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Management and Conservation Note

Monitoring Golden-Cheeked Warblers on Private Lands in Texas

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ABSTRACT A majority of North American breeding habitat for neotropical migrants exists on private lands, requiring monitoring strategies focused on habitat in these private holdings. We outline study designs and protocols using repeated presence–absence surveys across a gradient of patch sizes to develop a range-wide monitoring program for the endangered golden-cheeked warbler (*Dendroica chrysoparia*) in Texas, USA. We surveyed 200–400 point-count locations across approximately 30 private properties annually from 2005 to 2008. We used data from our surveyed patches ($n = 147$) and the Ψ (occupancy), p (detection), and $\gamma = 1 - \varepsilon$ parameterization to estimate patch dynamics and associated detection probabilities for golden-cheeked warblers. Patch size had a strong association with patch occupancy, and all patches >160 ha were predicted to be occupied. We found no evidence that large golden-cheeked warbler populations located on public lands in the vicinity of our study area influenced occupancy dynamics. We conducted simulations across a range of detection probabilities to evaluate potential sample sizes for both standard- and removal-based occupancy modeling. Simulations using parameter estimates from our analysis indicated that removal-based sampling is superior to standard sampling. Based on our results, surveying golden-cheeked warbler presence in oak–juniper (*Quercus*–*Juniperus*) patches under a removal modeling framework should be considered as one alternative for range-wide monitoring programs because patch-level monitoring would be necessary to estimate proportion of range occupied. Large contiguous patches are rare across the species' range; hence, conservation and management of the mosaic of smaller patches within a landscape context would be required for maintaining species viability. Thus, we recommend the identification of areas where smaller, contiguous patches represent a significant portion of the available habitat within the local landscape and targeting these areas for habitat maintenance and improvement.

KEY WORDS breeding range, *Dendroica chrysoparia*, fragmentation, golden-cheeked warbler, habitat loss, patch area, patch occupancy, Recovery Credit System.

The golden-cheeked warbler (*Dendroica chrysoparia*) is a federally endangered neotropical migratory passerine with a known breeding range across about 35 counties ($\geq$95% private ownership) in central Texas, USA (Fig. 1; Pulich 1976, Deboer and Diamond 2006, Magness et al. 2006). Within the warblers' breeding range, mature oak (*Quercus* spp.)–Ashe juniper (*Juniperus ashei*) woodlands provide foraging habitat, nesting cover, and shredded bark used as nesting substrate (Pulich 1976, Ladd and Gass 1999). However, declines in oak–juniper woodlands (United States Fish and Wildlife Service 1992) and the small percentage of breeding habitat found on public lands (<5% of total area within the breeding range) requires that conservation planning for the warbler must incorporate habitat on private lands. Understanding the combined impacts of habitat loss and fragmentation, as well as the impacts of private lands on species distribution and demography, is vital to recovery (United States Fish and Wildlife Service 1992).

Several models of habitat distribution of the golden-cheeked warbler have been constructed to guide conservation efforts (e.g., DeBoer and Diamond 2006, Magness et al. 2006). Habitat delineations are usually based on presence or absence data collected during point-count surveys on private and public lands (Wahl et al. 1990). However, current habitat models have been based on a limited number of survey points across the species' range ($n = 49$, DeBoer and Diamond 2006; $n = 202$, Magness et al. 2006). Although attempts have been made to predict distribution of warbler habitat, recent studies have relied on short-term (single season) and limited-visit ($\leq$2) surveys to establish species presence for identifying general habitat metrics (Wahl et al. 1990, DeBoer and Diamond 2006, Magness et al. 2006).

Limited data exist for modeling golden-cheeked warbler demographics across the species' range, with most data derived from studies on Ft. Hood, Coryell County (Fig. 1; Anders 2000, Alldredge et al. 2004, Anders and Dearborn 2004, Baccus et al. 2007, Peak 2007). Recent efforts to quantify golden-cheeked warbler population size have been based on a combination of density estimates from approximately 30 years ago (Pulich 1976), from the intensively managed Ft. Hood populations (Jettj et al. 1998), or from a small number of transects ($n = 11$, Wahl et al. 1990). Density estimates are then combined with aforementioned estimates of available breeding habitat (e.g., Wahl et al. 1990, DeBoer and Diamond 2006, Magness et al. 2006) to estimate population size (Rappole et al. 2005). These derived population estimates remain unreliable for use in the range-wide management and conservation of the species.

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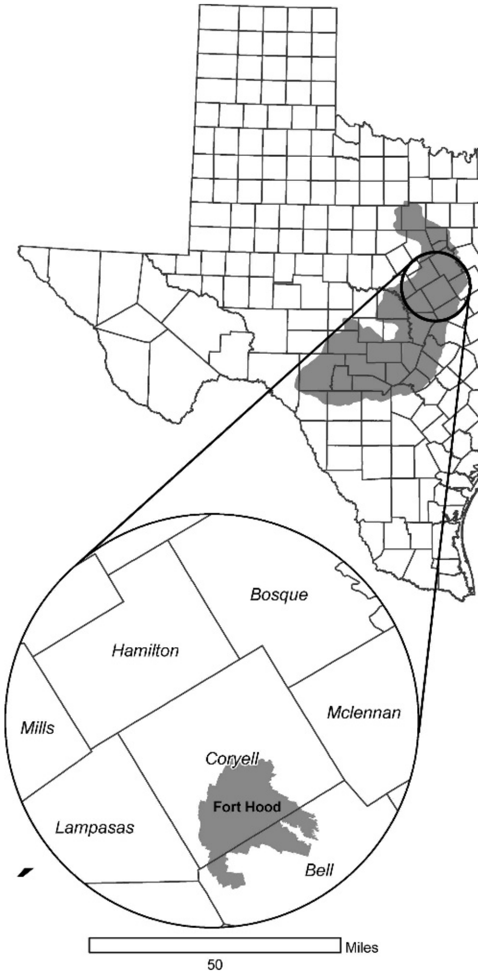

Figure 1. Study area where golden-cheeked warbler habitat patch surveys were conducted during 2006–2008 relative to Ft. Hood and the breeding range of the golden-cheeked warbler in central Texas, USA.

Periodic assessments of changes in populations are necessary to understand implications of management (Pollock et al. 2002, Nichols et al. 2008). Successful monitoring programs for avian species require that managers use reliable estimators for rapidly detecting population trends and measuring the magnitude of such changes (Williams et al. 2002). Our objective is to test and standardize population monitoring protocols for golden-cheeked warblers in the vicinity of Ft. Hood, Texas using repeated presence–absence surveys and make recommendations for expanded monitoring efforts throughout the breeding range. In addition, we evaluated potential sampling approaches for implementing range-wide distribution and monitoring surveys for golden-cheeked warblers.

STUDY AREA

We conducted our research centered on the Leon River watershed in the Lampasas Cut Plains and Cross Timbers and Prairies region of central Texas (Fig. 1; Gould 1975). This region was characterized by ecological sites of steep adobe, low stony hills, and loamy bottomlands. Dominant tree species included Ashe juniper, oaks, ash (*Fraxinus* spp.), and elm (*Ulmus*) species, as well as pecan (*Carya illinoinensis*) and hackberry (*Celtis laevigata*). Approximately 84% of the area was mixed-use agriculture, consisting of rangeland and croplands with ongoing urban development near the Interstate 35 corridor. Approximately 13% of our study area was mature oak–juniper woodland, primarily in patches <18 ha. Patches >18 ha made up >80% of the total mature oak–juniper woodland (Butcher 2008).

METHODS

Avian studies often define sampling sites as locations where measurements of presence–absence or abundance are collected (e.g., point-count stations; Ralph et al. 1995, Nichols et al. 2000, Thompson 2002). However, sites defined by such criteria are not likely to be a landscape unit of ecological importance to the species of interest. Given the endemism of golden-cheeked warblers to patches of oak–juniper woodlands (Pulich 1976, Ladd and Gass 1999), we defined oak–juniper patches as being the operational sampling unit for considering occupancy. In addition, this scale is likely the same scale at which measurements of demography (abundance, survival, productivity) would be relevant from a recovery or management perspective (Gilpin and Hanski 1991, MacKenzie and Royle 2005, MacKenzie et al. 2006).

We delineated oak–juniper patches using unsupervised classifications of Landsat Thematic Mapper images with ERDAS IMAGINE 9.2. We used Landsat images representing summer, spring, and autumn to distinguish between evergreen and deciduous trees to separate mixed oak–juniper patches from continuous oak patches (e.g., riparian areas). We used ArcMap 9.2 to locate point-count stations within identified juniper–oak forest patches. We estimated patch area (ha) using the VLATE 1.1 (Lang and Tiede 2003) extension of ArcMap. We estimated a proximity index for each sample patch based on the size and distance of all patches having edges within a specified search radius (400 m; Magness et al. 2006) of the focal patch (Gustafson and Parker 1992). We assessed classification accuracy following the descriptive technique described by Congalton (1991). We visited 161 systematically placed reference plots (30 $\times$ 30 m) to determine vegetation cover and composition. We defined mixed juniper–deciduous forest as forest with >50% canopy cover, of which $\geq$10% was juniper and $\geq$10% was deciduous species. The overall accuracy of the unsupervised classification was 78%. The probability that a reference point was correctly classified as juniper–deciduous forest was 79% and probability that a reference point was correctly classified as other was 75%.

Our interest was in surveying patches of habitat on private lands within the region surrounding known populations at Ft. Hood, and our sampling frame consisted of accessible private properties. We based selection of patches for surveying on availability of potential golden-cheeked warbler habitat, which we delineated using our habitat classification schema. For each accessible property (n = 30), we systematically distributed point-count stations throughout available oak–juniper woodland patches. The number of surveyed point-count stations and patches surveyed varied over time depending on property access, ranging between 200 to 400 total point-count locations. Each point-count location was separated by >250 m from other stations. In addition, surveyors listened during movements between points for the warbler as well as several additional species of management interest known to occupy our study area. During pilot field work evaluating data collection and survey methodology (2003–2005), we surveyed each point-count location 3 times under a standard occupancy design (MacKenzie et al. 2002, 2006). Preliminary analysis of 2003–2005 data indicated that the number of repeated surveys should be increased to 6 surveys to better evaluate variation in warbler detection rates across the breeding season (B. A. Collier, Texas A&M University, unpublished data). Given results of our pilot analysis (2003–2005), we then used data collected from 2006 to 2008 for the present analysis.

We transitioned our 2008 survey efforts to a removal modeling approach where 2 observers traversed between point-count stations within a patch simultaneously but independently (MacKenzie and Royle 2005) because our pilot analysis indicated that detection rates where high (>50%) and declined in conjunction with changes to warbler reproductive phenology (e.g., territory settling, incubation, nesting feeding; Ladd and Gass 1999). According to the removal design, an observer's survey ended when he or she made a positive detection. However, because observers operated independently, the other observer continued to survey within the patch until he or she made a positive warbler detection or until the patch was completely traversed and surveyed. Thus, for each survey occasion, possible encounter histories for detections by one or both observers were 10, 01, 11, or 00 (detection by first observer only, detection by second observer only, detection by both observers, no detections, respectively). If no positive detections were made during a survey, we conducted additional surveys following the above protocol for a maximum of 6 presence–absence surveys (3 visits by 2 observers over 3 weeks) for any patch, equivalent to the number of sample surveys conducted during 2006–2007. Our survey techniques were consistent from 2006 to 2008 with observers randomly allocated to sample locations, point-count stations traversed during morning hours (0600–1100 hr), and repeated visits to a patch separated by <7 days.

Selection of habitat patches for surveying did not require presence of golden-cheeked warblers, only presence of predicted warbler habitat. We avoided site selection bias in our estimates of occupancy because we did not have preexisting knowledge of the potential occupancy state (MacKenzie and Royle 2005). Property ownership distribution was variable; therefore, in some cases we did not have access to the entirety of a patch. However, we assumed that habitat and warbler distribution was not influenced by nonbiological boundaries (e.g., property lines) so all points within a patch were equally likely to have warblers within the vicinity.

We used data from our surveyed patches and the Ψ (occupancy), p (detection), and $\gamma = 1 - \varepsilon$ parameterization in PRESENCE (MacKenzie et al. 2006) to estimate patch occupancy and associated detection probabilities for golden-cheeked warblers. We defined the primary sampling occasions as years (3 yr, 2006–2008) and our secondary sampling occasions were the repeated patch visits that occurred during the warbler breeding season ($\leq$6 visits from 2006 to 2008; Mar–Jul). For our candidate models, we focused modeling of detection on session-dependent covariates associated with the sampling process. We expected that as the season progressed, detections would decline as breeding activities shifted from territory establishment and mating to other reproductive activities (e.g., nesting, feeding nestlings; Ladd and Gass 1999), and based on previous analyses of earlier data (M. L. Morrison, Texas A&M University, unpublished data), we regarded this parameter as fixed in all our models. Thus, we modeled survey week as a session-dependent covariate and we defined 15 March as the beginning of week 1, because this date is when warblers began arriving at our study area.

Our breeding survey observations suggested that golden-cheeked warblers occupied a wide variety of patches ranging from 1 ha to >1,000 ha. Given the dependence on oak–juniper patches, as the size of habitat patches increased we expected some threshold level (Lindenmayer and Luck 2005) of patch area at which $p(\Psi) = 1$. Because management for golden-cheeked warblers has been concentrated on a few public holdings (e.g., Ft. Hood; Anders and Dearborn 2004, Baccus et al. 2007) under the expectation that birds would be recruited into surrounding areas from these source populations (e.g., United States Fish and Wildlife Service 2001), we modeled distance from Ft. Hood as a predictor for warbler patch occupancy. We used an information theoretic approach to model selection and assessed model strength based on Akaike's Information Criterion adjusted for small sample size (AIC_c) and Akaike weights (w_i; Burnham and Anderson 2002). When model selection uncertainty occurred, we used multimodel inference and provide model-averaged estimates of parameters (Burnham and Anderson 2002).

Using parameter estimates from our best-fitting model, we estimated average occupancy for surveyed patches of habitat. Based on our average occupancy estimates (0.495) we used R (R Core Development Team 2008) to simulate potential sample sizes necessary for a range of estimated detection probabilities and repeated survey frequencies. We assumed a fixed variance of the occupancy parameter [$\mathrm{var}(\hat{\Psi}) = 0.05$] for all simulations, and we evaluated sample requirements across a range of minimum (standard design) and maximum (removal design) repeated visits. Based on our results (see below) we simulated sample requirements over the range of detection probabilities garnered from the first 2 months of the breeding season when birds were actively engaged in reproductive activities (e.g., territory establishment). We used the sample size formulas of MacKenzie and Royle (2005) for both standard and removal modeling designs to determine optimal sample sizes under both data collection methods that would be optimal for monitoring golden-cheeked warbler distribution across their range.

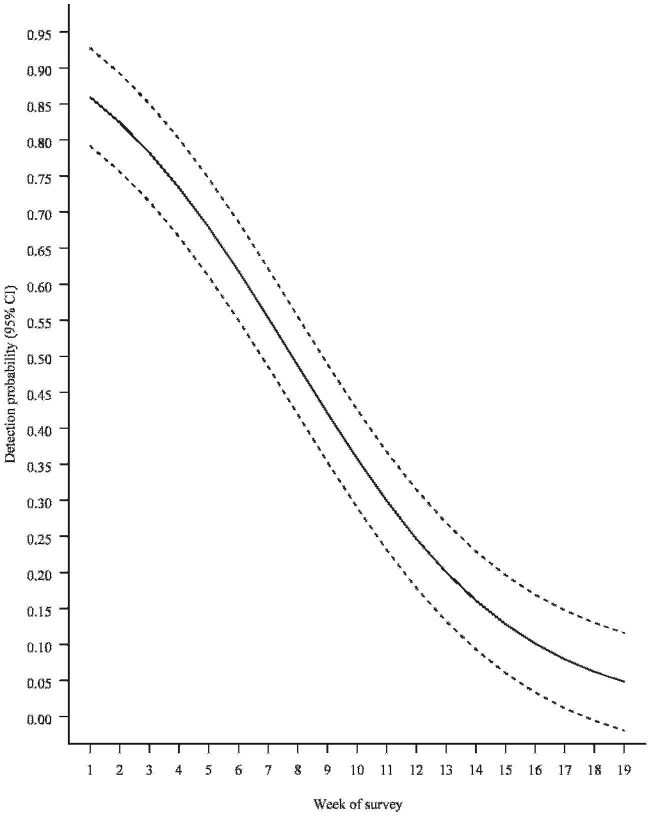

Figure 2. Predicted weekly (15 Mar = week 1) detection probabilities for golden-cheeked warbler habitat patch occupancy surveys conducted in central Texas, USA, 2006–2008.

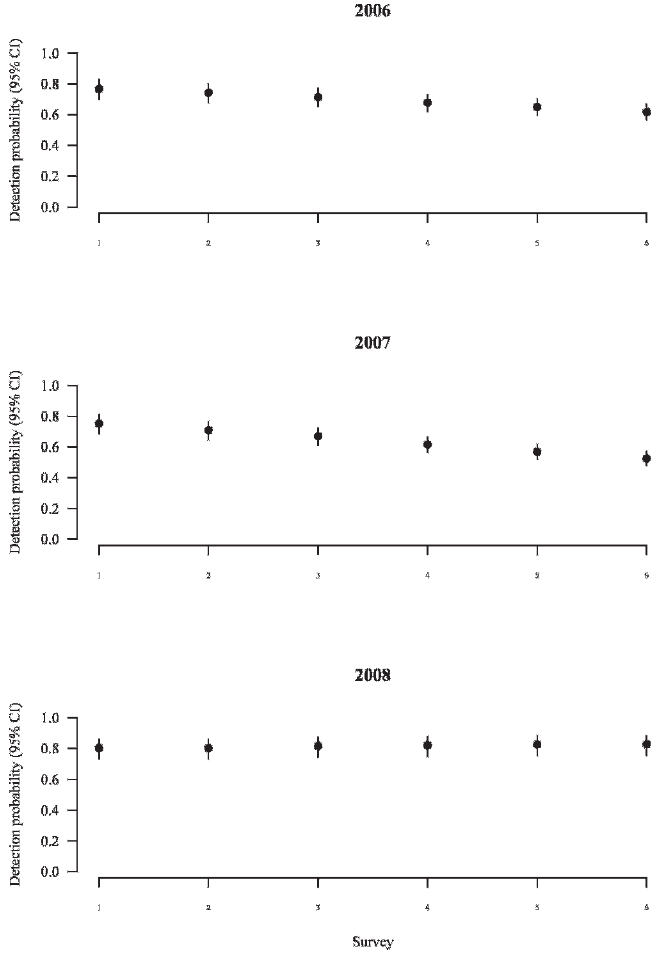

Figure 3. Detection probabilities across survey periods for golden-cheeked warbler habitat patch occupancy surveys conducted in central Texas, USA, 2006–2008.

RESULTS

We monitored 147 habitat patches for ≥ 1 breeding season between 2006 (72 patches), 2007 (94 patches), and 2008 (39 patches). Patch sizes averaged 45 ha (SD = 111) and ranged from 0.54 ha to 1,043 ha. Our modeling of detection probabilities showed a consistent pattern of declining detections as week of the year progressed (Fig. 2). Secondary, occasion-specific detection probabilities associated with our robust design were high for each period and declined as expected over the course of the season. The one exception to this finding was in 2008 when our removal modeling approach with double observers reduced the number of required visits to sites, which reduced the amount of the breeding season we spent surveying (Fig. 3). Our models including patch area as a main or interactive effect had more support than models for occupancy as a function of other variables (Table 1). Model-averaged predictions across the range of patch area showed an increase in patch occupancy, reaching the threshold [prob(Ψ) = 1] at 160 ha in size (Fig. 4). We evaluated competing models for patch proximity and distance from Ft. Hood; however, none were supported in our analysis. Models using patch proximity (intercept = −0.1893 [SE = 0.198], slope = 0.001863 [SE = 0.00064]), or distance from Ft. Hood (intercept = 0.2604 [SE = 0.178], slope = 0.0000001 [SE = 0.00024]) as predictors for occupancy indicated that neither factor was likely impacting occupancy dynamics at the scale we evaluated.

Our simulation results showed that both removal and standard designs tended to converge on optimal numbers of patches to survey between 90 patches and 110 patches as detection probability increased (Fig. 5). For our simulated results, we found that to estimate a standard error equal to 0.05 for occupancy, the number of sites to survey was <120 as long as the maximum number of allowable visits was ≥ 4 for removal designs. For the standard design, the number of sites to survey was <150, assuming each site would be surveyed ≥ 3 times each season (Fig. 5).

DISCUSSION

Using an appropriately defined sampling unit, different monitoring programs for rare species such as the golden-cheeked warbler can be evaluated, and issues associated with low detections can be more adequately investigated rather than relying on complex statistical models (McDonald 2004, Royle 2006, Morrison et al. 2008). High detection estimates suggest our choice of sampling units (i.e., the patch rather than points within a patch) was appropriate for evaluating our monitoring program's primary state variable of interest, patch occupancy (Bailey et al. 2004). Occupancy surveys developed for monitoring that treat survey points within a habitat patch as independent sampling units are likely

Table 1. Candidate models used to examine the effects of oak–juniper habitat patch area (Patch Area) and distribution (Proximity), distance from potential source populations on Ft. Hood (DistFtHood), and survey timing (vwk) on patch occupancy and detection of golden-cheeked warblers in the Leon and Bosque River watersheds of Texas, USA, 2006–2008.

Model notation	No. of parameters	$-2LL$[a]	ΔAIC_c[a]	w_i[a]
p(vwk)Psi(PatchArea)Gamma(PatchArea)	6	831.727	0	1.00
p(vwk)Psi(Proximity)Gamma(PatchArea)	6	854.36	22.63	0
p(vwk)Psi(Ft. Hood)Gamma(PatchArea)	6	860.62	28.89	0
p(vwk)Psi(PatchArea)Gamma(t)	6	876.33	44.60	0
p(vwk)Psi(PatchArea)Gamma(Proximity)	6	885.94	54.21	0
p(vwk)Psi(PatchArea)Gamma(t.)	5	889.55	55.82	0
p(vwk)Psi(PatchArea)Gamma(Ft. Hood)	6	889.55	57.82	0
p(vwk)Psi(.)Gamma(t)	5	906.17	72.44	0
p(vwk)Psi(Ft. Hood)Gamma(t)	6	905.22	73.50	0
p(vwk)Psi(Proximity)Gamma(.)	5	912.18	78.46	0
p(vwk)Psi(.)Gamma(.)	3	984.08	146.35	0

[a] $-2LL = -2$ log-likelihood; ΔAIC_c = Akaike's Information Criterion adjusted for small sample size, difference from the best model; w_i = Akaike wt.

pseudoreplicated (Hurlbert 1984). Point-count surveys are appropriate if the primary interest is in determining the relationship between local (e.g., within-patch) habitat conditions and bird presence (Lauver et al. 2002, Kroll et al. 2007). However, use of points as the sampling unit is not appropriate for long-term, range-wide monitoring because perturbations that affect individual dynamics operate at a scale much larger than the point and may be associated with processes associated with inter-patch territory establishment and territory success or failure.

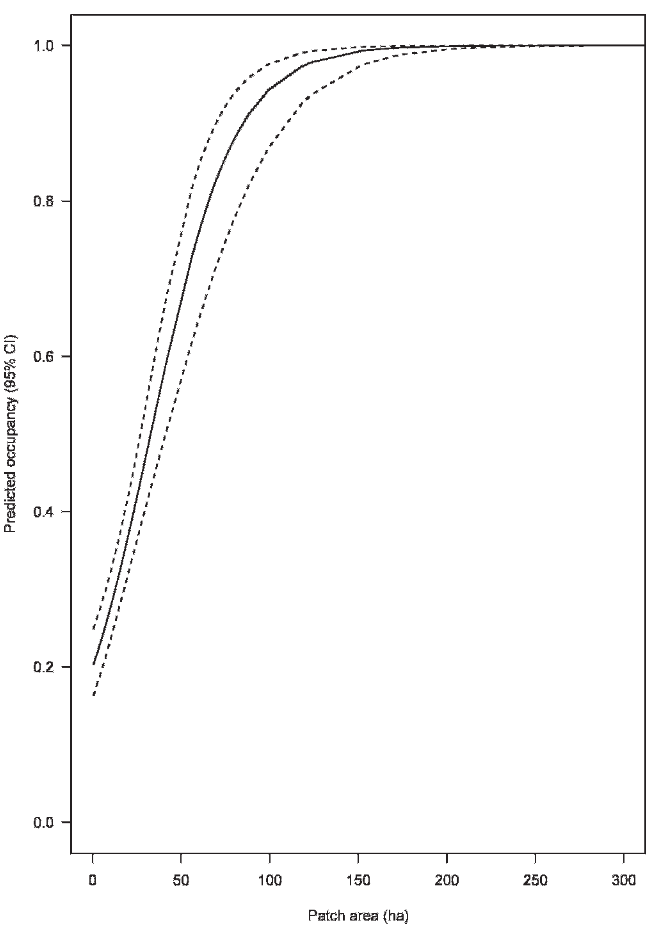

Figure 4. Predicted occupancy and associated 95% prediction interval for golden-cheeked warbler habitat patches surveyed in central Texas, USA, 2006–2008. Note the prediction range is truncated at 300 ha [p(Ψ) = 1] while maximum patch area surveyed was approximately 1,042 ha.

Using a random-changes occupancy model we expected no relationship between t and $t+1$ in predictions of occupancy. The relationship between occupancy in time 1 and future sampling occasions was a function of the covariates used for predicting $\hat{\Psi}_1$, and $\hat{\gamma}_1$ and $\hat{\gamma}_2$ (MacKenzie et al. 2006). Our expectation that occupancy would be positively associated with patch area seems logical because positive relationships between occupancy, local abundance, and regional distribution are common patterns in population ecology (Gaston et al. 1997, He and Gaston 2000, Holt et al. 2002). Within larger patches that had high occupancy probabilities, increased focus should be put on estimating within-patch state variables (i.e., intra-patch distribution and movements, abundance, survival, and productivity). Given the wide range of patch sizes across the breeding range of Texas (present study, Ladd and Gass 1999), our results indicate that golden-cheeked warbler occupancy surveys should focus on patches ≤ 160 ha because 1) factors influencing presence would be most likely to influence smaller patches; 2) smaller patches represent a large proportion of the occurrence of available habitat on private lands across many of the species' recovery regions; and 3) smaller patches are caused by increasing fragmentation via land ownership changes across the breeding range and, hence, are more likely to be degraded over time due to less management (Sanders 2005). Providing incentives for habitat conservation on private lands is one option for reducing impacts of habitat fragmentation. A program that provides incentives to landowners for managing golden-cheeked warbler habitat is being implemented and evaluated in our study region (Recovery Credit System; Wilkins et al. 2008).

We did not find evidence that locally abundant populations on Ft. Hood influenced warbler distribution and occupancy on adjacent private land (proposed by Anders and Dearborn 2004, Baccus et al. 2007). We suggest several plausible explanations: 1) Ft. Hood is not serving as a source population for golden-cheeked warblers in the Leon River watershed; 2) dispersal of birds from Ft. Hood had already saturated our study area before our study began; 3) colonization or extinction processes occurred at a much

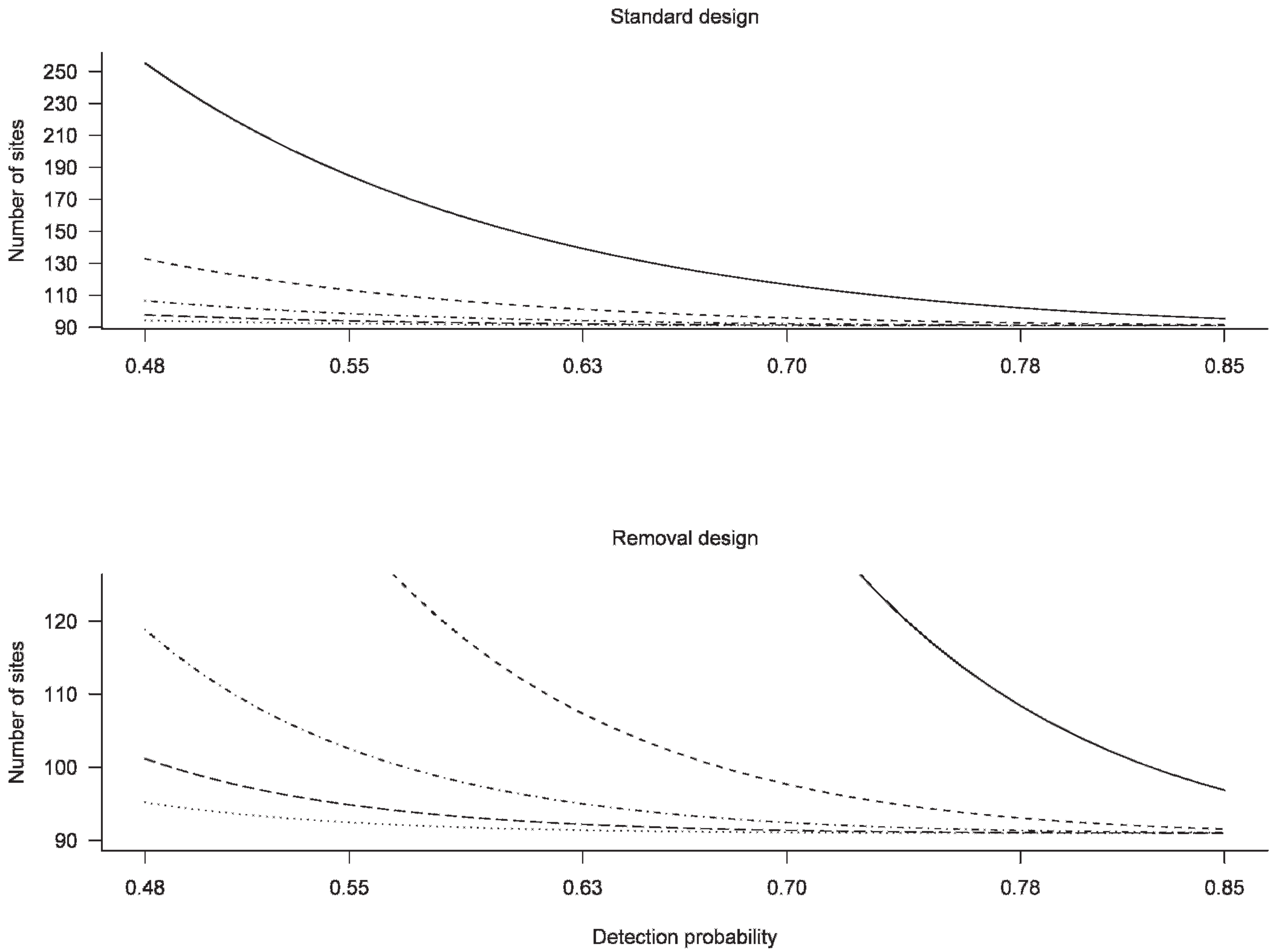

Figure 5. Simulated number of sites necessary to survey for golden-cheeked warblers under both standard and removal occupancy designs to attain a standard error of the occupancy estimate of 0.05 based on detection probabilities associated with the period 15 March to 15 May survey periods used in Texas, USA, during 2006–2008. We ran simulations across a range of K (no. of surveys) shown by the solid line ($K = 2$) through the dotted line ($K = 6$). Under a standard design, K represents the minimum number of surveys necessary to attain the prespecified level of precision, whereas under the removal design, K represents the maximum number of surveys that would be required if presence was not confirmed.

finer resolution (within-patch or territories) than we evaluated; or 4) sampling patches transitioning into and out of our study based on property access restrictions simply inhibited our ability to accurately estimate these processes. Thus dynamic processes associated with colonization–extinction dynamics, if those are biologically interesting and meaningful for species recovery, would likely necessitate estimation based on intra-patch dynamics focused specifically on measurement within the utilized territory of the bird.

Issues associated with low detection probabilities can be more adequately investigated using sample survey (i.e., design-based) approaches rather than the less rigorous model-based inferences (Royle 2006). We surveyed for 19 weeks to estimate detection probabilities over the course of the breeding season and we likely violated the closure assumption (MacKenzie et al. 2006). However, because our intention was to fully evaluate a broad range of factors influencing distribution and occupancy, gaining knowledge of how detection varied temporally warranted expanding the survey period. Hence, our pilot survey results (B. A. Collier, unpublished data) and this study indicated that the temporal scale of surveying most influenced detection probability within the patch.

Our results concur with the general results from MacKenzie and Royle (2005) wherein removal designs were efficient in situations where occupancy exceeded 30%, regardless of detection probability (MacKenzie and Royle 2005). However, the number of surveys under a removal design is a random variable and can necessitate a greater number of overall surveys when detections do not occur, so there is an element of chance associated with removal design (MacKenzie and Royle 2005). One plausible approach to increasing efficiency under a removal design would be to incorporate a cost function that addresses costs associated with survey visits by individuals compared to multiple observers during the same survey event. Specifying this cost function is critical, because optimal sampling designs must include a consideration of available resources. For example, if multiple observers could survey a location concurrently, then logistical costs associated with survey effort could be reduced, while sample intensity (e.g., no. of sample surveys conducted) could be increased. Thus, while the researcher must be willing to repeatedly survey a site for up to *n* times under a removal design to gain the efficiency benefits (MacKenzie et al. 2006), simple changes in survey design could potentially offset any increased costs associated with removal models.

Management Implications

Future golden-cheeked warbler surveys should be conducted between 15 March and 1 May each year to take advantage of high detection probabilities during this period. In the context of recovery planning, monitoring and evaluating patch-occupancy dynamics should occur among smaller patches (<160 ha). Work within larger patches should focus on intra-patch distribution, patch level abundance, and productivity. Future monitoring data following our design should be used for supporting approaches to minimize or mitigate against future habitat loss in highly vulnerable areas across the species' range. We suggest that the study design and analyses used herein for the golden-cheeked warbler would be applicable to other rare, woodland endemic species.

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