

# FOREST EDGES NEGATIVELY AFFECT GOLDEN-CHEEKED WARBLER NEST SURVIVAL

REBECCA G. PEAK<sup>1</sup>

*The Nature Conservancy, P.O. Box 5190, Fort Hood, TX 76544-0190*

**Abstract.** I used an information-theoretic approach to determine support for hypotheses concerning the effects of edge and temporal factors on Golden-cheeked Warbler (*Dendroica chrysoparia*) nest survival on Fort Hood Military Reservation, Texas, during 2003–2006. I predicted that nest survival would be greater earlier in the breeding season than later in the breeding season, in areas with less forest edge than in areas with more forest edge, and during the laying and incubation stages than during the nestling stage. I used the logistic-exposure method to model nest survival as a function of the explanatory variables and to produce model-based estimates of daily and period survival. The overall daily survival rate was 0.96 (95% CI: 0.94, 0.97) and overall period survival was 0.34 (95% CI: 0.23, 0.46). Forest edge density had the strongest effect on nest survival. Nest survival decreased as forest edge density increased. Period survival tended to decrease as the breeding season progressed, but the 95% confidence intervals of the model-averaged parameter estimates overlapped. These results demonstrate that effective conservation strategies designed to provide high-quality breeding habitat for this endangered species should include measures to reduce predation by edge-adapted predators.

**Key words:** *Dendroica chrysoparia*, edge effects, endangered species, information-theoretic approach, logistic exposure method, nest survival, temporal factors.

## Los Bordes de Bosque Afectan Negativamente la Supervivencia de los Nidos en *Dendroica chrysoparia*

**Resumen.** Utilicé un enfoque de la teoría de la información para determinar el apoyo a las hipótesis referentes a los efectos de borde y del tiempo en la supervivencia de los nidos de *Dendroica chrysoparia* en la Reserva Militar Fort Hood, Texas, entre 2003 y 2006. Predije que la supervivencia de los nidos sería mayor al inicio que hacia finales de la estación reproductiva, en las áreas con menos efecto de borde que en las áreas con más borde de bosque y durante las etapas de puesta e incubación que durante la etapa de cría de los pichones. Utilicé el método de exposición logística para modelar la supervivencia de los nidos como función de las variables explicativas y para producir estimados basados en los modelos de supervivencia diaria y del período. La tasa de supervivencia general diaria fue de 0.96 (95% IC: 0.94, 0.97) y la supervivencia general del período fue de 0.34 (95% IC: 0.23, 0.46). La densidad del borde del bosque tuvo el efecto más fuerte sobre la supervivencia de los nidos. La supervivencia de los nidos disminuyó a medida que la densidad del borde del bosque aumentó. La supervivencia del período tendió a disminuir a medida que avanzó la estación reproductiva, pero los intervalos de confianza del 95% de los parámetros estimados promediados entre modelos se superpusieron. Estos resultados demuestran que las estrategias efectivas de conservación diseñadas para brindar hábitat de cría de alta calidad para esta especie en peligro deberían incluir medidas para reducir la depredación por parte de los depredadores adaptados al borde.

## INTRODUCTION

Reviews of studies examining the effects of edges on forest-nesting migratory passerines support a general pattern of decreased nest success near habitat edges (Paton 1994, Andrén 1995, Hartley and Hunter 1998, Sisk and Battin 2002, but see Lahti 2001). However, results vary among species, habitats, and regions and no

absolute pattern to account for this variation is evident. Most studies of edge effects have used artificial nests (Yahner and Wright 1985, Wilcove et al. 1986, Andrén and Angelstam 1988), which may not reflect processes affecting natural nests (Willebrand and Marcström 1988). Additionally, most studies to date have not considered how fragmentation at the landscape scale affects nest success. Studies from the midwestern United States report decreased levels of nest predation with increasing forest cover in highly fragmented, predominantly agricultural landscapes (Dono-

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<sup>1</sup> E-mail: rpeak@tnc.org

van et al. 1995, Robinson et al. 1995), while results of a study from the western United States show the opposite effect (Tewksbury et al. 1998). Regional differences in the effects of landscape-scale fragmentation on nest predation may reflect differences in the abundance and activity patterns of predators among landscapes (Donovan et al. 1997, Chalfoun et al. 2002, Thompson et al. 2002).

Since the U.S. Fish and Wildlife Service implicated habitat loss as the major reason for listing the Golden-cheeked Warbler (*Dendroica chrysoparia*) as federally endangered in 1990, three studies have examined the effects of habitat fragmentation on reproductive success. Fink (1996) found a negative correlation between patch size and level of nest predation and some tendency for levels of nest predation to be greater near forest edges, but results were not significant. Maas-Burleigh (1998) found that reproductive success was significantly greater in unfragmented than in fragmented areas, and Coldren (1998) found that reproductive success was greater in territories farther from an edge and positively correlated with patch size. These studies used artificial nests or indices of reproductive success, so results may not reflect rates of predation or success of natural nests (Willebrand and Marcström 1988, Thompson et al. 1998).

My objective was to examine the effects of forest edge and temporal factors on Golden-cheeked Warbler nest survival on Fort Hood Military Reservation, Texas. I used an information-theoretic approach (Burnham and Anderson 2002) to determine support for edge and temporal factors on nest survival. I constructed a set of a priori candidate models, representing alternative hypotheses about the effects of forest edge density, the cubic effect of day of year, nest stage, and year on nest survival. Stake et al. (2004) identified the Texas rat snake (*Elaphe obsoleta lindheimeri*) as the most frequent predator of Golden-cheeked Warbler nests, so I used information regarding the activity and abundance patterns of rat snakes to make the following predictions: (1) nest survival would be greater earlier in the breeding season than later in the breeding season because snake predation is positively correlated with date of the breeding season (Stake 2003); (2) nest survival would be greater in areas with less forest edge than in

areas with more forest edge because rat snakes are more abundant along forest edges (Weatherhead and Charland 1985, Durner and Gates 1993); (3) nest survival would be greater during the laying and incubation stages than during the nestling stage because visitation of rat snakes to nests increases in the last few days of the nestling period (Stake 2003); and (4) nest survival would vary among years, reflecting annual changes in prey or predator abundance and activity patterns (Sherry and Homes 1992, Holmes et al. 1996, Trine et al. 1998).

## METHODS

### STUDY SPECIES

The Golden-cheeked Warbler breeds in the juniper-oak (*Juniperus ashei-Quercus* spp.) woodlands of central Texas. Males begin arriving on the breeding grounds in early March and females arrive in mid to late March (Ladd and Gass 1999). Females initiate nest building 2–5 days after arrival and it peaks in mid-April (Ladd and Gass 1999). They place nests in the mid to upper level of trees (Ehrlich et al. 1988). Golden-cheeked Warblers are single-brooded, although they will make up to three nesting attempts throughout the breeding season if a previous attempt is not successful (Ladd and Gass 1999; RGP, unpubl. data). Thus, nest initiation occurs asynchronously throughout the breeding season. Adults begin departing from the breeding grounds in mid-June (Ladd and Gass 1999).

### STUDY AREA

A crew of 12 seasonal field biologists and myself conducted this study on Fort Hood, an 87 890 ha active military installation in Bell and Coryell Counties, Texas (30°10'N, 97°45'W). Fort Hood is located within the Crosstimbers and Southern Tallgrass Prairie and Edwards Plateau Ecoregions (The Nature Conservancy 1997) and contains an estimated 21 422 ha of warbler habitat (Hayden et al. 2001). Eckrich et al. (1999) and Hayden et al. (2001) provide detailed descriptions of Fort Hood.

We located and monitored nests in five study sites during the 2003–2006 breeding seasons. Researchers established the study sites over the last decade as part of a long-term intensive

demographic monitoring study implemented in accordance with the terms and conditions outlined in the Biological Opinion (U.S. Fish and Wildlife Service 1993). Study sites ranged in size from 164 to 250 ha. All sites were comprised of closed-canopy (65%–76% canopy cover) woodlands dominated by Ashe juniper (*Juniperus asheii*) and a variety of oaks (*Quercus* spp.) with variable amounts of understory cover. The east side of Fort Hood, where two of the study sites were located, contained more continuous juniper-oak woodland habitat than the west side of Fort Hood, where the remaining three study sites were located (Pekins 2006).

#### NEST SEARCHING AND MONITORING

We located nests in study sites from mid-March to mid-June using adult behavioral cues. Once we located a nest, we marked it with plastic flagging placed  $\geq 10$  m away and monitored it every 2–3 days. We checked nests daily as the estimated incubation, hatching, and fledging date approached to ensure we recorded the correct stage and status of the nest. Since heights and locations of nests often precluded us from seeing nest contents, we used parental activity (laying, incubation, or feeding) to assess status as successful or failed. At each visit, we recorded date, time of visit, nest stage (building, laying, incubation, or nestling), description of nest contents if possible, and status.

We considered a nesting attempt complete when all nestlings fledged or the adults abandoned the nest prior to the fledging date. We confirmed fledging by visually locating fledglings or by observing parents carrying food either to fledglings or repeatedly to an area near the nest from which begging calls were heard. If a nest fledged  $\geq 1$  conspecific young, we considered it successful. If no fledglings were located or a renesting attempt was located within the territory shortly after completion of the nesting attempt, we considered the nest to have failed. Brown-headed Cowbirds (*Molothrus ater*) have been actively controlled at Fort Hood since 1988 (Eckrich et al. 1999) so I did not consider the effects of parasitism on nest survival. We recorded Universal Transverse Mercator (UTM) coordinates for each nest with a Garmin 12 (Garmin International, Olathe, Kansas) global positioning unit to an accuracy of  $\leq 5$  m.

#### FOREST EDGE DENSITY METRICS

We calculated forest edge density from a vegetation map prepared in 1998 by Pacific Meridian Resources (Atlanta, Georgia) derived from Landsat Thematic Mapper 30 m resolution imagery using Digital Orthophotography Quarter Quadrangles as the base layer. We condensed the original 16 vegetation classes into the following land-cover categories: (1) forest (juniper, live oak [*Quercus fusiformis*], upland deciduous, north slope deciduous, south slope deciduous, alluvial deciduous, post oak [*Quercus stellata*], or maple [*Acer* spp.]); (2) grassland (live grassland herbaceous, dormant grassland herbaceous, urban grassland, and brush piles); (3) water; (4) bare ground; and (5) hardscapes and roads. We defined edge as the boundary between forest and any other land-cover type, which was usually bare ground or grassland. We used Patch and Spatial Analyst (Grid 3.1 extension, ArcView 3.2, ESRI, Redlands, California) to calculate forest edge density within a 100 m radius around each nest site. Forest edge density was the length of forest edge in meters divided by the area of the landscape in hectares. We chose a 100 m radius around each nest because the results of studies examining the spatial ecology of rat snakes suggest a local spatial scale is more appropriate than a landscape spatial scale (Stickel and Cope 1947, Fitch and Shirer 1971, Weatherhead and Hoysack 1989, Durner and Gates 1993) and the land-cover map was not precise enough to support a more detailed analysis. The 100 m radius buffers around some nests overlapped (four in 2003, 18 in 2004, 11 in 2005, and 20 in 2006), so we quantified percentage of overlap to determine if the forest edge density metric associated with each nest was sufficiently different from all other nests to proceed with data analysis. Percent overlap was 7% in 2003, 14% in 2004, 9% in 2005, 14% in 2006, and 38% overall, indicating that buffers were sufficiently different for each nest.

#### STATISTICAL ANALYSES

I used an information-theoretic approach (Burnham and Anderson 2002) to evaluate support for 16 a priori candidate models that represented my hypotheses concerning the effects of forest edge and temporal factors on Golden-cheeked Warbler nest survival on Fort Hood Military Reservation. My set of a priori

TABLE 1. Results of model selection examining factors affecting nest survival of Golden-cheeked Warblers on Fort Hood Military Reservation, Texas, 2003–2006. Sixteen candidate models were considered. The first eight listed represent the  $\geq 90\%$  confidence set.  $\text{Log}_e(L)$  is the value of the maximized log-likelihood function,  $K$  is the number of parameters in the model,  $\text{AIC}_c$  is Akaike's information criterion for small sample sizes and  $\Delta\text{AIC}_c$  is the scaled value of  $\text{AIC}_c$ , and  $w_i$  is the Akaike weight which represents support for each model. Day of year<sup>3</sup> is the cubic effect of day of year.

Model	$\text{Log}_e(L)$	$K$	$\Delta\text{AIC}_c^a$	$w_i$
Forest edge density, stage, day of year <sup>3</sup>	-346.03	7	0.00	0.22
Forest edge density	-351.05	2	0.00	0.22
Forest edge density, day of year <sup>3</sup>	-348.17	5	0.25	0.19
Forest edge density, stage, day of year <sup>3</sup> , year	-344.05	10	2.10	0.08
Stage, day of year <sup>3</sup>	-348.18	6	2.29	0.07
Forest edge density, day of year <sup>3</sup> , year	-346.40	8	2.75	0.06
Forest edge density, year	-349.50	5	2.92	0.05
Forest edge density, stage	-350.54	4	2.99	0.05
Day of year <sup>3</sup>	-351.06	4	4.03	0.03
Year, stage, day of year <sup>3</sup>	-346.77	9	5.51	0.01
Forest edge density, stage, year	-349.01	7	5.96	0.01
Null	-355.44	1	6.78	0.01
Year, day of year <sup>3</sup>	-349.89	7	7.73	0.00
Stage	-354.82	3	9.55	0.00
Year	-354.55	4	11.02	0.00
Year, stage	-353.98	6	13.88	0.00

<sup>a</sup> The  $\text{AIC}_c$  value for the top model was 706.10.

candidate models included a temporal effects model with cubic effect of day of year, nest stage (for each nest observation interval), and year; an edge effects model with forest edge density; all one-, two-, and three-way combinations of temporal and edge effects variables; a global model with all the explanatory variables; and a null model with only an intercept (Table 1). I included the cubic effect of day of year in the models because previous studies of passerines have demonstrated a nonlinear decrease in daily survival rate as the breeding season progresses (Dinsmore et al. 2002, Grant et al. 2005). I evaluated the goodness-of-fit of the global model with a Hosmer and Lemeshow (2000) goodness-of-fit test and checked for overdispersion in the data using the Pearson  $\chi^2$  test statistic for the global model (Burnham and Anderson 2002). I used tolerance values (PROC REG, SAS Institute, Cary, North Carolina) for variables in the global model to diagnose multicollinearity (Allison 1999).

I used the logistic-exposure method (Shaffer 2004) to model nest survival as a function of the explanatory variables and to produce model-based estimates of nest survival. Like logistic regression, logistic exposure is based on a generalized linear model (McCullagh and Nelder 1989) with a binomial response distribution

(1 = successful, 0 = failed), a predictor function that yields daily survival estimates between 0 and 1, and a logit link function. However, the logit link function used in logistic exposure has been modified to account for the fact that the probability of surviving an interval is dependent upon interval length (Shaffer 2004). I used PROC GENMOD in SAS version 9.1 (SAS Institute 2004) to fit the logistic-exposure models (Shaffer and Thompson 2007).

I used Akaike's information criterion for small sample sizes ( $\text{AIC}_c$ ) to rank models from the most to the least supported given the data (Burnham and Anderson 2002). I used effective sample size (Rotella et al. 2004) to compute  $\text{AIC}_c$  ( $n$  = the number of successful nest observation days + the number of intervals that ended in failure). Since no single model received overwhelming support ( $w_i \geq 0.90$ ), I present model-averaged parameter estimates, odds ratios, predictions and their unconditional standard errors, and 95% confidence intervals (CI) from the group of models with a combined  $w_i \geq 90\%$  (Burnham and Anderson 2002).

I estimated daily survival rates as a function of the explanatory variables that had the strongest effects using model-averaged estimates from the  $\geq 90\%$  confidence model set

TABLE 2. Descriptive statistics for covariates used in logistic-exposure models examining survival of Golden-cheeked Warbler nests. Day of year is the ordinal date of a given year. Observation interval is the number of days between nest checks. Forest edge density is the length of forest edge in meters divided by the area of the landscape in hectares.

Variable	Median $\pm$ SD	Minimum	Maximum
Day of year	117.0 $\pm$ 14.8	89.0	163.0
Observation interval (days)	2.0 $\pm$ 1.2	1.0	4.0
Forest edge density (m ha <sup>-1</sup> )	21.1 $\pm$ 10.8	2.6	42.7

(Burnham and Anderson 2002). I varied the continuous covariate of interest at incremental levels across its observed range of values while controlling for effects of the other continuous covariates in the model by holding them at their observed medians (Shaffer and Thompson 2007; Table 2). I used population proportions of three, 12, and 10 days for the laying, incubation, and nestling stages, respectively, and assumed a balanced population across all other categorical covariates. I estimated period survival as the daily survival rate expanded for the entire nesting cycle of 25 days (Shaffer and Thompson 2007). I converted model-averaged coefficients to odds ratios when appropriate because of their more intuitive interpretation. For example, an odds ratio of 1.5 for the laying stage would indicate that the odds of nest survival was 50% greater during the laying stage than during the nestling stage, the reference category. The percentage of change in the odds ratio for each one-unit change in a continuous variable is interpreted by subtracting one and multiplying the odds ratio by 100 (Allison 1999).

## RESULTS

We monitored 53 nests in 2003, 63 nests in 2004, 60 nests in 2005, and 93 nests in 2006, for

an effective sample size of 2506. The Hosmer and Lemeshow (2000) goodness-of-fit test indicated that the global model fit the observed values ( $\chi^2_8 = 4.0$ ,  $P = 0.86$ ). The overdispersion parameter ( $\hat{c}$ ) equaled 1.03, indicating that the global model adequately fit the data, thus I did not correct for overdispersion. Tolerance values were  $\geq 0.62$  for all variables, suggesting that multicollinearity was not a problem (Allison 1999).

Eight models accounted for  $\geq 90\%$  of the total Akaike weight and became my final model set (Table 1). The top three models all received similar support based on their scaled AIC<sub>c</sub> values and Akaike weights (Table 1). Forest edge density had the strongest effect on nest survival: this variable appeared in seven of the top eight models and the 95% CI of the odds ratio did not include one (Table 1, 3). The odds of nest survival were 2% lower for each m per ha increase in forest edge density. The most supported models also contained the temporal effects of nest stage and cubic effect of day of year (Table 1), however the 95% CI of the odds ratios for these variables included one (Table 3), making it difficult to assess the strength of these effects. There was no support for the temporal effect of year.

TABLE 3. Model-averaged parameter estimates and unconditional standard errors (SE) and odds ratios with unconditional 95% confidence intervals for factors identified as affecting nest survival of Golden-cheeked Warblers on Fort Hood Military Reservation, Texas, 2003–2006.

Parameter	Estimate $\pm$ SE	Odds ratio (95% CI)
Intercept	54.31 $\pm$ 48.50	0.00 (0.00, 0.00)
Day of year	-1.22 $\pm$ 1.17	0.29 (0.03, 3.07)
Day of year <sup>2</sup>	0.01 $\pm$ 0.01	1.01 (0.99, 1.03)
Day of year <sup>3</sup>	-0.00 $\pm$ 0.00	1.00 (1.00, 1.00)
Forest edge density	-0.02 $\pm$ 0.01	0.98 (0.95, 0.99)
Laying versus nestling	-0.48 $\pm$ 0.63	0.62 (0.18, 2.19)
Incubation versus nestling	-0.15 $\pm$ 0.22	0.86 (0.56, 1.34)
2003 versus 2006	-0.06 $\pm$ 0.13	0.94 (0.72, 1.22)
2004 versus 2006	-0.06 $\pm$ 0.12	1.06 (0.83, 1.36)
2005 versus 2006	-0.02 $\pm$ 0.07	0.98 (0.85, 1.13)

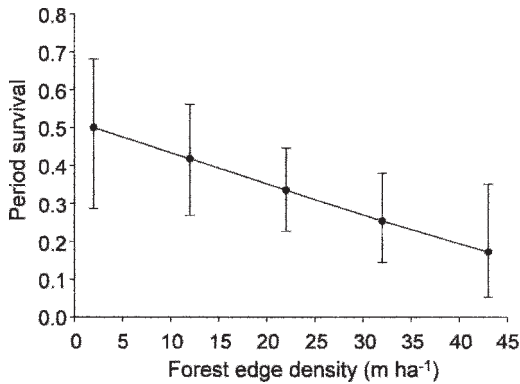


FIGURE 1. Period nest survival ( $\pm 95\%$  confidence intervals) decreased as forest edge density (m per ha) increased for Golden-cheeked Warblers on Fort Hood Military Reservation, Texas, 2003–2006.

The overall daily survival rate was 0.96 (95% CI: 0.94, 0.97) and overall period survival was 0.34 (95% CI: 0.23, 0.46), assuming a three-, 12-, and 10-day laying, incubation, and nestling stage, respectively. Period survival was greater in areas with less forest edge (0.50) than in areas with more forest edge (0.17; Fig. 1). Although the most supported models also contained nest stage and cubic effect of day of year (Table 1), the model-averaged estimates associated with these parameters were not precise. Daily survival rates did not differ among stages (Fig. 2). Period survival estimates showed a decreasing trend from earlier to later in the breeding season, however the 95% CIs overlapped (Fig. 3).

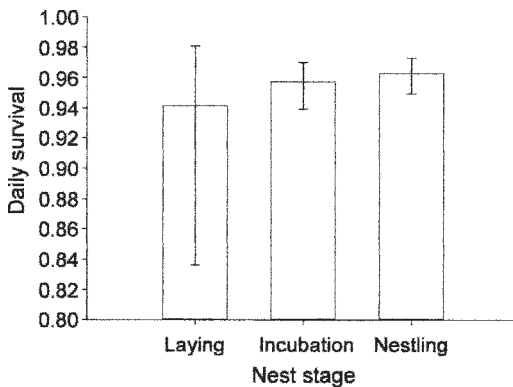


FIGURE 2. Daily nest survival ( $\pm 95\%$  confidence intervals) did not differ among the laying, incubation, and nestling stages for Golden-cheeked Warblers on Fort Hood Military Reservation, Texas, 2003–2006. The effective sample size is 2506 for all nest stages.

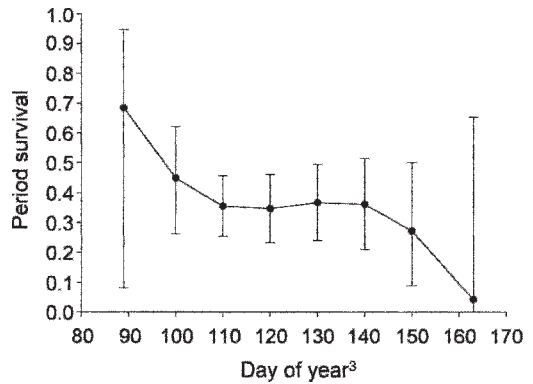


FIGURE 3. Period nest survival ( $\pm 95\%$  confidence intervals) decreased as the breeding season progressed for Golden-cheeked Warblers on Fort Hood Military Reservation, Texas, 2003–2006. Day of year<sup>3</sup> is the cubic effect of day of year.

## DISCUSSION

I found that nest survival was higher in areas with less forest edge, which is consistent with results of previous studies examining the effects of forest fragmentation on Golden-cheeked Warbler reproductive success (Fink 1996, Col-dren 1998, Maas-Burleigh 1998). The results of other studies of forest-nesting migratory passerines have been mixed, with a decrease in nest success near edges found in some cases (Gates and Gysel 1978, Chasko and Gates 1982, Wilcove et al. 1986, Andrén and Angelstam 1988) but not others (Yahner and Wright 1985, Angelstam 1986, Ratti and Reese 1988, Tewks-bury et al. 1998). Variation in the effect of edge on nest success could result from differences in the activity and abundance patterns of nest predators along edges (Odum 1958, Johnston and Odum 1965, Bider 1968). Chalfoun et al. (2002) found that the response of nest predators to fragmentation is complex, taxon-specific, and context-dependent. Texas rat snakes are the most frequent predator of both Golden-cheeked Warbler and Black-capped Vireo (*Vireo atricapilla*) nests on Fort Hood (Stake and Cimprich 2003, Stake et al. 2004). Studies have found that black rat snakes (*Elaphe obsoleta obsoleta*) preferentially use forest edges (Weatherhead and Charland 1985, Durner and Gates 1993) because they provide the thermal properties of both adjacent habitat types, allowing greater flexibility for thermoregulation (Blouin-Demers and Weatherhead 2004). Re-

search currently being conducted on Fort Hood suggests that Texas rat snakes also preferentially use edges (J. Hutchins, University of Illinois, pers. comm.).

The most supported models also contained temporal effects, although the strength of these effects is more difficult to interpret because their parameter estimates were not precise. Nest survival tended to decrease as the breeding season progressed, which is consistent with the results of previous studies conducted on Fort Hood examining factors affecting nest survival of Golden-cheeked Warblers and Black-capped Vireos (Stake 2003, Bailey 2005). Declines in nest survival as the breeding season progresses could reflect a change in predator activity over the course of the breeding season. Schaub et al. (1992) found a correlation between nest predation rates, snake activity, and progression of the breeding season of Florida Scrub-Jays (*Aphelocoma coerulescens*). Snake activity on Fort Hood peaks from May through June (J. Hutchins, pers. comm.). Golden-cheeked Warblers begin nesting in late March, and thus may experience greater nest survival earlier in the breeding season because cooler ambient temperatures during this time reduce foraging activity of snakes. Greater nest survival earlier in the breeding season also could reflect changes in the predator community throughout the breeding season. Stake et al. (2004) documented avian predators, particularly American Crows (*Corvus brachyrhynchos*), as the second most frequent type of predator of Golden-cheeked Warbler nests. Corvid density has been positively correlated with nest predation (Andrén et al. 1985) and shown to be greater in more fragmented landscapes (Rich et al. 1994, Donovan et al. 1997).

Daily survival did not differ among the different nesting stages, which is not what I predicted. The broad 95% CI for laying stage indicates a high degree of variation in the sample, so even if a real difference existed, I may not have detected it because of the small number of observation intervals during the laying stage. Some previous studies have found decreased nest survival during the laying and incubation stages (reviewed by Martin 1992, Peak et al. 2004, Bailey 2005), while others have found lower nest survival during the nestling stage (Young 1963, Robertson 1972, Schaub et al. 1992, Burhans et al. 2002). Variation in nest

survival rates during the nesting cycle may reflect temporal patterns in the predator community or availability of alternative prey (Thompson and Nolan 1973) or cues used by dominant predators to locate nests (MacDonald 1973, Herzog and Burghardt 1974, Eichholz and Koenig 1992).

This study demonstrates the importance of using demographic parameters, such as nest survival, to assess habitat quality (van Horne 1983, Vickery et al. 1992). Although Golden-cheeked Warblers may use habitat edges (Kroll 1980, Magness et al. 2006), these quantitative results demonstrate that forest edges do not provide high-quality breeding habitat on Fort Hood. Consequently, effective conservation strategies designed to provide high-quality breeding habitat for this endangered species should include measures to reduce predation of Golden-cheeked Warbler nests by edge-adapted predators. Natural resource professionals can reduce forest edge density by maintaining large, contiguous patches of mature juniper-oak woodlands. Additionally, controlling populations of browsing animals, implementing measures to control oak wilt, and promoting reforestation of cleared areas such as fence rows, trails, grazed areas, pastures, and logged areas also can reduce forest edge density.

Donovan and Thompson (2001) suggested a nest survival rate of 0.25 to 0.30 is required to balance juvenile and adult mortality. On Fort Hood, nest survival estimates for the Golden-cheeked Warbler (0.32–0.37) have been above this range during the past four breeding seasons, suggesting that, at least in some years, Fort Hood functions as high-quality breeding habitat for this endangered species (Pulliam 1988) and thus plays a critical role in maintaining its long-term viability. Fort Hood contains some of the largest remaining patches of Golden-cheeked Warbler breeding habitat in the Lampasas Cut Plain region of its breeding range (R. Wahl, D. Diamond, and C. D. Duncan, Ecological Services, unpubl. data). Since edge effects may be driven by habitat patterns at larger spatial scales (Donovan et al. 1997, Thompson et al. 2002) the results of this study provide a basis for comparison with studies in other parts of the breeding range where land use patterns are different and population parameters may vary.

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