et al. 1998, Dearborn & Sanchez 2001, DeBoer & Diamond 2006, Peak 2007). However, there were many locations within Ashe juniper–oak woodlands at Fort Hood where we did not detect golden-cheeked warblers, which suggests that there are other fine-scale and broad-scale features that may determine habitat occupancy. Our analysis was focused on identification of fine-scale variability in mature Ashe juniper–oak woodland habitat characteristics that may influence occupancy. Broader, landscape-scale features were not evaluated in this analysis

The 4 readily interpretable PCs used in our analysis explained 52% of the total variance in the habitat variables. The variables with high loadings in each of these components were all related to the species composition and structure of the tree component of the habitat (Table 2). These results suggest that golden-cheeked warblers tend to favor heavily wooded habitats that contain both Ashe juniper and hardwood species. Other regional studies also reported that Ashe juniper was the most important species in golden-

Table 2. *Dendroica chrysoparia*. Loadings for the first 4 principal components (PCs) of 27 habitat variables measured at 95 potential golden-cheeked warbler habitat locations. Components were analyzed with the Varimax method (SYSTAT Software). **Bold** variables were used to interpret and name PCs. Dbh: diameter at breast height. See 'Materials and methods' for definitions of the height strata

Habitat variables	PC-1 Ratio Ashe juniper to hardwoods	PC-2 Total cover upper canopy	PC-3 Ashe juniper cover lower canopy	PC-4 Age-size of Ashe juniper
Percentage explained by rotated PCs	16.48	12.32	12.08	11.24
Juniper density m ⁻²	0.37	0.18	0.16	0.53
Juniper dbh	-0.04	0.08	0.06	0.86
Dbh all species	0.14	0.00	0.10	0.87
Juniper total cover (%)	0.48	0.35	0.59	0.41
Other woody species total % vegetative cover	-0.65	0.38	0.07	-0.21
Ratio juniper/other woody species	0.89	-0.05	-0.01	0.14
Juniper cover (%)				
Stratum A	0.41	0.01	0.72	0.03
Stratum B	0.46	0.15	0.66	0.31
Stratum C	0.47	0.32	0.32	0.53
Stratum D	0.16	0.73	0.14	0.49
Stratum E	0.04	0.29	0.11	0.16
Ratio juniper/other woody species				
Stratum A	0.81	0.08	0.07	-0.01
Stratum B	0.83	0.01	-0.01	-0.03
Stratum C	0.64	-0.19	-0.01	0.23
Stratum D	0.32	0.26	0.04	0.23
Stratum E	0.08	-0.02	0.02	-0.01
Total vegetative cover (%)				
Stratum A	-0.28	-0.12	0.78	-0.01
Stratum B	-0.07	0.15	0.80	0.15
Stratum C	0.17	0.64	0.25	0.23
Stratum D	-0.13	0.92	-0.03	0.03
Stratum E	-0.22	0.55	-0.09	-0.35
Total vegetative cover (%)	-0.16	0.66	0.60	0.01
Canopy closure (%)	0.07	0.18	-0.01	0.11
Herbaceous cover (%)	-0.21	-0.08	-0.03	0.04
Graminoid cover (%)	0.17	-0.10	-0.05	-0.01
Litter cover (%)	0.01	0.12	0.18	0.01
Bare ground-rock cover (%)	0.02	-0.02	0.06	0.03

cheeked warbler habitat, with oaks playing an important role in foraging (Kroll 1980, Ladd 1985). Logistic regression showed that PC-1 (ratio of Ashe juniper to other species) had the strongest and only statistically significant relationship with golden-cheeked warbler occurrence. Prior unpublished research conducted at Fort Hood indicated that habitat selection by golden-cheeked warblers might be influenced by the presence of large contiguous patches of mixed woodlands, with a 3:2 ratio of evergreen/deciduous vegetation and a heterogeneous canopy (G. H. Eckrich pers. comm.). We found that golden-cheeked warbler detections were more likely in habitats with higher ratios of Ashe juniper (approximately 4:1), but other species, primarily oaks, were always present (Table 1).

Golden-cheeked warblers generally construct nests 3 to 7 m off the ground and rarely forage <2 m off the ground (Ladd & Glass 1999, Dearborn & Sanchez 2001). Our study did not specifically identify nesting or

foraging locations. However, our data suggest that golden-cheeked warblers are selecting stands with a higher ratio of Ashe juniper to other species, especially in the mid- to upper canopy (4 to 8 m), which generally corresponds to previously reported nesting and foraging locations.

At Fort Hood, Dearborn & Sanchez (2001) found that breeding habitat of golden-cheeked warblers was limited to Ashe juniper-oak woodlands with a minimum of 75% canopy closure. Dearborn & Sanchez (2001) also reported significant differences in canopy closure when comparing nest sites to paired non-nest sites, although they speculated that the difference was an artifact of how canopy closure was measured at nest sites. Our data did not show a significant relationship between golden-cheeked warbler detection and canopy closure, although our data for mean canopy closure for both occupied and unoccupied habitat was >75%.

Our primary objective for this study was to identify fine-scale differences in habitat variables between occupied and unoccupied golden-cheeked warbler locations. Overall, we found that few of the habitat variables measured at the West Fort Hood study site differed between occupied and unoccupied golden-cheeked warbler locations within the general Ashe juniper–oak woodland. However, our data indicate that a 4:1 ratio of Ashe juniper to other woody species is an important feature of golden-cheeked-warbler habitat, particularly in the mid- to upper canopy at Fort Hood, Texas. These data indicate that the conservation and development of mature oak–Ashe juniper woodlands with the proper ratio of Ashe juniper to other species could improve golden-cheeked warbler habitat within existing woodland patches.

Acknowledgements. We thank R. Murray, K. Convery, E. Wolf, S. Keane, and J. Thompson for valuable field assistance. We also thank R. Peak and R. Kostecke for valuable comments on earlier versions of this manuscript.

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Editorial responsibility: Lian Koh,
Zurich, Switzerland

Submitted: July 11, 2010; *Accepted:* February 12, 2010
Proofs received from author(s): May 13, 2010