DETECTION PROBABILITIES, OCCUPANCY AND SURVEY EFFORT OF GOLDEN-CHEEKED WARBLERS *(DENDROICA CHRYSOPARIA)* USING DETECTION – NONDETECTION SURVEYS

THESIS

Presented to the Graduate Council
of Texas State University-San Marcos
in Partial Fulfillment
of the Requirements

for the Degree

Master of SCIENCE

by

Cynthia Ann Watson, B.A.

San Marcos, Texas
August 2006

ACKNOWLEDGEMENTS

I thank my mother, LaRue Harris for teaching me to persevere and my father, Stanley Baker for always encouraging me to do my best. For being the best sister one could ask for, I thank Angela Baker. I would especially like to thank my husband, Richard Watson for standing by my side and always believing in me.

Many thanks to my committee members, Drs. Floyd Weckerly, Paula Williamson, Craig Farquhar and Jeff Hatfield. I am grateful to co-chair Dr. Weckerly for guiding me through the statistics involved in my research. I also thank co-chair Dr. Williamson for her great inspiration and constant source of encouragement. I thank committee members Dr. Hatfield for his expertise in study design and statistics and Dr. Farquhar for his avian expertise and teaching me how to be a field biologist.

I am grateful to the Texas Parks and Wildlife Department for granting research permits and allowing access to Government Canyon State Natural Area and Garner State Park. I would like to express my gratitude to Deidre Hisler and Erik Holmback at Government Canyon and Craig VanBarlee at Garner State Park. I also thank the United States Fish and Wildlife Service and particularly the Balcones Canyonlands National Wildlife Refuge for allowing me to use the refuge as a study site.

Many thanks to the following people for their various contributions: Darryl MacKenzie, Larissa Bailey, Jim Hines, Jim Nichols, Chuck Sexton, Deborah Holle, Kathy Granillo, Bill Howe, Jenny Wilson, Rosa Huerta, Robert Pine, Renne Loeheffner and Alisa Shull.

My research would not have been possible without the assistance of my field crew: Dr. Weckerly, Jana Milliken, Greg Cryer, Cindy Sperry, Chris Keistler, Dawn Romaine - Huston, Deena Francis, Angela Baker and Richard Watson. Thanks to all of you for doing your best work in spite of steep terrain and cacti.

Finally, I am most grateful to the United States Geologic Survey and the United States Fish and Wildlife Service for funding my thesis research.

This manuscript was submitted on July 21, 2006.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Page

ABSTRACT

DETECTION PROBABILITIES, OCCUPANCY AND SURVEY EFFORT OF

GOLDEN-CHEEKED WARBLERS *(DENDROICA CHRYSOPARIA)*

USING DETECTION - NONDETECTION

SURVEYS

by

Cynthia Ann Watson, B.A.

Texas State University-San Marcos

August 2006

SUPERVISING PROFESSORS: FLOYD W. WECKERLY AND PAULA S.

WILLIAMSON

Surveys to detect the presence and absence of endangered species may not consistently cover an area nor account for imperfect detection. We evaluated a revised detection - nondetection survey method of the federally endangered golden-cheeked warbler (GCWA, *Dendroica chrysoparia*). The methodology allows a surveyor to survey consistently among sites and allowed us to estimate probability of detection (the extent of imperfect detection) and occupancy (proportion of sample units occupied at a site) using newly developed mark - recapture techniques in the program PRESENCE. From this information we then determined the survey effort required to estimate occupancy with a specified precision (coefficients of variation $\leq$0.2). Three sites were selected across the breeding range of GCWA in central Texas. At each site, 28 - 36 detection stations were placed 200 meters apart. Each detection station was surveyed 9 times during the breeding season in 2 consecutive years. Surveyors stayed up to 8 minutes at detection stations recording GCWA detected by sight or sound. We built models to assess the potential influence of environmental covariates (e.g. slope, aspect, canopy cover) on detection and occupancy and possible change in occupancy and detection probabilities within a breeding season, between years, and among sites. Using information - theoretic model selection procedures we found that detection probabilities and occupancy varied among sites, between years and within a breeding season. Detection probabilities ranged from 0.19 to 0.79 and occupancy ranged from 0.52 to 1.0. These estimates were, in turn, used to determine that 9 surveys of 32 stations at a site will be needed to have estimates of occupancy with coefficients of variation of 0.2. These findings assume no further surveys are needed in that breeding year after detection of GCWA at detection stations.

CHAPTER I

INTRODUCTION

Survey protocols for animal populations are often established that fail to explain what the resulting data will be used for in overall species management (MacKenzie et al. 2006). To apply survey results to a broader management context, three questions should be considered when designing a monitoring program. One, why is an animal population studied; two, what data or estimate are to be obtained; and how will it be obtained and three, are species detected imperfectly (MacKenzie et al. 2006)? Until recently, surveys typically have not accounted for failure to detect species of interest; rather it was assumed that if a species was not detected, it was absent. Relying on survey methods that fail to account for imperfect detection can lead to biased estimates of species presence and abundance (MacKenzie et al. 2003). However, by clearly defining objectives and assessing imperfect detection, managers can develop survey protocols that provide reliable information. Managers, therefore, can make informed management actions for species that are difficult to detect (MacKenzie et al. 2006), for example, the federally endangered golden-cheeked warbler (GCWA, *Dendroica chrysoparia*).

To assess GCWA occurrence and determine appropriate mitigation for development, the United States Fish and Wildlife Service (USFWS) issues scientific permits to qualified individuals to conduct presence - absence surveys (hereafter detection - nondetection surveys, MacKenzie 2005). Current methodology required under USFWS permits consists of at least 5 surveys conducted 5 days apart during the GCWA breeding season, 15 March – 15 May. A surveyor walks a property and records the approximate or exact location of any birds identified by sight or sound with the intent of determining the number of territories. Findings are often inconsistent among surveyors because the extent of area surveyed and the time of day surveys are conducted can vary and may influence detection of GCWA (Skirven 1981, Robbins 1981, Bibby et al. 1992). Also, habitat attributes such as dense vegetation and topography may hinder detection of avian species (Dawson 1981, Oelke 1981) and birds that may be present can go undetected. At present it is unknown to what extent a lack of detecting GCWA during a survey is attributable to survey methodology or to birds that are indeed not present. This is problematic considering the USFWS relies on this method to estimate presence and mitigation (based on the number of occupied acres) for impacts from development to GCWA habitat. However by using survey procedures that uniformly survey an area and by estimating detection probabilities or extent of imperfect detection (Mackenzie et al. 2002), reliable estimates of detection (detection of 1 or more birds) and occupancy (percent of sample units occupied) may be obtained. With such information, it is possible to include problems of detection when assessing the survey effort required to document occupancy of GCWA at sample units.

Moreover, development of multi-season models allow for change in occupancy within breeding seasons (MacKenzie et al. 2003). Heretofore, estimating detection probabilities required that sample units were in 1 of 2 states, occupied or vacant throughout the entire breeding season (MacKenzie et al. 2002). Considering that GCWA may migrate in and out of an area within the breeding season this is an unrealistic (Pulich 1976, Best 1981, Bolsinger 1997, Ladd and Gass 1999).

We evaluated a detection – nondetection survey method of GCWA that surveyed consistently among sites. Detection probabilities and occupancy of sample units by GCWA were estimated while examining the extent that these parameters were influenced by climatic and habitat attributes and whether occupancy of sample units changed during the breeding season. These estimates were then used to calculate survey effort required to estimate occupancy with a specified level of precision (MacKenzie and Royle 2005).

It is our intent that these results will contribute to monitoring GCWA range-wide. To date no such investigation has been conducted on this species or other species with similar life history characteristics.

CHAPTER II

METHODS

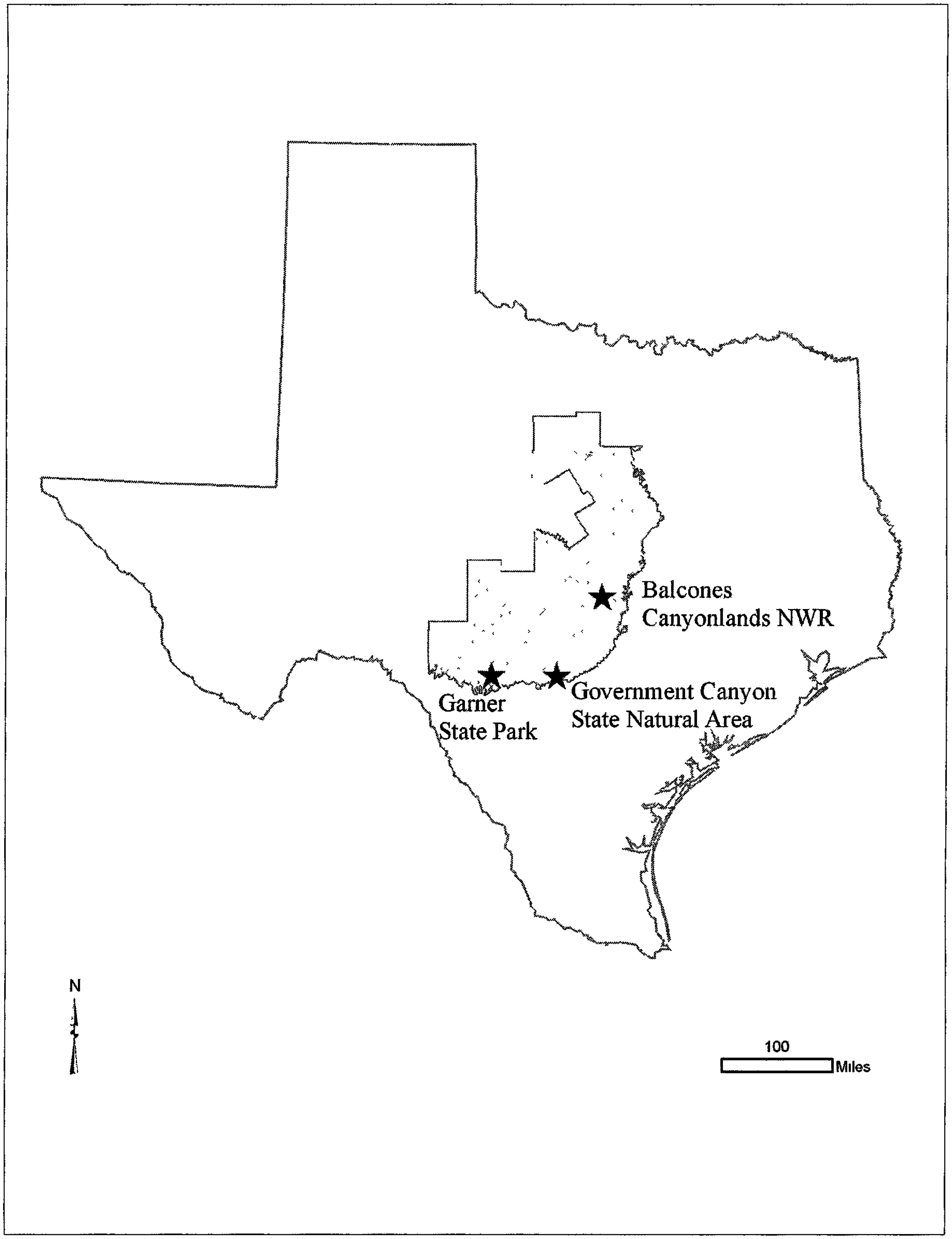
Three sites were selected across the breeding range of GCWA in central Texas. Sites were selected to represent geographic variation in habitat attributes and GCWA density. Study sites included Government Canyon State Natural Area (GCSNA), Garner State Park (GSP) and Balcones Canyonlands National Wildlife Refuge (BCNWR) (Figure 1). The study area at GSP had the steepest topography (range 427 – 573 m), BCNWR was moderately steep (323 – 396 m) and GCSNA had the least amount of topographic variation (329 – 381 m). GCSNA is on the northwestern periphery of San Antonio, Texas. Residential development is on-going and encroach the boundaries of one-half of the state natural area. BCNWR and GSP are more rural with comparatively less residential development in the areas adjacent to these sites. Habitat in these areas has been described as woodlands of nearly continuous canopy cover represented by Ashe juniper (*Juniperus ashei*, at least 4.5 m tall) and a mixed deciduous component including Texas oak (*Quercus buckleyi*), live oak (*Q. fusiformis*), shin oak (*Q. sinuata*), cedar elm (*Ulmus crassifolia*), Texas ash (*Fraxinus texensis*), and escarpment black cherry (*Prunus serotina*) (Pulich 1976, Ladd 1985, Wahl et al. 1990, USFWS 1992, Beardmore 1994, Campbell 1995, Ladd and Gass 1999, Dearborn and Sanchez 2001). Several studies have documented the importance of higher canopy height and closure to GCWA (Pulich 1976, Wahl et al. 1990, Beardmore 1994, Campbell 1995, USFWS 1996, Ladd and Gass 1999, Horne and Anders 2000, DeBoer and Diamond 2006).

These woodlands were generally found in mesic areas such as steep-sided canyons and slopes. Adjacent uplands were drier and contained juniper-oak woodlands comprised of Texas oak, live oak, post oak (*Q. stellata*), and blackjack oak (*Q. marilandica*) (Ladd and Gass 1999). The average annual rainfall was 86 centimeters (cm) at BCNWR, 84 cm at GCSNA and 59 cm at GSP. The average annual temperature was similar among sites (20°C) (NOAA 2006).

The size of study plots were determined by the area that could be surveyed in one day given terrain and density of vegetation. Thus, 100 hectare (ha) detection grid was established at GCSNA and an 80 ha grid was established at BCNWR. Detection grids consisted of transects spaced 200 meter (m) apart and each transect had 6 detection stations spaced every 200 m. BCNWR had 30 detection stations and GCSNA had 36 stations. Steep topography at GSP prohibited the establishment of a detection grid. Therefore, 28 detection stations were set up along existing park trails covering an area of 168 ha. Each station at GSP was, on average, 197 m apart, the range was 40 m with 160 m the smallest distance and 200 m as the largest. This distance was chosen because we believed it was adequate to avoid detecting the same bird at two adjacent points insuring that the data were independent. Also, it is greater than the distance across the average territory size of 6.4 ha, a 143 m diameter circle (Holiman and Craft 1999, Ladd and Gass 1999, Anders et al. 2000, Bailey and Fushille 2000, DeBoer and Diamond 2006). Assuring that data are independent is an assumption of occupancy models (MacKenzie et al. 2005).

Figure 1. Study Sites.

Three study sites within the golden-cheeked warbler (*Dendroica chrysoparia*) breeding range where occupancy and detection probabilities were estimated during spring 2005 and spring 2006.



During the 9 week period from 15 March to 15 May 2005 - 2006 (breeding year one and two), detection - nondetection surveys were conducted on a weekly basis. To ameliorate observer bias, observers had to demonstrate a hearing threshold of ≤ 20 decibels (Cyr 1981, Ramsey and Scott 1981) and were trained to recognize GCWA songs (Kepler and Scott 1981). Each survey commenced near sunrise and was conducted under suitable weather conditions for surveying avian species (Robbins 1981). Surveyors recorded climatic data including temperature, wind speed and precipitation at the beginning and end of each survey because they may affect detection and bird behavior (these data were verified with National Oceanic and Atmospheric Administration records) (Verner 1985, Rosenstock et al. 2002). At each detection station, one observer remained for up to 8 minutes and recorded whether GCWA were detected by sight or sound. A surveyor could leave the detection station before 8 minutes if GCWA were detected. The initial detection station surveyed changed between weeks to insure all detection stations were surveyed at different times.

During the second breeding year habitat attributes that may influence detection probabilities were measured, including woody canopy cover (separated into categories – total canopy cover, Juniper, and deciduous), canopy height, slope and aspect. At each detection station and at locations 10 meters in each cardinal direction, canopy cover was measured with a densiometer (Mueller-Dumbois and Ellenberg 1974). Canopy height was measured with a range pole at each detection station (Mueller-Dumbois and Ellenberg 1974). Slope and aspect were obtained from digital elevation models (Sabins 1997).

Data Analysis

Models (Table 1) were estimated using mark – recapture estimators in program PRESENCE (MacKenzie et al. 2002). We built models to assess the potential influence of environmental covariates, the possible change in occupancy of detection stations within and among years, and influence of site and season on detection and occupancy (Sokal and Rohlf 1995, MacKenzie et al. 2002). To assess season and year effects, multi-season models were constructed (MacKenzie et al. 2003). Multi-season models require ≥2 surveys in survey seasons and constant residence status of sample units or closure within seasons. Sample units throughout an entire season are either occupied or vacant. Over the two year study, there were six seasons, three in each breeding year (i.e., surveys 1 to 3 were in season one, surveys 4 to 6 were in season two and so on). Surveys were grouped in increments of three because of the possible influence of GCWA migration and breeding behavior on detection and occupancy. For example, GCWA migrate from their wintering grounds in Central America from mid March to mid April (Pulich 1976). In April, successful mating pairs of GCWA lay a clutch of eggs that hatch in approximately twelve days. Once the eggs hatch, male singing occurs less frequently (Ladd and Gass 1999), hence detection may be more difficult. By May, it is possible that some nesting pairs may have been predated or parasitized causing them to attempt to renest (Ladd and Gass 1999) which may or may not be in the same territory. Multi-season models included parameters for occupancy (Ψ), colonization (γ), extinction (ε) and probabilities of detection (p) (MacKenzie et al. 2003). Models that did not consider seasonal changes estimated Ψ and p using single-season models (MacKenzie et al. 2002). Environmental covariates of climatic data (temperature and wind speed) and habitat (slope, elevation, canopy cover [total, deciduous and Juniper] and canopy height) were continuous variables. The residual elevation at each site (detection station elevation – mean elevation at site) was used in analyses. Remaining continuous covariates were standardized to have a mean of 0 and standard deviation of 1 to improve reliability of parameters estimates (MacKenzie et al. 2006). The remaining covariates of aspect and time of day were coded as indicator and categorical variables, respectively. The time of day a detection station was surveyed was placed in categories, e.g. 1 hour before sunrise to 1 hour after sunrise was category 1, 1 - 2 hours after sunrise was category 2, and so on up to 7 hours after sunrise which was category 7. Models were selected using the information – theoretical approach (Burnham and Anderson 2002). A model or models that fit the data, relative to the number of parameters in the model, had a small Akaike Information Criterion (AIC) and high Akaike weight (Akaike 1973). If a multi-season model was selected, occupancy in the next season was estimated using a formula from MacKenzie et al. 2005:

$$\Psi_{t+1} = \Psi_t(1 - \varepsilon_t) + (1-\Psi_t)\gamma_t.$$

Subscripts t and t + 1 denote a particular season and the following season, respectively.

Table 1. Model Selection Summary.

Model selection summary of multi and season single models analyzing whether environmental and climatic attributes influenced parameter estimates. Models estimated probability of occupancy (Ψ) probability of detection (p) as well as colonization (γ) and extinction (ε) of golden cheeked warblers. AIC is the Akaike Information Criterion value; ΔAIC is the difference in AIC value for a model compared to the best fit model; *w* is the AIC model weight; -2ll is twice the log likelihood; and *NPar* is the number of parameters (MacKenzie et al. 2006). Covariates assessed possible influence of site, year, season, time of day (time), wind speed (wind), temperature (temp), elevation (elev), canopy cover (juniper [juas], deciduous [decid], total canopy cover [tot can]), canopy height (can ht), slope, aspect, and no influence of a predictor (.). A + symbol denotes the additive influence of two covariates.

Model	AIC	*w*	*Npar*	*-2ll*
Ψ(site),γ(site+year),ε(site+year),p(site+season)	1910.3	0.999	19	1872.3
Ψ(site),γ(site),ε(site),p(site)	1926.8	0.001	12	1902.9
Ψ(site),γ(site+year),ε(site+year),p(site)	1929.72	<0.001	14	1901.7
Ψ(site),p(site)	1966.55	<0.001	6	1954.6
Ψ(site),γ(site),ε(site),p(time of day)	1995.10	<0.001	11	1973.1
Ψ(site),γ(site+year),ε(site+year),p(time)	1998.83	<0.001	13	1972.8
Ψ(site),γ(site),ε(site),p(wind)	2004.88	<0.001	11	1982.9
Ψ(site),γ(site),ε(site),p(temp)	2005.84	<0.001	11	1983.8
Ψ(site),γ(site),ε(site, year),p(temp)	2009.77	<0.001	13	1983.8
Ψ(juas),γ(.),ε(.),p(juas)	2018.78	<0.001	6	2006.8
Ψ(juas),γ(year),ε(year),p(juas)	2022.34	<0.001	8	2006.3
Ψ(tot can),γ(.),ε(.),p(tot can)	2083.45	<0.001	6	2071.5
Ψ(.),γ(.),γ(.),p(.)	2085.64	<0.001	4	2077.6
Ψ(tot can),γ(year),ε(year),p(tot can)	2087.27	<0.001	8	2071.3

Table 1. (Cont.)

Ψ(decid),γ(.),ε(.),p(decid)	2088.29	<0.001	6	2076.3
Ψ(aspect),γ(.),ε(.),p(elev)	2089.41	<0.001	8	2073.4
Ψ(can ht),γ(.),ε(.),p(can ht)	2089.52	<0.001	6	2077.5
Ψ(decid),γ(year),ε(year),p(decid)	2092.07	<0.001	8	2076.1
Ψ(aspect),γ(year),ε(year),p(elev)	2093.18	<0.001	10	2073.2
Ψ(can ht),γ(year),ε(year),p(can ht)	2093.35	<0.001	8	2077.4
Ψ(juas),p(juas)	2158.32	<0.001	4	2150.3
Ψ(slope),p(aspect)	2263.82	<0.001	6	2251.8
Ψ(site),p(wind)	2267.29	<0.001	5	2257.3
Ψ(site),p(time)	2283.81	<0.001	5	2273.8
Ψ(site),p(temp)	2289.30	<0.001	5	2279.3
Ψ(tot can),p(tot can)	2296.51	<0.001	4	2288.5
Ψ(.),p(.)	2296.59	<0.001	2	2292.6
Ψ(decid),p(decid)	2297.63	<0.001	4	2289.6
Ψ(aspect),p(elev)	2298.38	<0.001	6	2286.4

Survey Effort

To determine survey effort required to detect GCWA and estimate occupancy, we used procedures for removal sampling from MacKenzie and Royle (2005) (Table 2). Removal sampling indicates the number of surveys to perform at detection stations and the number of detection stations to survey at sites. Removal sampling is when no further surveys are conducted once GCWA are detected at detection stations in that breeding year or in other words in the March 15 - May 15 survey period. The number of surveys was determined by using Table 3 from Mackenzie and Royle 2005 that is included herein as Table 2. The number of detection stations required to estimate occupancy with 10%, 15% and 20% coefficients of variation (ψ/SE[ψ]) was assessed using an equation from MacKenzie and Royle (2005):

$$s = \frac{\psi}{SE(\psi)^2}\left[(1-\psi) + \frac{p^*(1-p^*)}{(p^*)^2 - k^2 p^2 (1-p)^{k-1}}\right].$$

Where k is the number of surveys to conduct (obtained from table 3, MacKenzie and Royle [2005]) and p* is the chance of detecting the bird at least once in k surveys ($1-[1-p]^k$).

Coefficients of variation of <20% provide a reasonable level of precision of parameter estimates (Sokal and Rohlf 1995). For these calculations, we used the lowest detection probability estimates obtained from our analysis (MacKenzie and Royle 2005). Thus, our estimates of survey effort err on the side of caution, insuring survey effort is sufficient to estimate occupancy when GCWA are difficult to detect at sites assuming that they are indeed present.

CHAPTER III

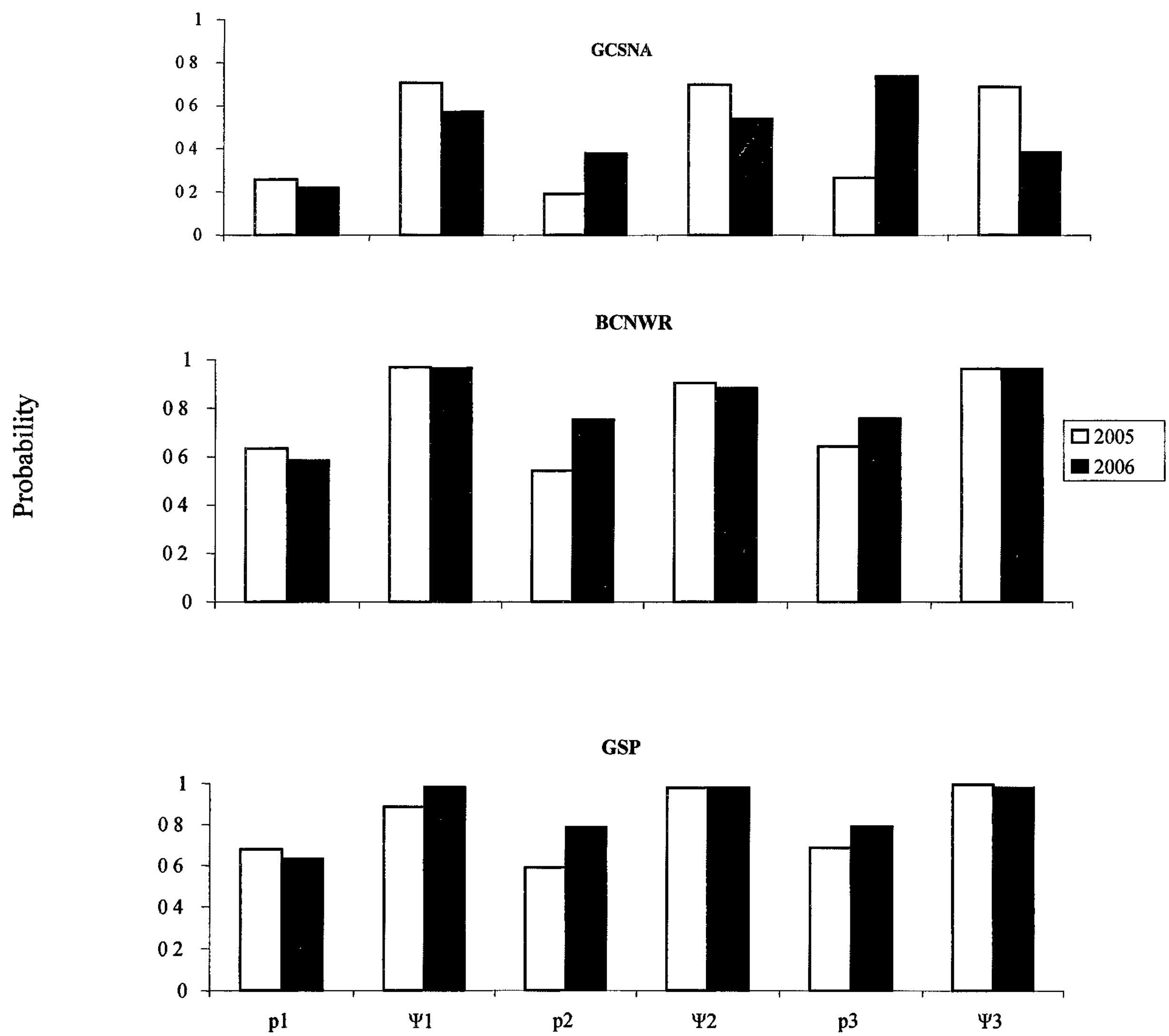
RESULTS

Every detection station at each site was surveyed 9 times in each year. Number of detections during a survey ranged from 1 to 9 at GCSNA, 7 to 24 at BCNWR, and 7 to 26 at GSP. For the environmental and habitat covariates, the means (and 1 standard deviation) at GCSNA, BCNWR, and GSP, respectively, were: time of day 1 (0.23), 1 (0.44), 2 (0.79); temperature 23° C (0.55), 21 (4.72), 23 (3.45); wind speed 17 kph (3.77), 12 (4.30), 15 (5.65); elevation 357 m (17.08), 368 (20.43), 490 (43.62); slope 10 (4.89), 10 (4.85), 15 (7.47); juniper canopy cover 11% (3.79), 45 (18.17), 40 (28.08); deciduous canopy cover 20% (17.22), 22 (6.49), 21 (24.85); total canopy cover 31% (17.55), 72 (27.83), 61 (27.19); and canopy height 6 m (1.4), 6 (1.5), 6 (1.9). For aspect, percentage of stations that faced to the north, east, west and south, respectively, were 14, 31, 39, 16 at GCSNA; 17, 43, 30,10 at BCNWR; and 36, 46, 14, 4 at GSP.

The multi-season model with a site covariate for occupancy, covariates of site and year that estimated colonization and extinction in an additive fashion, and covariates that estimated the additive influence of site and season on probability of detection clearly fit the data better than the remaining 28 models (Table 1). Among seasons during breeding year one at GCSNA, estimates of detection probabilities ranged from 0.19 to 0.26 and occupancy was about 0.70 in each season (Figure 2). During breeding year two, estimates of detection probabilities ranged from 0.22 to 0.38 among seasons and occupancy ranged from 0.53 to 0.57. At BCNWR, seasonal estimates of detection probabilities in breeding year one ranged from 0.54 to 0.64 and occupancy was about 0.96 in each season. In breeding year two, detection probabilities ranged from 0.58 to 0.76 and seasonal estimates of occupancy were about 0.90. Seasonal detection probability estimates in breeding year one at GSP ranged from 0.59 to 0.69 and occupancy estimates ranged from 0.89 to 1.0. In year two, detection probabilities ranged from 0.63 to 0.79 among seasons and occupancy estimates were about 0.98 in each season.

Figure 2. Detection and Occupancy.

Probability of occupancy (Ψ) and detection (p) of golden-cheeked warblers (*Dendroica chrysoparia*) during three seasons and two breeding years (2005 and 2006) at Government Canyon State Natural Area (GCSNA), Balcones Canyonlands National Wildlife Refuge (BCNWR), and Garner State Park (GSP) in central Texas.



We used estimates of occupancy (0.69) and detection (0.19) from GCSNA in year 1, season 2 to assess survey effort because that detection probability was the lowest estimated (Figure 2). Also, GCSNA is more representative of many areas likely to be surveyed as it is close to a rapidly urbanizing area. Many studies have documented GCWA as a forest interior species (Shaw 1989, Fink 1996, Maas and Schnell 1998, Horne and Anders 2000, DeBoer and Diamond 2006), therefore individuals occupying habitat adjacent to edge or urban areas may be more difficult to detect because they may be less likely to occur there. Using Table 3 in MacKenzie and Royle (2005) (included here as Table 2) 16 surveys are recommended at detection stations with respective estimates of occupancy and detection of 0.7 and 0.2. Conducting 16 surveys in a 9 week breeding season may be considered unrealistic considering the time and personnel involved. To circumvent this issue we entered 9 surveys into the equation on p. 12 to determine the number of sites to have coefficients of variation for occupancy estimates of 10%, 15% and 20%, which were 149, 55, and 32, respectively. Considering that a coefficient of variation of 20% is acceptable we suggest using 32 detection stations. If the number of sites was determined when conducting 16 surveys the equation suggested that 59, 22 and 20 detection stations would be required to have 10%, 15% and 20% coefficients of variation. Without considering precision, one may infer incorrect conclusions from survey results (Rosenstock et al. 2002).

Table 2. Number of Surveys to Conduct.

Table 3 from MacKenzie and Royle 2005. "Optimal number of surveys to conduct at each site for removal design where all sites are surveyed until the species is detected." The probability of occupancy is Ψ and probability of detection is p.

	Ψ								
p	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.1	23	24	25	26	28	31	34	39	49
0.2	11	11	12	13	13	15	16	19	23
0.3	7	7	7	8	8	9	10	12	14
0.4	5	5	5	6	6	6	7	8	10
0.5	4	4	4	4	4	5	5	6	8
0.6	3	3	3	3	3	4	4	5	6
0.7	2	2	2	3	3	3	3	4	5
0.8	2	2	2	2	2	2	3	3	4
0.9	2	2	2	2	2	2	2	2	3

CHAPTER IV

DISCUSSION

We found that detection probabilities varied among sites, within and between breeding years. Given the range of detection probabilities we estimated (0.19 – 0.79), it is somewhat surprising that none of the environmental or habitat covariates influenced detection. Because 99% of GCWA detections were by sound, it would seem that variables that presumably affect attenuation of GCWA calls such as aspect, elevation, or canopy cover of woody vegetation would influence detection probabilities. This suggests that GCWA songs may attenuate well through dense vegetation.

Time of day was also expected to influence detection because many birds presumably call more frequently early in the morning than in mid day (Pulich 1976, Richards 1981, Robbins 1981, Skirven 1981, Bibby et al. 1992, Bolsinger 2000). Perhaps one reason that time of day did not influence detection is that most surveys were over by 1500 at GCSNA and BCNWR while surveys at GSP typically ended by 1300. It is possible that GCWA call throughout the day at our study sites or the decline in frequency of calls after dawn is not so dramatic that GCWA can not be detected. Also, rate of calling by GCWA may be affected by factors not explored here such as mating status (paired or unpaired) or presence of predators (Engels 1997, Bolsinger 2000). Within sites, detection probabilities of GCWA displayed no consistent pattern with occupancy, but among sites detection probabilities were higher when occupancy was also high (Figure 2). This suggests that detection, at least to some extent, may have been influenced by high occupancy or abundance of GCWA, a reasonable assumption in a territorial species (Royle and Nichols 2003, Longoria and Weckerly *In Press*). When more birds are present at sites, GCWA may be more readily detected because activities such as rate of calling or movement (e.g. territorial defense) that influence detection may be greater. In turn, the increased ease of detection may motivate observers to maintain a higher state of alertness.

Our findings suggest that perfect detection of GCWA is unlikely with detection – nondetection surveys, such as the one examined here and, perhaps, with any other existing survey methodology. If steps are not taken to account for imperfect detection then estimates of occupancy will be biased low. That is, at some sample units where GCWA are present, they will be missed. Because we also found no influence of environmental or habitat covariates on detection and there is no predictable pattern of occupancy, the extent to which GCWA are missed will probably vary from site to site.

Occupancy of detection stations by GCWA was not influenced by covariates of slope, aspect and attributes of the tree canopy that may reflect habitat quality and, therefore, occupancy (Pulich 1976, Dawson 1981, Wahl et al. 1990, Beardmore 1994, USFWS 1996, Horne and Anders 2000). Occupancy was best predicted by the site and the season within the breeding year. At BCNWR and GSP, occupancy was more consistent among seasons within years, perhaps related to the high occupancy at these sites. Occupancy at GCSNA varied slightly among seasons in year two as occupancy was nearly 0.6 in the first two seasons and declined to 0.52 in the third season. If the habitat such as that found at GCSNA is less suitable or of lower quality for nesting and rearing offspring, then the low and more variable occupancy is to be expected (Pulich 1976, Ladd and Gass 1999).

Multi-season models were developed to capture dynamics of change in occupancy over time and space to address ecological hypotheses (MacKenzie et al. 2003). We used multi-season models to assess changes in detection and occupancy within and between years to determine if it is reasonable to assume constant residence status within a breeding year. Previous studies examining survey effort of GCWA have assumed that occupancy and detection were constant during the time period surveys were conducted (Ott and Weckerly 2004). Multi-season models increase the flexibility in designing monitoring programs by allowing investigators to examine when detection probabilities are high in survey seasons. If detection probabilities are markedly high (>0.8) during a particular part of the survey season, then surveys should be conducted during that time frame.

Management Implications

Based on recommendations in MacKenzie and Royle 2005, we conclude to produce reliable estimates of occupancy 9 surveys should be conducted in the GCWA breeding season, March 15 through May 15 to have a 20% coefficient of variation. Each survey site should have 32 detection stations spaced at 200 m intervals. However, 32 detection stations may not fit into smaller survey locations. If this is the situation, as many detection stations as possible should be spaced at 200 m intervals. By reducing the number of detection stations the coefficient of variation may be greater than 20%, although this method is still beneficial as it surveys study locations in a uniform and repeatable manner making the results more comparable and reliable. Considering that there were no dramatic changes in detection probabilities across the three seasons we analyzed within the March 15 through May 15 (2005-2006) window, surveys should begin the first week of the breeding season and continue with constant effort using removal sampling. When using removal sampling once a detection station has a detection of GCWA it may be removed, i.e. not sampled again during the remaining surveys. If a manager's or biologist's objective of surveying is to determine presence or absence of GCWA or the percent of area occupied (occupancy) the method of conducting surveys presented herein is statistically defensible because it considers imperfect detection. Considering that GCWA are an endangered species, with a restricted range it is imperative to have reliable survey results. This information is especially crucial in areas similar to GCSNA where the probability of detection is 0.19, meaning that in 8 out of 10 surveys birds that are present will go undetected. By assessing imperfect detection, surveyors will know with confidence that if a species is present they will conduct the number of surveys necessary to detect it

APPENDIX

During the first breeding year, in addition to the surveyors that conducted detection – nondetection surveys, a separate set of observers spot mapped birds (International Bird Census Committee 1970, Bibby et al. 1992, IBCC 1970) (mapped the location of detection away from detection station) to assess whether birds were missed during detection - nondetection surveys. To ensure independent data sets (i.e. unbiased data), each set of observers did not discuss their findings with one another. At BCNWR three surveyors spot-mapped while another surveyor conducted detection - nondetection surveys. At GCSNA and GSP one observer spot-mapped and another single observer conducted detection – nondetection surveys. Spot mappers recorded time and climatic conditions at the beginning and ending of each survey. They also recorded global positioning system (GPS) coordinates of bird observations

We compared occupancy estimates from 2005 of 0.7 at GCSNA, 0.96 at BCNWR and 0.98 at GSP (from the best fit model) (Table1) to the percentage of detection stations that had at least one spot mapped bird within 100 m. The proportions were 0.7 at GCSNA, 1.0 at BCNWR and 0.9 at GSP. These proportions were similar to occupancy generated in PRESENCE and provide a field test indicating that these estimates are reliable.

BIBLIOGRAPHY

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle, in *International Symposium on Information Theory*, 2^{nd} ed. Eds. Akadeemiai Kiadi, 267-281. Budapest: Hungary.

Anders, A. D., J. S. Horne and L. L. Sanchez. 2000. Relationship between habitat characteristics and demography of golden-cheeked warblers on Fort Hood, Texas: 2000 Annual Report. The Nature Conservancy, Fort Hood, Texas.

Bailey, J. W. and P. R. Fushille. 2000. Monitoring of the golden-cheeked warbler 2000 field season. Travis County Parks and Preserves, Project No. 0810-00001. Travis County Texas.

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

Best, L. B. 1981. Seasonal changes in detection of individual bird species. Studies in Avian Biology 6: 252:261.

Bibby, C. J., N. D. Burgess and D. A. Hill. 1992. *Bird Census Techniques*. New York: Harcourt Brace & Co., Publishers. pp. 257.

Bolsinger, J. S. 1997. Patterns of use and variation in the songs of the Golden-cheeked warbler (*Dendroica chrysoparia*). M. S. Thesis. University of Massachusetts.

Bolsinger, J. S. 2000. Use of two song categories by golden-cheeked warblers. Condor 102: 539-552.

Burnham, K. P. and D. R. Anderson. 2002. *Model Selection and Inference*. New York: Springer Verlag.

Campbell, L. 1995. *Endangered and Threatened Animals of Texas*. Texas Parks and Wildlife Department. pp. 130.

Cyr, A. 1981. Limitation and variability in hearing ability in censusing birds. *Studies in Avian Biology* 6:327-333.

Dawson, D. G. 1981. Counting birds for a relative measure (index) of density. *Studies in*

Avian Biology 6:12-16.

Dearborn, D. C. and L. L. Sanchez. 2001. Do golden-cheeked warblers select nest locations on the basis of patch vegetation? The Auk 118: 1052-1057.

DeBoer, T. S. and D. D. Diamond. 2006. Predicting presence-absence of the endangered golden-cheeked warbler (*Dendroica chrysoparia*). The Southwestern Naturalist 51: 181-190.

Engels, T. M. 1997. The conservation biology of the golden-cheeked warbler (*Dendroica chrysoparia*). M. S. Thesis. The University of Texas at Austin.

Fink, M. L. 1996. Factors contributing to nest predation within habitat of the golden-cheeked warbler, Travis County, Texas. M. S. Thesis, Texas A&M University, College Station.

Holiman, W. C. and R. A. Craft. 1999. Dispersal, age structure and survivorship of the golden-cheeked warbler on Fort Hood, Texas in 1999. In: Endangered Species monitoring and management at Fort Hood, Texas: 1999 Annual Report, The Nature Conservancy, Fort Hood, Texas.

Horne, J. S. and A. D. Anders. 2000. A model for predicting golden-cheeked warbler presence using local and landscape-scale habitat variables: Status Report. In: Endangered species monitoring and management at Fort Hood, Texas: 2000 Annual Report, The Nature Conservancy, Fort Hood, Texas.

International Bird Census Committee. 1970. An international standard for a mapping method in bird census work recommended by the International Bird Census Committee. Audubon Field Notes 24 (6): 722-726.

Kepler, C. B. and J. M. Scott. 1981. Reducing bird count variability by training observers. *Studies in Avian Biology* 6: 366-371.

Ladd, C. G. 1985. Nesting Habitat Requirements of the Golden-cheeked warbler. M. S. Thesis. Southwest Texas State University.

Ladd, C. and L. Gass. 1999. Golden-cheeked Warbler (*Dendroica chrysoparia*) in *The Birds of North America*, No. 420, eds. A. Poole and F. Gill, Philadelphia: The Birds of North America, Inc.

Longoria, M. P. and F. W. Weckerly. *In Press*. Estimating detection probabilities from sign of collared peccary. Journal of Wildlife Management.

Maas, D. S. and G. D. Schnell. 1998. Effects of habitat fragmentation on demographics of golden-cheeked warblers (*Dendroica chrysoparia*). M. S. Thesis, University of Oklahoma, Norman.

Mackenzie, D. L. 2005. What are the issues with 'presence/absence' data for wildlife managers? Journal of Wildlife Management 69: 849-860.

Mackenzie, D. L. and J. A. Royle. 2005. Designing occupancy studies: general advice and allocating survey effort. Journal of Applied Ecology 42: 1105-1114.

MacKenzie, D. L., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83 (8): 2248-2255.

Mackenzie, D. I., J. D. Nichols, J. E. Hines, M. G. Knutson and A. D. Royle. 2003. Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. Ecology 84: 2200-2207.

Mackenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Polluck, L. L. Bailey and J. E. Hines. 2006. *Occupancy Estimation and Modeling*. Boston: Academic Press.

Mueller-Dumbois, D. and H. Ellenberg. 1974. *Aims and Methods of Vegetation Ecology*. New York: John Wiley & Sons

National Oceanic and Atmospheric Administration. 2006. http://ols.nndc.noaa.gov/plolstore/plsql/olstore.prodspecific?prodnum=C00095-PUB-A0001#TABLES

Oekle, H. 1981. Limitations of estimating bird populations because of vegetation structure and composition. *Studies in Avian Biology* 6: 316-321.

Ott, J. A. and F. W. Weckerly. 2004. Recommended revisions to presence/absence surveys of golden-cheeked warblers. Final Report, U. S. Fish and Wildlife Service.

Pulich, W. 1976. *The Golden-cheeked Warbler, A Bioecological Study*. Texas Parks and Wildlife Department, Austin, Texas. 172 pp.

Ramsey, F. L and J. M. Scott. 1981. Tests of hearing ability. *Studies in Avian Biology* 6: 341-345.

Richards, D. G. 1981. Environmental acoustics and censuses of singing birds. *Studies in Avian Biology* (6): 297-300.

Robbins, C. S. 1981. Bird activity levels related to weather. *Studies in Avian Biology* (6): 301-310.

Rosenstock, S. S., D. R. Anderson, K. M. Giesen, T. Leukering and M. F. Carter. 2002. Landbird counting techniques: current practices and an alternative. The Auk 119: 46-53.

Royle, J. A. and J. D. Nichols. 2003. Estimating abundance from repeated presence absence data or point counts. Ecology 84: 777-790.

Sabins, F. F. 1997. *Remote Sensing; Principles and Interpretations.* New York: W.H. Freeman and Company. 494 pp.

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

Skirven, A. A. 1981. Effect of time of day and time of season on the number of observations and density estimates of breeding birds. *Studies in Avian Biology* (6): 271-274.

Sokal, R. R. and F. J. Rohlf. 1995. *Biometry.* New York: W. H. Freeman and Company.

U. S. Fish and Wildlife Service. 1992. *Golden-cheeked Warbler Recovery Plan.* USFWS, Endangered Species Office, Albuquerque, NM. 88 pp.

U. S. Fish and Wildlife Service. 1996. Golden-cheeked warbler population and habitat viability assessment report. United States Fish and Wildlife Service, Austin, Texas.

Verner, J. 1985. Assessment of counting techniques. Current Ornithology 2: 247-302.

Wahl, R. D., D. D. Diamond and D. Shaw. 1990. The golden-cheeked warbler: a status review. United States Fish and Wildlife Service, Albuquerque, New Mexico.

VITA

Cynthia Ann Watson was born in Odessa, Texas, on April 28, 1973. She entered the University of Texas at Austin in 1997 where she was a student athlete and member of National Collegiate Athletics Association, women's rowing team. She received a Degree of Bachelor of Arts in 2002 majoring in Geography, with a minor in Zoology. Also in 2002, she entered the Graduate College at Texas State University-San Marcos. While earning her Master of Science she worked at the United States Fish and Wildlife Service as a wildlife biologist responsible for the recovery of endangered karst invertebrates.

Permanent Address: 8201 Edgemoor Place.

Austin, Texas 78749

This thesis was typed by Cynthia Ann Watson.