AN ABSTRACT FOR THE THESIS OF

Jeffrey C. Miller for the Master of Science Degree in

Biology presented on

Tiltle: Habitat Relationships and Conservation of Bats within the Red Hills of Kansas and Oklahoma.

Abstract approved:

There is limited understanding of habitat use by bats in the Great Plains and few steps taken toward their conservation, relative to other wildlife. This gap of knowledge, including specific knowledge of two Species in Need of Conservation (SINC) noted by the state of Kansas in the Red Hills region, must be filled for adequate bat conservation. I investigated bat distribution in relation to encroaching woody vegetation and elevation on both the landscape level and local scale habitat (e.g., tree cover) used within riparian corridors (Chapter 2). Acoustic data were used to model probability of occurrence in relation to vegetative and topographic characteristics within the region. The probability of occurrence of one species, *Myotis velifer*, was positively associated with tree canopy cover and negatively associated with elevation. I obtained habitat use within riparian corridors by mist netting live bats. The capture rates of *M. velifer* and *Corynorhinus townsendii* were found to be positively related with canopy cover. I also obtained information on the physical characteristics of summer roosting locations of a SINC species in Kansas, *Antrozous pallidus*, by tracking radioed individuals to their diurnal roosting sites (Chapter 3). Information gathered from these investigations, and published

research, also was used to construct a recovery plan (Chapter 4) that will be submitted to the Kansas Department of Wildlife, Parks, and Tourism. This plan will help guide conservation and management decisions for these two species by including roosting and foraging habitat information that is critical for their persistence within the state of Kansas.

HABITAT RELATIONSHIPS AND CONSERVATION OF BATS WITHIN

THE RED HILLS OF KANSAS AND OKLAHOMA

A thesis

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PREFACE

Within this thesis there are five chapters that make up its entirety. Each chapter is formatted to the respective journal or agency to which it will be submitted. The first chapter is a brief summary of this thesis project and chapter five is a general conclusion. All but Chapter 3 has been formatted to follow guidelines of the *Journal of Wildlife Management*. The third chapter is written in the format of the *Transactions of the Kansas Academy of Science*. Lastly, the fourth chapter will be submitted the Kansas Department of Wildlife, Parks, and Tourism for their records. The Animal Care and Use Committee at Emporia State University approved all research activities prior to collection (ESU-ACUC-07-016, ESU-ACUC-09-004, ESU-ACUC-10-008). State scientific collecting permits were obtained from KDWPT (SC-067-2009 and SC-117-2010) and the Oklahoma Department of Wildlife Conservation (4619-2009 and 4885-2010).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The conservation of an organism can be better directed by the understanding of that animal's habitat use and behavior. Many studies have been done on roosting habitats and foraging habitats of bats (Kunz and Fenton 2003). Although nocturnal foraging habitat studies have increased throughout North America within recent years (Patriquin and Barclay 2003, Ober and Hayes 2008, Weller 2008) there is limited published information on nocturnal habitat use by bats within the Central Great Plains. I studied foraging habitats of nine species of suborder Microchiroptera within the Red Hills region of Kansas and Oklahoma for two summers (2009-2010). These species included the pallid bat (*Antrozous pallidus*), Townsend's big-eared bat (*Corynorhinus townsendii*), the big brown bat (*Eptesicus fuscus*), the red bat (*Lasiurus borealis*), the hoary bat (*Lasiurus cinereus*), the cave myotis (*Myotis velifer*), the evening bat (*Nycticeius humeralis*), the eastern pipistrelle (*Perimyotis subflavus*), and the Brazilian free-tailed bat (*Tadarida brasiliensis*). Habitats for bats vary greatly within this region, marked by its dynamic topographic character consisting of tabletops, buttes, and rolling hills above tributaries of the Arkansas drainage basin. This area also varies in vegetative structure and can be categorized by grassland, coniferous forest, and deciduous and coniferous mixed forest, and cropland. Many of the wooded habitats have increased from historic extents and are of general conservation concern in the region with regard to their effect on grassland wildlife (Coppedge et al. 2001, Briggs et al. 2002).

Chapter 2 will discuss distributional patterns of bats in relation to encroaching woody vegetation and topography and riparian habitat characteristics. Acoustic bat detectors and mist nets were used to survey habitat use by bats at two scales within the Red Hills of Kansas and Oklahoma.

Chapter 3 will focus on one of the species *A. pallidus*, which is notable as one of the species in need of conservation (SINC) identified by Kansas Department of Wildlife, Parks, and Tourism (Sparks and Choate 2000). My report of the diurnal roost characteristics of the pallid bat from two summers in the Red Hills region of Kansas and Oklahoma notes the physical characteristics of roosting habitat used by this species.

Chapter 4 is the species recovery plan for the two SINC species in Kansas *A. pallidus* and *C. townsendii*. The plan provides natural history background of these species and suggested management goals, objectives, and strategies for achieving the overall goal of preventing the further endangerment of *A. pallidus* and *C. townsendii* in Kansas.

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CHAPTER 2

Nocturnal Habitat Use by Bats in the Red Hills of Kansas and Oklahoma

ABSTRACT There is limited understanding of habitat use by bats in Great Plains grasslands beyond their roosting sites. Of interest here are distributional patterns of bats in relation to encroaching woody vegetation and topography. Acoustic bat detectors and mist nets were used to survey nocturnal habitat use by bats at two scales within the Red Hills of Kansas and Oklahoma: across landscapes and within riparian corridors, respectively. Acoustic data were used to model probability of occurrence in relation to tree cover and elevation across landscapes. Nine species were detected from acoustic and mist net surveys. Across all landscapes, probability of *Myotis velifer* occurrence was positively related to tree canopy cover and negatively related to elevation. No other statistically significant predictors of probability of occurrence were found for any other bat species. Mist netting revealed that capture rates of two species, *Corynorhinus townsendii* and *M. velifer*, were positively—though weakly—related to tree canopy cover. No other significant patterns of habitat use were detected from mist net captures. At the current scale of woody encroachment of the Red Hills region, I found that woody cover did not negatively affect bats, but rather some appear to be actively using these wooded habitats for foraging or shelter during nocturnal flights.

INTRODUCTION

Bats are sensitive to alterations and disturbances to their foraging habitat, which may compromise their survival and reproduction. For example, habitat loss and fragmentation may increase the commuting distances required from roosts to other suitable foraging habitat (Tuttle 1979, Racey and Entwistle 2002, Kunz et al. 2007). Habitat use by bats may be responsive to insect availability or aerial clutter, which may be affected by changes to vegetative structure. Insect availability may be greater near forest edge and riparian areas (Murdoch et al. 1972, Walsh and Harris 1996), and vertical vegetation structure can also contribute to physical obstruction to flight paths and echolocation efficiency for bats (Norberg and Rayner 1987, Walsh and Harris 1996, Ober and Hayes 2008).

Although grasslands are still predominant in the Great Plains, this region has been experiencing woody encroachment by eastern red cedar (*Juniperus virginiana*) since U.S. westward colonization (Coppedge et al. 2001, Briggs et al. 2002, Horncastle et al. 2005). Woody encroachment of upland prairie by red cedar emanates from low-lying riparian areas (Briggs et al. 2002). Such encroachment may be contributing or diminishing habitat for some bat species in the Great Plains. Some species may benefit from woody encroachment in otherwise open habitats. Many bat researchers have reported riparian areas with trees and woody vegetation as important foraging habitats for bats (Vaughan et al. 1997, Verboom and Spoelstra 1999, Patriquin and Barclay, 2003). In Britain, vespertilionid bats exhibited greater activity near woodlands and water than open habitats (Walsh and Harris 1996), perhaps attributable to higher insect densities in the former habitats. Fellers and Pierson (2002) and Caire et al. (1984) both reported primary foraging by *Corynorhinus townsendii* along the edges of riparian vegetation; although, reports of the use of open fields and old fields have also been documented for this bat (Burford and Lacki 1995). In addition to *C. townsendii*, *Myotis velifer* in Oklahoma was reported to utilize tree canopy and lower elevation for foraging (Fitch et al. 1981, Caire et al. 1984). *Myotis lucifugus* had been reported by Kalcounis and Brigham (1995) to use areas close to canopy edge also to forage. However, some bat species prefer open habitat for foraging and navigation, but may require nearby trees for roosting and protection (Burford and Lacki 1995, Walsh and Harris 1996, Downs and Racey 2006). *Eptesicus fuscus* and *Lasiurus cinereus* more often foraged above forest canopy and away from trees (Ober and Hayes 2008). Additionally, *Lasionycteris noctivagans* used patchy edges of forest more frequently than closed forest habitat (Patriquin and Barclay 2003, Ober and Hayes 2008). Smaller, more maneuverable bats may be able to obtain insects within cluttered forests whereas larger and faster bats may use areas further away from aerial clutter (Patriquin and Barclay 2003, Ober and Hayes 2008), though smaller species may also use uncluttered areas above streams (Ober and Hays 2008).

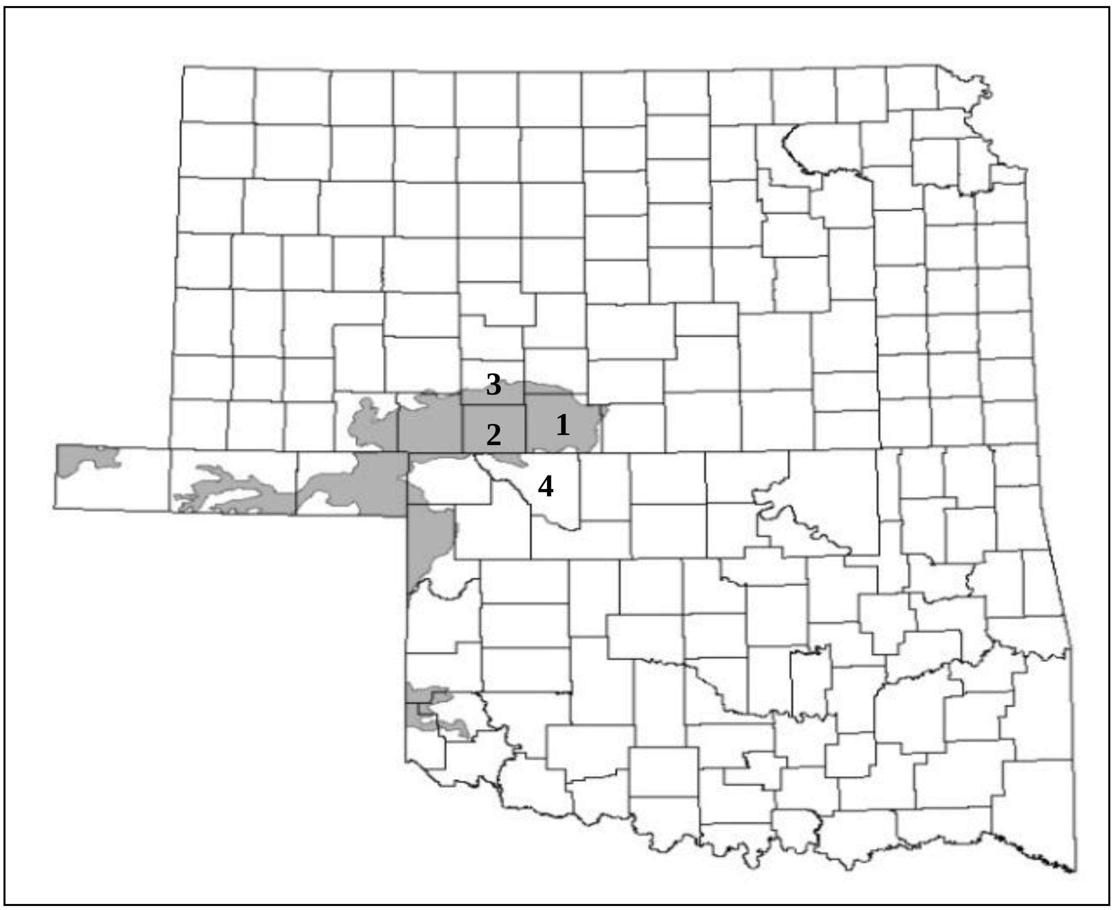
Little is known about bats in the Great Plains where grasses are predominant and trees are less abundant. I investigated habitat use by bats within the Red Hills region of Kansas and Oklahoma. This region contains the largest number of caves and cavernicolous bats in Kansas (Sparks and Choate 2000). The Red Hills region is a large landscape of mixed grass prairie that has been experiencing woody encroachment of eastern red cedar. Of particular interest is how bats were distributed along gradients of canopy cover, tree density, and elevation. Habitat use was investigated at two spatial scales. First, the probability of occurrence of various bat species was estimated across broad, topographically variable landscapes using acoustic detection. Second, habitat use by bats was assessed within riparian corridors from capture rates using mist nets. Among all bat species in the region, Kansas Department of Wildlife, Parks, and Tourism (KDWPT) had listed two species, *C. townsendii* and *Antrozous pallidus*, as species in need of conservation (SINC). These two species within Kansas are restricted to the Red Hills Region, and an investigation of these SINC species, as well as all other bat species in this region, will be important for habitat management in attempts to recover these species (Chapter 4).

METHODS

Study Area

The Red Hills (Fig. 2-1) is comprised of mainly mixed-grass prairie dominated by little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), side oats grama (*Bouteloua curtipendula*), and blue grama (*Bouteloua gracilis*). Intermittent patches of eastern red cedar woodlands, deciduous, and mixed woodlands are found primarily within the lower elevations of these watersheds, but variably extend into uplands. The area contains cliffs, tabletops, and canyons separated by tributaries of the Arkansas River. Aquatic-associated habitats included mixed riparian woodlands and coniferous (*Juniperus*) riparian woodlands with varying densities of trees and ponds bordered by various amounts of woody vegetation. In addition to the diverse landscape there are over 400 known caves and numerous crevices that have developed within the

Figure 2-1. The Red Hills (shaded area) of Barber County (1), Comanche County (2), and Kiowa County (3) in Kansas and Woods County (4) in Oklahoma. (Figure adapted from Prendergast et al. 2010).


3
2
1
4

soft gypsum and sandstone bedrock (Young and Beard 1993). Within Kansas these caves and crevices serve as roosting sites to the largest number and diversity of cavernicolous bats in the state (Sparks and Choate 2000).

Data were collected over the summers of 2009 and 2010 on three study sites (hereafter, NB, GY, and MH). Each was 2 km in diameter (314 ha) and was centered on a known winter roosting site for a SINC bat (either *C. townsendii* or *A. pallidus*). Median elevations at NB, MH, GY, range from 548 to 600 m, 527 to 584 m, and 524 to 567 m, respectively.

Acoustic Detection

I made acoustic recordings of bats to measure habitat use across the 314-ha landscapes. I used AnaBat SD1-CF bat detectors (*Titley* Scientific, Ballina, Australia) from late May to mid-August in both 2009 and 2010 to record bat activity across each study area. A grid of 48 points, spaced 250 m apart, was established within each circular, 1-km radius study site. All points were visited eight times (four visits per year) on each study area, except for MH where only three complete visits were made to all 48 points in 2009 (19 points at MH were visited four times in 2009). Thus, 1,123 point visits were made for recording during the duration of the project. The order of point visitation within sites was rotated in an attempt to eliminate repetition of recoding times at a given point. Because sites could not be sampled in their entirety in one evening, recordings were made among consecutive nights spanning 2 to 3 nights per site. I recorded bat activity at several points each night for 3 h after sunset. Each observer was equipped with two AnaBat detectors in which one detector was used to record at 1.5 m high for 5 min and the other detector at 5 m high for the next 5 min resulting in a 10 min recording duration at each recording point (calls were pooled between the recording heights for analyses). AnaBat transducers were housed within a 90° polyvinyl chloride elbow. This elbow was attached to direct the cone of reception directly upward to assess bat activity directly over the observers and to maintain consistency in directionality across recordings.

Recordings were downloaded and analyzed using a personal computer and AnaLook software (Titley Electronics, Ballina, Australia). I analyzed graphical spectrograms (change in frequency, kHz, over time) to identify bat species. This was done by comparing call characteristics from spectrograms to a local bat call library I created from mist netting in the region. Additionally, I used a North American bat call library from Titley Scientific, and from the southeastern U.S. bat call library (L. Robins, Missouri State University, unpublished data). I created my Red Hills bat call library by capturing bats in mist nets and recording their vocalizations subsequent to release. Basic call characteristics for identification included minimum and maximum frequencies and overall call structure (e.g., shape of frequency-time curves). Acoustic identification was simplified due to the bat community containing only one *Myotis* species (*M. velifer*). Not all call files were usable as some lacked a full call sequence needed for species identification. Acoustic calls that had limited clarity with excessive background noise or fewer than three pulses in the call sequence were omitted from identification. Only identifiable calls were used for occupancy modeling.

Mist Netting

I used mist netting to investigate habitat use by bats within riparian corridors. Bats were captured from 6 June to 11 August in 2009 and 31 May to 30 July 2010 using mist nets placed across pools on ephemeral streams and ponds (commonly used as habitats for drinking and foraging; Walsh and Harris 1996). Nets were 2.6 (m) high and 6, 9, or 12 m in length. A total of 44 net nights were completed over the two years, resulting in approximately two netting attempts (four individual nets per attempt) per week. Netting locations were chosen within each site and were rotated amongst all possible netting locations within that site both years. If netting locations were sparse and needed to be used again during the year, no locations were repeated two nights in a row. Four nets were deployed each night of sampling resulting in 142 different net locations. Each night, netting locations were positioned 16 m to 126 m apart, given the availability of pools. Overlapping of netting stations did occasionally take place. However, multiple uses of netting locations did not constitute independent samples; rather numbers of bat captures were averaged across visits per net location.

Netting occurred for 3 h after sunset during which nets were checked every 45 min in 2009 and every 30 min in 2010, as escapee bats and net damage was apparent from 2009. I identified all species of bats captured and recorded from each individual weight (g), forearm length (mm), and tragus length (mm). Sex was determined by visual inspection and reproductive status of females was determined by palpation of the mammaries as well as the visual inspection of the abdomen (Racey 1969). Tissue biopsies 2.0 mm were taken from the right wing and were used to mark individuals to indicate capture. No bats were ever recaptured during the two summers of our investigation.

Habitat Measurements

Habitat variables measured at each acoustic recording point included percent canopy cover of trees and elevation. Canopy cover percentage was measured toward the four cardinal directions from each point using a spherical densitometer, where canopy cover was averaged across the four readings per point (Lemmon 1956). Tree density was measured as described below for mist net sampling points, but these data were not included in the analysis of acoustic data because (1) my lack of confidence in reasonably treating outliers in tree density estimates across landscapes and (2) tree density data presented unresolvable model convergence issues in program PRESENCE (these analytical issues were not apparent in riparian zones used for mist netting where tree densities were not as drastically variable as in uplands, the latter being where most recording points were located). Elevation (m above sea-level) was measured at each point using a global positioning system. Relative elevation per sampling point was then calculated by subtracting the recording point elevation from the median elevation across all recording points per research site. Point-specific elevation relative to median site elevation was used as median elevation varied among sites.

Centers of mist nests constituted sampling points for habitat variables pertinent to net captures of bats. At these points I measured width (m) and depth (cm) of the underlying water pool, deciduous tree density (trees / ha), eastern red cedar (hereafter “cedar”) density, all tree density, and canopy cover percentage. Water width (m) and depth (cm) were measured using a vinyl measuring tape. Tree densities were estimated per ha using the point-quarter method (Krebs 1999). However, because vegetative clutter was of interest, the distance (m) to the closest branch of a tree was measured rather than the distance to the nearest stem. Canopy cover was measured using a spherical densiometer.

Statistical Analyses

Probability of occurrence was modeled (occupancy modeling) from the acoustic data using the multi-season analysis in program PRESENCE 3.1 (Hines 2010). In my study, the "seasons" constitute the two sampling years. This program calculates four different parameters: probability of occurrence (ψ), probability of colonization (γ), probability of extinction (ε), and probability of detection (p) from presence-absence data among repeat sampling visits. PRESENCE estimates ψ by simultaneously accounting for imperfect p (MacKenzie et al. 2002). I modeled only ψ and p in relation to various covariates (i.e., estimates of γ and ε remained constant in all models, though their estimates are reported). Probability estimates for both ψ and p were modeled against various covariates (e.g., habitat measures) and overall estimates for ψ and p were determined from weighted averages among best-fit models. When the top model set (ΔAIC $\leq$ 2) contained only weak models with the covariate year for p, the average p across both years from those models was used in computing an overall weighted average of p across all other top models.

Covariates for ψ and p included canopy cover and point-specific elevation. Year was included as a covariate for p only, as seasonal variation in ψ is not estimable in multi-season modeling. All linear covariates (canopy cover and elevation) were Z-transformed prior to analyses in PRESENCE. Covariates were tested for collinearity using Pearson correlation in SAS (SAS Institute, Cary, NC.) prior to occupancy modeling, where correlated covariates ($P < 0.05$) would not have been included in tandem in occurrence and detection models (no such correlations were found among the variables used). Thirty-two candidate models, constituting all additive combinations of covariates for ψ and p, were created for each species (Table 2-1). When extreme (near 1 or 0) estimates or unreasonably large standard errors of γ or ε were found in models accompanied by variance-covariance matrix warnings or non-convergence of models, these parameters were fixed to 1 or 0 (J. E. Hines, U.S. Geological Survey, personal communication). Competing models within the top candidate set with unresolvable covariance matrix warnings were not included in final model-averaged parameter and slope estimates.

Capture per unit effort (CPUE) for bats in mist nets was calculated by dividing the number of bats captured per net by the product of net length and number of nights sampled at that same net location in a given year. Multiple linear regressions in SAS (Proc MIXED; SAS Institute, Inc., Cary, North Carolina) was used to compare CPUE to habitat variables. Combinations of covariates included water width, canopy cover, deciduous tree density, cedar tree density, and all tree density. Covariates were tested for collinearity using Pearson correlation and correlated covariates ($P < .05$) were not included in the same model. This *a priori* elimination of covariate inclusion resulted in 11 models per species (Table 2-2).

Table 2-1. Candidate models for probabilities of occupancy (ψ) and detection (*p*) of bats using the program PRESENCE 3.1. Covariates include year (YR), canopy cover percentage (CC), and constant parameters with no covariates (.).

Models and covariates	**Models and covariates**
(ψ) {.} (p) {.}	(ψ) {EL} (p) {.}
(ψ) {.} (p) {YR}	(ψ) {EL} (p) {YR}
(ψ) {.} (p) {CC}	(ψ) {EL} (p) {CC}
(ψ) {.} (p) {CC,YR}	(ψ) {EL} (p) {CC,YR}
(ψ) {.} (p) {EL}	(ψ) {EL} (p) {EL}
(ψ) {.} (p) {EL,YR}	(ψ) {EL} (p) {EL,YR}
(ψ) {.} (p) {CC,EL}	(ψ) {EL} (p) {CC,EL}
(ψ) {.} (p) {CC,EL,YR}	(ψ) {EL} (p) {CC,EL,YR}
(ψ) {CC} (p) {CONS}	(ψ) {CC,EL} (p) {CONS}
(ψ) {CC} (p) {YR}	(ψ) {CC,EL} (p) {YR}
(ψ) {CC} (p) {CC}	(ψ) {CC,EL} (p) {CC}
(ψ) {CC} (p) {CC,YR}	(ψ) {CC,EL} (p) {CC,YR}
(ψ) {CC} (p) {EL}	(ψ) {CC,EL} (p) {EL}
(ψ) {CC} (p) {EL,YR}	(ψ) {CC,EL} (p) {EL,YR}
(ψ) {CC} (p) {CC,EL}	(ψ) {CC,EL} (p) {CC,EL}
(ψ) {CC} (p) {CC,EL,YR}	(ψ) {CC,EL} (p) {CC,EL,YR}

Table 2-2. Model selection results of capture rates of three bat species in relation to habitat variables in the Red Hills of Kansas and Oklahoma, 2009-2010. Shown are Akaike's Information Criterion corrected for small sample size (AIC_c), deviation from the best-fit model (ΔAIC_c), and AIC_c weight (w_i), Covariates include canopy cover (CC), water width (WW), densities of all trees (AD), deciduous density (DD), and cedar density (CD). "." indicates a constant model with no covariates.

	Myotis velifer			***Corynorhinus townsendii***			***Antrozous pallidus***		
Model	**AIC_c**	**ΔAIC_c**	**w_i**	**AIC*c***	**ΔAIC_c**	**w_i**	**AIC*c***	**ΔAIC_c**	**w_i**
.	37.3	0.00	0.96	-442.1	0.00	0.82	-416.3	0.00	0.99
CC	-30.4	6.9	0.03	-439.0	3.1	0.17	-400.5	15.8	0.0003
WW	-14.2	23.1	9.3E -06	-410.9	31.2	6.5E -08	-371.5	44.8	1.8E -10
AD	-7.2	30.1	2.8E -07	-409.4	32.7	6.5E -08	-383.7	32.6	8.3E -08
CD	-3.9	33.4	5.4E -08	-400.3	41.8	6.9E -10	-374.9	41.4	1.0E -09
DD	-3.7	33.6	4.9E -08	-394.9	47.2	4.6E -11	-369.9	46.4	1.8E -10
CC,DD	2.2	39.5	2.5E -09	-392.7	49.4	1.5E -11	-354.0	62.3	2.9E -14
AD,WW	16.0	53.3	2.5E -12	-378.5	63.6	1.2E -14	-338.9	77.4	1.5E -17
DD,WW	19.0	56.3	5.7E -13	-364.3	77.8	1.0E -17	-325.4	90.9	1.8E -20
CD,WW	19.2	56.5	5.2E -13	-369.5	72.6	1.4E -16	-330.3	86	2.1E -19
CD,DD	29.7	67	2.7E -15	-353.3	88.8	4.3E -20	-328.6	87.7	9.0E -20

I used an information theoretic approach (Akaike's Information Criterion; "AIC") (Burnham and Anderson 2002) to select best-fit models of covariates in predicting ψ, *pi*, and CPUE. From all candidate models for each statistical procedure above (acoustic monitoring and mist-net data) best-fit models were demarcated with $\Delta AIC \leq 2$ and $\Delta AIC_c \leq 2$, respectively (AIC is the default criterion in PRESENCE; AIC_c is adjusted for sample size and is available in Proc MIXED). Weighted averages of all probability estimates and slope parameters (β) values, including standard errors and 95% confidence intervals for slopes, were calculated from top Models using Akaike weights (w_i). Significance of slope parameters (β) was determined by comparing confidence intervals to zero.

RESULTS

Acoustic detection across landscapes

A total of 1,347 echolocation recordings were gathered from 1,123 visits across all 144 acoustic-monitoring points from 2009 and 2010. Unidentifiable recordings made up nearly 350 (26%) of all recordings, and 233 (17%) calls were grouped (calls overlapping other species) and could not be identified to species. This resulted in a total of 764 (57%) species specific echolocation calls across all points. Nine species were identifiable from call spectrograms from 764 echolocation recordings (Table 2-3). Occupancy modeling was done for seven species which did not include *C. townsendii* or *L. cinereus* because these bats were detected only at two and three sampling points, respectively.

On the landscape level, canopy cover from all three sites ranged from 0% to 98%, but most points had measurements under 10 % (Fig. 2-2). Point-specific elevation at GY, MH, and NB ranged from -18.5 to 33.5 m, -21.75 to 15.75 m, and -27 to 30 m, respectively. In riparian habitat, canopy cover used in CPUE modeling ranged from 0 to 100% (Figs. 2-3 and 2-4). Deciduous tree and cedar tree density estimations ranged from 0.53 to 954,930.47 and 0.24 to 3,819,721.86 per ha, respectively. While water widths ranged from 0 - 9.3 m across.

Three models were competitive (ΔAIC $\leq$ 2.0) in predicting occupancy of *M. velifer* (Table 2-4). The best-fit model for *M. velifer* had an AIC weight of 34% and included the covariates canopy cover and elevation for ψ and covariates year, canopy cover, and elevation for *p*. The weight-averaged probabilities of occurrence, colonization, and extinction for *M. velifer* among these top models were ψ = 0.70 (SE = 0.05), γ = 0.37 (SE = 0.12), and ε = 0.05 (SE = 0.04), respectively. The weight-averaged probability for *p* showed an increase from 2009 *p* = 0.25 (SE = 0.02) to 2010 *p* = 0.35 (SE = 0.03). Untransformed weighted estimates of the probability of detection indicated that the covariate canopy cover (β = 0.07; $CI_{.95}$= 0.00, 0.14) appears to have a weak positive relationship, and elevation (β = -0.070; $CI_{.95}$= -0.15, 0.01) did not influence detection and was not significantly different from zero. Model-averaged β estimates for ψ indicated a profound positive relationship with the covariate canopy cover (β = 2451.60; $CI_{.95}$ = 2449.39, 2453.81), and a negative relationship with elevation (β = -0.79; $CI_{.95}$ = -1.37, -0.20).

Table 2-3. Number of acoustic detections for nine species of bats within the Red Hills of Kansas and Oklahoma, 2009 and 2010.

Common name	**Species**	***n***
Cave myotis	*Myotis velifer*	361
Brazilian free-tail bat	*Tadarida brasiliensis*	314
Big brown bat	*Eptesicus fuscus*	26
Evening bat	*Nycticeius humeralis*	16
Tri-colored bat	*Perimyotis subflavus*	16
Red bat	*Lasiurus borealis*	15
Pallid bat	*Antrozous pallidus*	11
Hoary bat	*Lasiurus cinereus*	3
Townsend's big-eared bat	*Corynorhinus townsendii*	2

Figure 2-2. Distribution of canopy cover across all three sites in the Red Hills of Kansas and Oklahoma, 2009 and 2010.

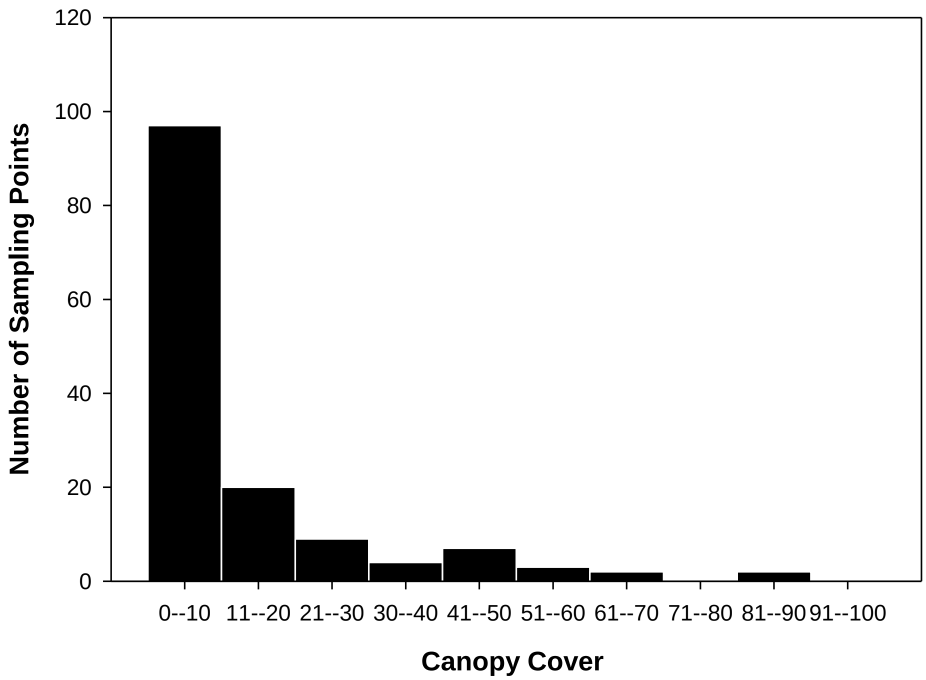
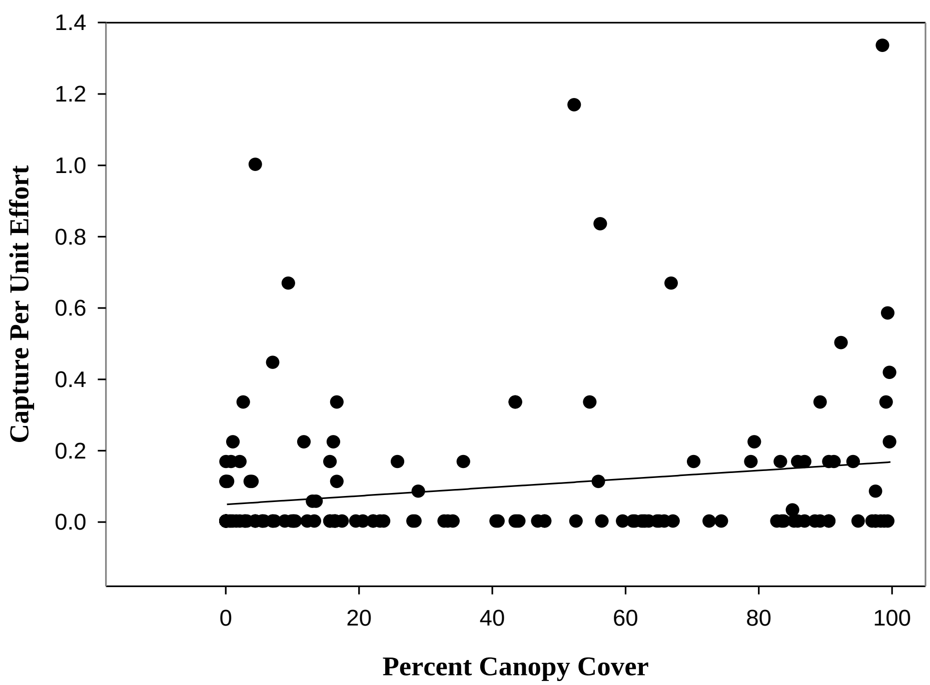

120
100
80
60
40
20
0
Number of Sampling Points
0--10
11--20
21--30
30--40
41--50
51--60
61--70
71--80
81--90
91--100
Canopy Cover

Figure 2-3. Capture per unit effort (see text) of *Myotis velifer* in relation to canopy cover percentage.



1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Capture Per Unit Effort
0
20
40
60
80
100
Percent Canopy Cover

Figure 2-4. Capture per unit effort of *C. townsendii* (see text) in relation to canopy cover percentage.

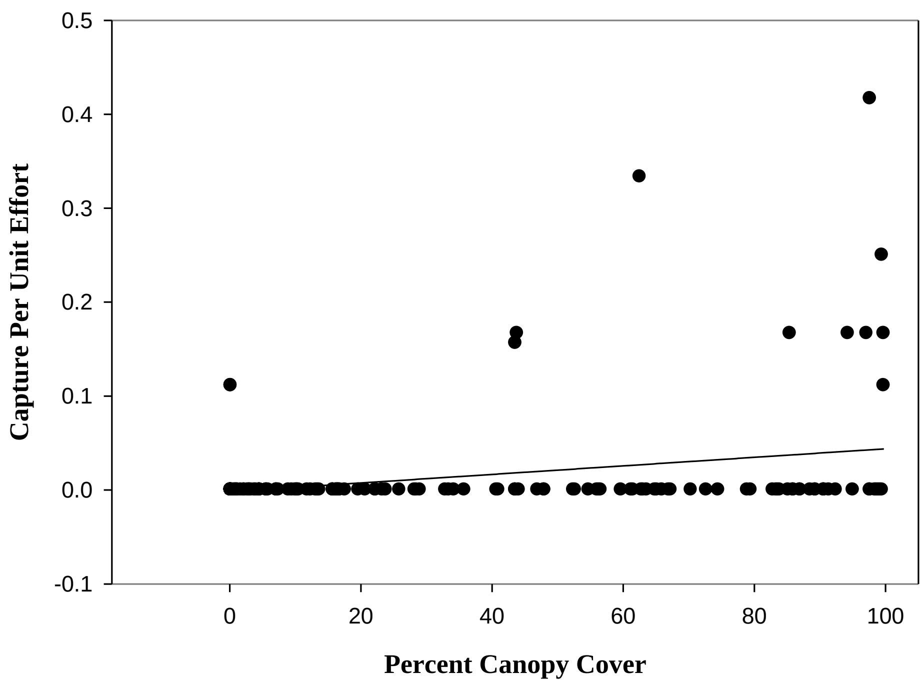

0.5
0.4
0.3
0.2
0.1
0.0
-0.1
Capture Per Unit Effort
0
20
40
60
80
100
Percent Canopy Cover

Table 2-4. Best-fit models for the probability of occurrence (ψ) and detection (p) of bats in the Red Hills of Kansas and Oklahoma, 2009-2010. Among 32 candidate models, only top models with ΔAIC $\leq$ 2.0 were considered plausible models; these are listed for each species. Covariates modeled for ψ and p include point-specific elevation (EL), canopy cover (CC); (.) indicates parameters in models lacking covariates. Shown are Akaike's Information Criterion (AIC), deviation from the best-fit model (ΔAIC), AIC weight (w_i), and number of parameters (k) for all candidate models. Asterisks signify that those models have covariance matrix warnings and output was not considered in final weighted calculations.

Species		Best fit models	AIC	ΔAIC	w_i	k
Myotis velifer		(ψ) {CC,EL} (p) {YR,CC,EL}	1362.11	0.00	0.34	9
		(ψ) {CC,EL} (p) {YR,CC}	1362.90	0.79	0.23	8
		(ψ) {CC,EL} (p) {YR,EL}	1363.10	0.99	0.21	8
Tadarida brasiliensis		(ψ) {.} (p) {YR,CC,EL}	1244.30	0.00	0.18	7
		(ψ) {.} (p) {YR,EL}	1244.32	0.02	0.18	6
		(ψ) {CC} (p) {YR,CC,EL}	1244.74	0.44	0.15	8
		(ψ) {CC} (p) {YR,EL}	1245.67	1.37	0.09	7
		(ψ) {EL} (p) {YR,EL}	1245.99	1.69	0.08	7
		(ψ) {EL} (p) {YR,CC,EL}	1245.99	1.69	0.08	8
Eptesicus fuscus	*	(ψ) {CC} (p) {CC,EL}	232.74	0.00	0.26	7
		(ψ) {CC} (p) {CC}	233.76	1.02	0.15	6
	*	(ψ) {CC,EL} (p) {.}	234.32	1.58	0.11	6
	*	(ψ) {CC} (p) {YR,CC,EL}	234.59	1.85	0.10	8
Nycticeius humeralis		(ψ) {.} (p) {.}	174.70	0.00	0.15	4
		(ψ) {.} (p) {EL}	175.77	1.07	0.09	5
		(ψ) {CC} (p) {.}	175.79	1.09	0.09	5
	*	(ψ) {.} (p) {YR}	176.56	1.86	0.06	5
		(ψ) {.} (p) {CC}	176.59	1.89	0.06	5
		(ψ) {EL} (p) {.}	176.70	2.00	0.05	5
Perimyotis subflavus		(ψ) {CC,EL} (p) {.}	163.13	0.00	0.23	4
		(ψ) {CC,EL} (p) {EL}	163.34	0.21	0.21	5
		(ψ) {CC,EL} (p) {CC,EL}	164.77	1.64	0.10	6
		(ψ) {CC,EL} (p) {CC}	164.81	1.68	0.10	5
		(ψ) {CC,EL} (p) {YR}	165.03	1.98	0.09	5
Lasiurus borealis		(ψ) {CC} (p) {EL}	149.87	0.00	0.14	5
		(ψ) {CC} (p) {.}	150.41	0.54	0.11	4
		(ψ) {CC} (p) {CC}	150.64	0.77	0.10	5
		(ψ) {CC} (p) {CC,EL}	150.96	1.09	0.08	6
		(ψ) {CC,EL} (p) {.}	151.70	1.83	0.06	5
		(ψ) {CC} (p) {YR,CC}	151.73	1.86	0.06	6
		(ψ) {CC,EL} (p) {EL}	151.74	1.87	0.06	6
		(ψ) {CC} (p) {YR, EL}	151.78	1.91	0.06	6
Antrozous pallidus	*	(ψ) {CC,EL} (p) {CC,EL}	105.92	0.00	0.44	7
	*	(ψ) {CC,EL} (p) {YR,CC,EL}	107.71	1.79	0.18	8

Six models were competitive (ΔAIC $\leq$2.0) in predicting occupancy of *Tadarida brasiliensis* (Table 2-4). The top model had an AIC weight of 18% with no covariates for ψ, but contained year, canopy cover, and elevation as affecting *p*. The weight-averaged probabilities of occurrence, colonization, and extinction for *T. brasiliensis* were ψ = 0.57 (SE = 0.05), γ = 0.22 (SE = 0.12), and ε = 0.10 (SE = 0.04), respectively. The weight-averaged probability for *p* increased from 2009 *p* = 0.33 (SE = 0.03) to 2010 (*p* = 0.42 (SE = 0.03). The average β estimate of probability of detection in relation to canopy cover showed no significant difference from zero (β = -0.05; $CI_{.95}$= -0.11, 0.01); however, *p* was negatively related to elevation (β = -0.31; $CI_{.95}$ = -0.45, -0.18). Model-averaged β estimates for ψ indicated canopy cover (β = 0.09; $CI_{.95}$ = -0.10, 0.28) and elevation (β = -0.03; $CI_{.95}$ = -0.12, 0.06) were not significantly different from zero.

Four models for occupancy by *E. fuscus* had ΔAIC $\leq$2.0; however, three of the four top models had variance-covariance warnings and were not considered for predicting occupancy. Thus, I only considered one model as best-fit with a weight of 15% (Table 2-4). This model included canopy cover as a covariate for both ψ and *p*. Estimates of probability of occurrence, colonization, extinction, and year for *E. fuscus* were ψ = 0.014 (SE = 0.00), γ = 0.0 (SE = 0.00), ε = 0.11 (SE = 1006.06), and *p* = 0.05 (SE = 143.05) respectively. Probability of detection for *E. fuscus* was positively influenced by the covariate canopy cover (β = 0.13; $CI_{.95}$ = 0.03, 0.23). Model-averaged β estimates for ψ indicated a profound negative influence of canopy cover (β = -222.29; $CI_{.95}$ = -226.19, -218.39). Despite these results coming from the best-fit, best-diagnosed model, the standard error estimates for probability estimates appear unreasonably extreme and all results from this model should be interpreted with much caution. The same generally applies to the best-fit PRESENCE models for all species henceforth (not regression models from mist net data); however, the results from those best-fit PRESENCE models are nevertheless presented.

Nycticeius humeralis had six top models with ΔAIC $\leq$2.0. One of these models was not used for model averaged estimates due to a covariance-variance matrix warning (Table 2-4). The top probability of occurrence model was weighted 15% and included no covariates in parameterizing ψ or *p*. Other models included the covariates canopy cover for ψ and canopy cover, elevation, and year for *p*. The weight-averaged probabilities of occurrence, colonization, extinction, and year for *N. humeralis* were ψ = 0.40 (SE = 1196.06), γ = 0.00 (SE = 27.65), ε = 0.18 (SE = 1705.70), and *p* = 0.09 (SE = 70.63) respectively. Of the five remaining models, the probability of detection included only two covariates, canopy cover and elevation, in two independent models; although, neither β estimates were significantly different from zero (β = 1.09; $CI_{.95}$ = -3.29, 5.47 and β = 0.02; $CI_{.95}$ = -0.07, 0.02, respectively). Furthermore, from the five remaining top models, only two models contained the single covariates canopy cover and elevation for ψ, and β estimate for ψ indicated that there was no influence from the covariate canopy cover (β = 1.09; $CI_{.95}$ = -3.29, 5.47) or elevation (β = -0.03; $CI_{.95}$ = -0.45, 0.39).

Five models for *P. subflavus* occupancy had ΔAIC $\leq$2.0. The best-fit model had a model weight of 23% and included canopy cover and elevation in ψ but no covariates were included for *p* (Table 2-4). The weight-averaged probabilities of occurrence, colonization, extinction, detection, and year for *P. subflavus* were ψ = 0.00 (SE = 0.00), γ = 1.0 (SE = 0.00), ε = 1.0 (SE = 0.00), and *p* = 0.02 (SE = 0.01), respectively (γ and ε

were fixed to 1 to address variance-covariance errors). Top models included canopy cover and elevation as covariates for probability of detection models. Probability of detection was not significantly influenced by the covariates canopy cover (β = -0.04; $CI_{.95}$ = -0.17, 0.09) or elevation (β = -0.11; $CI_{.95}$ = -0.28, 0.05). Model-averaged β estimates for ψ indicated no significant relationship with canopy cover (β = 13.93; $CI_{.95}$ = -2.74, 30.59) or elevation (β = 3.98; $CI_{.95}$ = -0.24, 8.21).

Lasiurus borealis occupancy was best explained by eight models (ΔAIC $\leq$ 2.0) (Table 2-4). The top model was weighted 14% and included canopy cover as a covariate for ψ and elevation for *p*. The weight-averaged probabilities of occurrence, colonization, extinction, and year for *L. borealis* were ψ = 0.07 (SE = 0.05), γ = 0.00 (SE = 0.00), ε = 0.40 (SE = 0.09), *p* = 0.05 (SE = 0.31), respectively (γ was fixed to 0 to address variance-covariance errors). The top models included canopy cover and elevation as covariates for *p*. Model-averaged slope estimates for *p* revealed no significant patterns with either canopy cover (β = -0.09; $CI_{.95}$ = -0.23, 0.06) or elevation (β = 0.10; $CI_{.95}$ = -0.03, 0.23). Model-averaged estimates for ψ indicated no significant relationship with canopy cover (β = 1.02; $CI_{.95}$ = -0.30, 2.34) or elevation (β = 0.02; $CI_{.95}$ = -0.03, 0.07).

Two top models for *A. pallidus* were competitive with ΔAIC $\leq$ 2.0. However, these two models were not used for final output as these two models contained the covariance matrix warnings (Table 2-4). The third-best model outside of the ΔAIC $\leq$ 2.0 threshold (w_i = 0.14) also contained a covariance matrix warning and was not used. The fourth proceeding model with ΔAIC = 3.34 (w_i = 0.08) did not result in a covariance matrix warning, and included canopy cover and elevation as covariates for ψ and elevation for *p*. The probabilities of occurrence, colonization, extinction, and detection for *A. pallidus* were ψ = 0.00 (SE = 0.00), γ = 0.22 (SE = 0.13), ε = 0.00 (SE = 0.00), and *p* = 0.10 (SE = 0.06) respectively (ε was fixed to 0 to address variance-covariance errors). From this model the *β* estimate for *p* revealed a significant negative pattern with elevation (*β* = -1.78; $CI_{.95}$ = -2.58, -0.97). Model estimates for ψ indicated no significant relationship with canopy cover (*β* = 1.77; $CI_{.95}$ = -1.15, 4.69) or elevation (*β* = 7.40; $CI_{.95}$ = -3.22, 18.02).

Riparian habitat use

A total of 169 individuals representing nine species were captured by mist nests across both years of study (Table 2-5). Correlated covariates that were not included in tandem in regression models were canopy cover and cedar density (*P* = 0.0184), canopy cover and all tree density (*P* = 0.0015), canopy cover and water width (*P* <0.0001), cedar density and all tree density (*P* = 0.0002), and deciduous density and all tree density (*P* <.0001) (Table 2-2). Capture rates of three species were included in regression models (*M. velifer*, *C. townsendii*, and *A. pallidus*) as these species were represented by at least 10 unique captures. Single, best-fit models (ΔAIC $\leq$2.0) for each species were the constant models containing no covariates. Interestingly, the next best-fit models for all three species contained the covariate canopy cover, which out-ranked all other covariate models by considerable margins.

Models including the canopy cover covariate for *M. velifer*, *C. townsendii*, and *A. pallidus* were 1,264,263.1, 568,070.0, and 362,217.4 times greater, respectively, than any other competing model. Slope estimates for CPUE of *M. velifer* (*β*=0.001; $CI_{.95}$ =

Table 2-5. Eight species of bats and their number of net captures within riparian habitat of the Red Hills of Kansas and Oklahoma, 2009 and 2010.

Common name	**Species**	***n***
Cave myotis	*Myotis velifer*	120
Townsend's big-eared bat	*Corynorhinus townsendii*	21
Pallid bat	*Antrozous pallidus*	13
Evening bat	*Nycticeius humeralis*	8
Red bat	*Lasiurus borealis*	3
Brazilian free-tail bat	*Tadarida brasiliensis*	2
Big brown bat	*Eptesicus fuscus*	1
Hoary bat	*Lasiurus cinereus*	1

0.00002, 0.002; $r^2 = 0.04$) and *C. townsendii* ($\beta = 0.0005$; $CI_{.95} = 0.0003, 0.0007$; $r^2 = 0.08$) were positively correlated with canopy cover (Figs. 2-3 and 2-4); however, the slope estimate for *A. pallidus* was not significantly different from zero ($\beta = -0.00003$; $CI_{.95} = -0.0002, 0.0002$; $r^2 = 0.0002$).

DISCUSSION

I found few patterns of habitat use by bats in the Red Hills. From analysis of acoustic data, only *M. velifer* exhibited any significant relationships of occurrence probability and any measured habitat variables. Probability of occurrence of *M. velifer* appeared to increase with canopy cover and decrease with elevation. *T. brasiliensis* had the second largest sample size of acoustic detections (Table 2-3); however, no relationships with occurrence were apparent from my data. Analysis of acoustic data indicated that *E. fuscus* appeared to exhibit a significantly negative relationship with canopy cover but these results are not dependable due to large estimates of standard errors. The same applies to results from PRESENCE models for every other species besides *M. velifer* and *T. brasiliensis*, which appears to be an artifact of small sample sizes of detections of the former species relative to those of *M. velifer* and *T. brasiliensis* (Table 2-3). The skewness of the canopy cover data (Fig. 2-2) may compound the problem of low sample size. From mist-net captures in riparian zones, all top models having the highest percentage of weight for the three species contained the constant model with no covariates; nonetheless, canopy cover was the sole covariate in the second best models for predicting the capture rates of three species, significantly so for *M. velifer* and *C. townsendii*.

There is a possibility that the positive relationships observed between CPUE of both *M. velifer* and *C. townsendii* and canopy cover might be due to these bats avoiding nets placed in more exposed, open areas. I suspect that this is not the case for several reasons. First, I caught many *M. velifer* in nets placed in open areas (Fig. 2-3). Second, tree density lateral to mist nets might be more important to net concealment than canopy cover, but there were no apparent relationship between CPUE and tree density for any species. Lastly, patterns of habitat use from acoustic data, with no likely concealment bias, corroborate the patterns identified from the netting data regarding the influence of canopy cover. Other patterns of detection probability from acoustic data included increases in *p* from 2009 to 2010, and decreases in *p* with elevation, for both *M. velifer* and *T. brasiliensis*.

Analysis of my acoustic and netting data indicates that *M. velifer* prefers canopy cover during nocturnal activity, which confirms previous findings that this bat prefers areas with greater tree canopy cover where the species has been observed to regularly forage (Fitch et al. 1981; Caire et al. 1984). Kunz (1974) reported that *M. velifer* was observed to forage in heavier wooded areas on cooler evenings and adjacent to and in open areas on warmer nights. *M. velifer* had also been observed in Oklahoma to forage in lower elevations over bodies of water close to vegetation, maintaining regular foraging flights at mid-canyon height or below (Caire et al. 1984). In Kansas, *M. velifer* was reported to forage at different elevations depending on the time of night and season (Kunz 1974). Immediately after emergence foraging heights were reported at 4 to 12 m high above ground and at predawn heights were observed at 4 to 12 m above ground (Kunz 1974). Also, foraging height was reported to be lower in early spring and in late autumn (Kunz 1974). This bat may be using these lower elevations due to increased foraging success in areas associated with greater woodland cover and over water (Caire et al. (1984). Additionally, this bat may be using lower elevations in this region to escape heavy winds during the summer months (Caire et al. 1984).

T. brasiliensis had the second largest sample size of acoustic detections, but I was not able to identify any relationship between occupancy and canopy cover or elevation. The failure to find any habitat relationships with *T. brasiliensis* could be due to very high flight elevations of this bat that is likely flying well above any obstructing woody vegetation. Davis et al. (1962) and Williams et al. (1973) had also reported this species using higher elevations for foraging well above the ground (e.g. 100-3000 m above ground level). The echolocations of this bat were recorded ubiquitously at nearly all points of my study.

Mist-netting in riparian zones revealed that *C. townsendii* was more associated with higher tree canopy cover in riparian zones of the Red Hills (Fig. 2-4). Our data corroborates to the findings of Caire et al. (1984) and Fellers and Pierson (2002) indicating that this species appears to use wooded regions for foraging. This bat has been reported to forage mainly along streams near high tree canopy cover and to generally prefer riparian habitats (Fellers and Pierson 2002). Also, Fellers and Pierson (2002) reported this bat to avoid open areas, such as pastures. Analysis of net capture rates of the other SINC species in Kansas, *A. pallidus*, did not reveal any relationship to canopy cover or elevation, perhaps due to low sample size.

MANAGEMENT IMPLICATIONS

Despite the limited patterns of habitat use found for all species in this study, most patterns that were found are associated with higher tree cover, a pattern that has also been reported for many bat species. Such areas are known to be key foraging areas for bats (Walsh and Harris 1996, Vaughan et al. 1997, Ober and Hayes 2008) and also provide protection from predators and windbreaks (Verboom and Spoelstra 1999, Patriquin and Barclay 2003). Alteration of riparian habitat, such as tree clearing to benefit grassland wildlife and ranching, may affect some bat species like *C. townsendii* and *M. velifer* more than others. Additional research should be completed to elucidate potential responses of individual species to local tree removal. In Kansas, the SINC species *C. townsendii* and *A. pallidus* are only located within the Red Hills region. Although these two species were not acoustically detected in large numbers, they were captured in mist nets, having the second and third largest numbers of captures, respectively. Recognizing the proliferation of eastern red cedar within this region, and responses by land managers to remove much of it (JCM, personal observation), some woody vegetation should remain in riparian zones, as it appears to provide important habitat for some bats, especially near known roost locations for *C. townsendii*. However, historical levels of naturally fire-protected riparian zones may be adequate to maintain local bat populations in the Red Hills.

Wind energy production in the Great Plains has been on the rise (Kunz et al. 2007), including in Kansas and Oklahoma. Many bats succumbing to wind-power mortalities have been migratory species; although few in comparison, sedentary bats also are killed by these structures such as *E. fuscus* and *M. lucifugus* (Arnett et al. 2008). Although, the majority of the bat species in the Red Hills are non-migratory, mortality rates of these bats may increase with proliferation of wind power development. Only one of the species I studied (*M. velifer*) exhibited significantly biased activity toward lower elevations, perhaps away from would-be wind turbines commonly erected on ridgetops (Arnett et al. 2008, Arnett et al. 2010). Further research could be targeted toward assessing bat occupancy in areas within the Red Hills with the highest potential for functional wind farms. Because of the abundant bat populations, the Red Hills is currently illustrated as an area of special “biological sensitivity” in the Kansas Natural Resource Planner (http://www.kars.ku.edu/maps/naturalresourceplanner/ -Accessed 30 Jun 2011); a cooperatively created on-line resource intended to advise developments such as wind power projects.

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CHAPTER 3

Roost-site characteristics of the pallid bat (*Antrozous pallidus*) in Kansas

ABSTRACT Little is known about roost-site characteristics of the pallid bat (*Antrozous pallidus*) in the Red Hills region of Kansas and Oklahoma. The species is listed as a Species in Need of Conservation within the state of Kansas. I investigated diurnal roost characteristics of the pallid bat during two summers in the Red Hills region of Kansas and Oklahoma. Mist nets were used to capture bats within three, 314-ha study sites. Radio transmitters were attached mid-dorsally to pallid bats. Radio tracking of transmitters commenced each day following radio attachment. Once roosts were located, physical characteristics of those roosts were recorded. Radio transmitters were attached to 10 pallid bats and 11 roost sites were identified. Two of the 10 pallid bats radioed were females, one of which was tracked to a suspected maternity roost shared by other individuals. The largest colony size that was visually confirmed contained 10 individuals, likely all males. Roost structures consisted of vertical or horizontal crevices or exfoliated cliff faces, though most roosts (n = 8) were characterized as vertical crevices. Cliff faces where roosts occurred had a generally westerly aspect (angular mean = 285° ± 51.3° s). Approximate lengths of roosting crevices ranged from 0.3 m to 3.2 m and approximate widths ranged from 3 cm to 20 cm. Approximate roost heights above talus piles ranged from 0 m to13 m. Most roost sites (n = 8) had no surrounding tree canopy cover. Distances from netting locations to roosts ranged from 120 m to 1200 m. Knowledge of roost sites used by pallid bats in the Red Hills could aid in management to protect habitat for this species.

INTRODUCTION

Bats use several different forms of roosting habitat for shelter, protection from predators, thermoregulation, and social interaction (Twente 1955; Beck and Rudd 1960; Tuttle 1976; Vaughan and O'Shea 1976; Kurta, Kunz and Nagy 1990; Ball 2002; Kunz and Fenton 2003). Roosting sites are critical for hibernation, mating, and the rearing of young, and the preferred locations vary across circadial and circannual cycles (e.g., winter roosts, summer roosts, diurnal roosts vs. nocturnal roosts, maternity roosts) (Norwak, Kunz and Pierson 1994; Kunz and Fenton 2003). From a conservation standpoint, anthropogenic displacement of roosting habitat for bats could induce greater commutes by bats to foraging sites, decrease survivorship of newly volant young (Ransome 1990; Tuttle 1976), increase rates of predation (Lewis 1996), and perhaps lead to abandonment of preferred roost sites (Tuttle 1979).

The insectivorous pallid bat (*Antrozous pallidus*) occurs in arid regions of western North America (Hermanson and O'Shea 1983). The species roosts within crevices in rocky outcrops, caves, and anthropogenic structures. These bats typically roost in small aggregations, including at maternity roosts (Ball 2002; Orr 1954; Packard and Judd 1968; Vaughan and O'Shea 1976), and sometimes roost solitarily (Orr 1954), although Twente (1955) reported a large aggregation of 50 male and 150 female bats in a barn in Kansas. Large groups of 200 or more have also been reported within natural caves in Kansas (Sparks and Choate 2000). Pallid bat maternity roosts have been described as being predominately horizontal crevices, perhaps facilitating the retrieval of fallen young and aiding in thermoregulation (Vaughan and O'Shea 1976; Hermanson and O'Shea 1983). Pregnant and lactating females have greater energy requirements; thus, roosting habitat that maintains a minimal thermal gradient may be preferred (Studier, Lysengen and O'Farrell 1973; Trune and Slobodchikoff 1979; Tuttle 1976; Kurta, Kunz, and Nagy 1990). Other roosting crevices used as bachelor roosts, and diurnal roosts of mixed genders, may be more vertical in nature and may have different microclimatic conditions, such as greater diel variability in temperature (Vaughan and O'Shea 1976). Roost sites of pallid bats in Arizona and Oregon included a variety of crevice types (e.g., horizontal, vertical, overhanging faces of cliffs, and exfoliated slabs of rock), which varied in heights along cliff faces and in temperature (Vaughan and O'Shea 1976; Lewis 1996). Pallid bats have also utilized anthropogenic structures such as barns, attics, and other buildings for roosts (Twente 1955; Beck and Rudd 1960).

The pallid bat occurs in Kansas at the eastern edge of its range limit (Vaughan and O'Shea 1976, Sparks and Choate 2000). As of 2011, the pallid bat was listed as a Species In Need of Conservation (SINC) by the Kansas Department of Wildlife and Parks (KDWP) and was only known in Barber and Comanche counties in the Red Hills region (Choate, Schmidt and Taggart 2011). The only known roost in Kansas was a single crevice used as a winter hibernaculum in Barber County (Sparks and Choate 2000; Prendergast, Jensen and Roth 2010). Lack of knowledge of the diversity of roosting structures used by pallid bats presents a disadvantage to the successful conservation of the species in Kansas. The Red Hills in Kansas has a great diversity of geological features that could serve as important roosting sites for pallid bats during the seasons in which this species is actively foraging. In this descriptive note, my objective was to document roost site characteristics of radio-tagged pallid bats during late spring and summer. I recorded (1) numbers and genders of bats at roosts, (2) types of roosts occupied by pallid bats (vertical crevices, horizontal crevices, and exfoliated cliff faces), (3) lengths and widths of roost crevices, (4) heights of roost sites, (5) directional aspect of cliff faces where roost crevices were located, (6) characteristics of tree cover surrounding cliffs chosen for roosting (canopy cover and distances to obstructing woody vegetation), and (7) distances of roosts from point of initial capture. Additionally, notes on the numbers of bats per roost and their reproductive statuses are presented.

MATERIALS AND METHODS

Study area — I captured and tracked bats in the Red Hills region of Kansas and Oklahoma in 2009 and 2010. The region is largely composed of mixed-grass prairie and woodlands of eastern red cedar (*Juniperus virginiana*) and is geologically defined by tablelands, rocky outcrops, canyons, and cliffs (Young and Beard 1993). The landscape has ephemeral streams as tributaries to the Arkansas River. Geological parent material consists of gypsum, sandstone, and shale with numerous crevices in cliff walls and hundreds of caves (Young and Beard 1993). These geological features serve as important roosting habitat for bats in this region including the pallid bat (Prendergast, Jensen and Roth 2010). I sampled bats on three different study sites within the Red Hills of Kansas and Oklahoma. Two research sites were located in Barber County, Kansas, and one site was in Woods County, Oklahoma. The sites were 2-km diameter circles positioned around known winter roosts of pallid and Townsend's big-eared (*Corynorhinus townsendii*, the other SINC bat in Kansas) bats. These sites were located on privately-owned land used primarily for cattle grazing.

Mist-netting and tracking—Pallid bats were captured from late May to mid-August in 2009 and 2010 using mist-nets placed across pools on ephemeral streams. A total of 44 net nights were conducted over the two summers, resulting in approximately two netting attempts per week. Netting locations were systematically chosen within each site and were rotated throughout the two years. Availability of netting pools was dependent upon the availability of ephemeral summer pools. Thirty seven netting stations consisted of four independent nets, 2.6 m high and 6, 9, or 12 m in length, which were positioned from 16 m to 126 m apart, given pool availability. A total of 142 independent net locations was used with some overlapping of netting sites across the two years. Bats were netted for 3 h after sunset, where nets were checked every 45 min in the first summer and every 30 min in the following summer to minimize escapees and damage to nets. I made records of all species of bats captured (Ch. 1), including species and morphometrics including, body (cm), tail (cm), ear (cm), tragus (cm), forearm (cm), and weight (g). Additionally, the sex, age, and reproductive statuses of these bats were recorded. Male and female pallid bats are notably distinguished by their genitalia. Ossification of wing joints was used to determine age. Pregnancy was determined by characteristics such as a noticeable distended abdomen, turgid mammories, and high body mass (Racey 1969).

I attached a 0.3-g radio transmitter to the mid-dorsum of each pallid bat captured using surgical adhesive. I then returned to points of capture the following morning and attempted to locate radioed pallid bats in the vicinity using a Yagi directional antenna and radio receiver. Roosting sites located via radio telemetry were monitored for three days after initial radio attachment in 2010. I monitored pallid bat roosts less frequently in 2009. Pallid bats were initially only located once in 2009, though multiple location records of some bats were made when tracking other individuals.

Roost characterization—Numbers of individuals occupying roosts were either counted visually or estimated if the roost was inaccessible. If the roost was inaccessible other observations were used to determine if multiple bats were present, including the presence of multiple transmitters in one roost or auditory cues.

Roost types were identified into two geological categories: crevices or exfoliated rock surfaces. These cracks within cliff walls ran perpendicular to the cliff face. These were then further subdivided into vertical or horizontal crevices based on their predominate angle. Oblique crevices were not identified and were far less common in the region relative to vertical or horizontal crevices (JCM *pers observ*.). Exfoliated surfaces were hollowed, dome-like structures protruding from—and parallel to—cliff faces, which differed from vertical or horizontal crevices that are perpendicular fractures within cliff faces. Additionally, measurements of length (m) and estimated widths of were taken at identified roost locations.

Height (m) of roost locations were measured from the top of talus piles along cliffs to the location of suspected roosting pallid bats within the roost site using a tape measure. I also measured the distance from the roost site to the top of the cliff escarpment. If actual roost locations could not be identified then an estimation of height was given.

Habitat characteristics of cliff faces were also measured. Directional orientation of cliff faces was measured using a compass bearing (°) perpendicular to—and facing from—the cliff face. Percentage of canopy cover of trees adjacent to cliff faces was averaged across two readings from half of a spherical densiometer taken at the top of the talus slope. These two readings were taken parallel to the cliffs face orientation where vegetation on half of the densiometer was read. Distance (m) to the closest tree from the roost site was measured in two quadrants of a 180° semi-circle demarcated by a line perpendicular to the cliff face. These distances were measured with a laser rangefinder and included only those trees whose crown height was within line of sight from the top of the talus. Distances (m) of roosts sites of radioed bats from their initial netting location were measured using Garmin Trip and Waypoint Manager (Garmin International, Inc., Olathe, Kansas).

RESULTS

Mist-netting and tracking— Across both years, 13 pallid bats were caught over 44 net nights. These bats were captured on two of the three study sites: in Barber County, Kansas and Woods County, Oklahoma, from eight different net locations. I attached radios transmitters to 10 of these 13 bats. From these 10 bats, 11 roost sites were located. In 2009, all three bats captured in Oklahoma received radio transmitter as well as three of the five bats captured in Kansas. In the first year, bats with radio transmitters in Oklahoma were tracked to four distinct roost sites within Oklahoma. Of the radioed bats in Kansas in 2009, two were followed to the same roost site in Kansas and one was untraceable. In 2010 all pallid bat captures occurred in Kansas and four of these five pallid bats had radio transmitters attached, including the only two females I captured. Of these females, one was determined to be gravid. One radioed male pallid bat was tracked to a mound on the ground where the roost was undetermined. In total there were six newly identified roost sites in Kansas and four in Oklahoma (Table 3-1).

Bats were tracked to multiple roost sites in 2009 and 2010 (Table 3-2). However, repeated tracking of radios was not initiated until the 2010 season. In 2009 one of two bats in Oklahoma was tracked to two additional roost locations. In 2010, four pallid bats were radioed including the pregnant female which was captured on 17 June and the second female, a juvenile, on 29 July. Three bats were tracked to multiple roosts including both female bats (Table 3-2). The pregnant female occupied a roost with a radioed male the first morning following attachment. The second and third mornings this female bat was found in a single roost shared by other pallid bats and sexes were not confirmed. However, this was the final roost to which I tracked her where I confirmed her repeated use of the roost for three days, possibly indicating it was a maternity roost. The male bat found roosting with the female bat had been tracked to this roost site on two different dates. However, the first roost used by this male was in a different location with 10 other individuals. The last female captured was tracked to three different roosts. The first roost located after attachment was occupied solitarily. She was then tracked to two other roost locations. The last two locations to which she was tracked were also shared by at least two other pallid bats. The largest group of pallid bats visually confirmed in a roost contained at least ten individuals (Table 3-2), while the smallest group confirmed contained three individuals. Multiple individuals occupied 8 of the 11 roost sites found. Many of the roosts were inaccessible to visual inspections; therefore, multiple bats were only able to be determined by the presence of more than one radio in the same roost location. An observation of only one solitary roosting bat was made in the second year. This was the last female found roosting alone in a small hole in 2010, but moved by the following morning to a roost with other individuals.

Table 3-1. Descriptions of roost sites of pallid bats from late-May to mid-August in 2009 and 2010, in Barber County (BR), Kansas, and Woods County (WD), Oklahoma.

Roost ID	Site	State/ County	Year	Date of location	Roost type	Cliff face bearing (°)	Height of roost (m)[a]	Length of crevice (m)[b]	Roost to escarpment height (m)	Obstructing vegetation direction and distance (m)[c]	Canopy cover (%)
1	NB	KS BR	2009	26-Jun	Vertical	287	3.1-4.2	7.6	3.4	N:20 S:20	0
2	MH	OK WD	2009	8-Jul	Vertical	93	1.1-4.3	5.5	1.2	N:12 S:8	0
3	MH	OK WD	2009	8-Jul	Exfoliation	325	1.55	2.7	0.8	E: 3 W:17	0
4	MH	OK WD	2009	22-Jul	Vertical	220	0-2.1	2.6	0.5	W: 31 E: 21	0
5	MH	OK WD	2009	24-Jul	Vertical	337	3.5-5.5	5.5	0	W: - E:79	0
6	NB	KS BR	2010	12-Jun	Exfoliation	188	2.3	2.5	0.2	E:5 W:3.5	29.3
7	NB	KS BR	2010	14-Jun	Vertical	278	13.5	14.2	0.7	-	0
8	NB	KS BR	2010	18-Jun	Vertical	246	0.62	1.0	0.48	N:4 S:21	0
9	NB	KS BR	2010	30-Jul	Horizontal	335	0	2.4	0	S: 5 N: 39	0
10	NB	KS BR	2010	31-Jul	Vertical & Horizontal	308	2.7	4.1	1.4	S: 5 N:17	8.3
11	NB	KS BR	2010	1-Aug	Vertical	276	3.8	5.1	1.3	N:6 S:4	2.8

[a] Heights of roosts were estimated if location of roosting bats could not be determined.
[b]Length of roosts crevices were estimated if actual location was roosting crevice could not be determined.
[c]Dash (-) indicates absence of vegetation

Table 3-2. Descriptions of pallid bats and their associated roosts from late-May to mid-August in 2009 and 2010, in Barber County, Kansas, and Woods County, Oklahoma. See Table 3-1 for corresponding roost site descriptions.

Roost ID	Year	Date of location	Radio frequency	Number of individuals[b]	Sex & reproductive Status[d]	Distance from net (m)
1	2009	26-Jun	164.147 164.235	2	AM AM	120
2	2009	8-Jul	164.309 164.338	2	AM AM	305
3	2009	8-Jul	164.034	6	AM	1200
4	2009	22-Jul	164.309 or 164.338[a]	1	AM	685
5	2009	24-Jul	164.309 or 164.338[a]	1	AM	268
6	2010	12-Jun	164.335	10	AM	282
7	2010	14-Jun	164.309 164.335	2	PF AM	422
8	2010	18-Jun	164.309	M[c]	PF	278
9	2010	30-Jul	164.441	1	JF	555
10	2010	31-Jul	164.441	6	JF	538
11	2010	1-Aug	164.411	3	JF	522

[a] Specific radio frequency was not determined.
[b] Minimum number of individuals detected.
[c] Multiple individuals were determined by audio confirmation.
[d] Adult male (AM), pregnant female (PF), and juvenile female (JF)

Roost site characterization—Nine roosts were crevices while the remaining three roosts were exfoliated rock surfaces (Table 3-1). Of the nine crevices, seven were vertical, one crevice was horizontal, and one crevice was categorized as both vertical and horizontal. The latter was a hanging boulder nearing separation from the cliff, where two large cracks that joined to make a 90° intersection where pallid bats appeared to be using both sides. Both crevices found to be occupied by the one pregnant female were oriented vertically.

Most roost locations in my study were inaccessible to observers as they were located well above talus piles within crevices. Many roost locations were estimated at >2 m in height (Table 3-1) from the top of the talus and were often only accessible by scaling or standing on large rocks. Heights of roosts ranged from ground level (mound on a hill break) to a height of 13.5 m above talus slopes. The roost on the small hill side was a horizontal exfoliation measuring 15 cm in diameter. This height measurement was not available, as it was located on a gentle declivity and could have easily been crushed by my body weight if not careful. Heights from the top of the suspected roost to escarpments ranged from 0 to 3.4 m.

Seven of the cliff faces (64%) oriented northwesterly between 276° and 337° while two (27%) more southwesterly between 188° and 287° and one remaining roost location faced eastward at 93° (Table 3-1). The mean bearing and angular deviation of these westerly facing cliffs is 285° ± 51.3° *s*. Roost crevice lengths ranged from a hole 15 cm in diameter to long vertical crevices exceeding 14 m. Crevice widths were later estimated to range from 3 cm to 20 cm.

Little to no canopy cover surrounded most roost locations (Table 3-1). In the three instances that overhead canopy cover was > 0%, the greatest cover percentage was at 29 %. The closest obstructing woody vegetation in front of a roost was a deciduous tree (species unknown) that was measured at 3 m. The closest obstructing eastern red cedar tree measured from the roost location was 3.5 m away from a roost. The mean obstructing deciduous tree in meters measured 41.2 ± 48.5 SD from the cliff face, while the mean distance of an obstructing cedar tree in meters was 13.4 ± 10.4 SD from the cliff face. Distances from roosts to nets where bats were radioed ranged from 120 m to 1200 m. However, the majority (64%) were < 300 m (Table 3-1).

DISSCUSSION

Few roosting locations of the pallid bat were known from the Red Hills prior to the current study. One roost location of winter hibernating pallid bats had been noted in the Red Hills for several years and was only recently reported by Sparks and Choate (2000) and Prendergast, Jensen and Roth (2010). Additionally, historical evidence of multiple pallid bats (approximately 200) within the region was reported by Sparks and Choate (2000). Recent records (Prendergast, Jensen and Roth 2010) may have indicated a recolonization of the pallid bat in Kansas since its absence from the known winter roosts in the mid-1970s (Sparks and Choate 2000). My study has documented eleven new summer roosting sites for pallid bats within natural, geological features of the Red hills, seven of those being within the state of Kansas. It is likely that many more pallid bats and roosts exist in Kansas. The suspected maternity roost I found will have been the first, documented maternity roost in a natural rock cavity in Kansas.

Multiple pallid bats were found in the same roosts within the Red Hills during the breeding season for this bat. This is congruent with previous reports by Twente (1955), Vaughan and O'Shea (1976), Hermanson and O'Shea (1983), and Lewis (1996). A suspected maternity roost was discovered 17 June 2010, when a pregnant female was tracked there and remained for several days, although sexes of all individuals within that roost were not determined. Nearly all roosting colonies of pallid bats that I found resemble previous documentation of colony sizes described by Vaughan and O'Shea (1976) and Prendergast, Jensen and Roth (2010). However, large aggregations of pallid bats, such as the approximate 200-bat roost reported by Sparks and Choate (2000), were not encountered.

Roost locations were found to be mostly in vertical crevices and exfoliation type geological formations, as described by Orr (1954), Packard and Judd (1968) and Vaughan and O'Shea (1976). Though, one roost location was a small opening on a hill side and a roost exhibiting both horizontal and vertical features was found. Vertical crevices dominate the region and have been documented to attract roosting pallid bats (Ball 2002; Orr 1954; Packard and Judd 1968; Vaughan and O'Shea 1976). Exfoliated crevices also are relatively common within the Red Hills and appear to present suitable structures for roosting pallid bats. Both crevices and exfoliations may provide adequate thermoregulatory mechanism for these roosting bats (Twente 1955; Beck and Rudd 1960; Tuttle 1976; Vaughan and O'Shea 1976; Kunz 1982; Kurta, Kunz and Nagy 1990; Ball 2002). The crevices occupied by the one pregnant female, including a suspected maternity roost, were oriented vertically, contrary to maternity crevices that are typically horizontal for the species (Vaughan and O'Shea 1976; Hermanson and O'Shea 1983).

Roost height may be important in thermoregulation and predator avoidance. Steep cliff faces and talus piles are a characteristic feature of the Red Hills. Such cliff faces were also noted as important for roosting pallid bats by Hermanson and O'Shea (1983). Roost sites situated high on cliffs may benefit thermoregulation by pallid bats. The height of a roost should affect the amount of solar radiation reaching the roost, where higher roosts might be less shaded by surrounding vegetation and surrounding topography toward evening when warmth may be beneficial for arousal. A similar suggestion was made by Betts (1998) where surrounding trees were distant from silver-haired bat (*Lasionycteris noctivagans*) roosts. Roost sites well above the talus height may also be important in protection from terrestrial predators as suggested by Betts (1998); a similar benefit has been documented for cavity nesting birds (Nilsson 1984; Rendell and Robinson 1990).

Orientation of cliff faces housing pallid bat roosts may also be important for thermoregulation. Cliff face orientation was predominantly westerly with the exception of one roost site facing east. A study on pallid bat roosts by Vaughan and O'Shea (1976) indicated that warmest roosts were warmed late in the day by the sun. A westerly orientation may assist in thermoregulation especially during summer months when daily temperatures are greatest in later daylight hours. Westerly facing roosts might help maintain a gradual warming of temperatures during the day, where cooler temperatures coincide with time periods of torpor and decreased metabolic activity during early morning and midday (Vaughan and O'Shea 1976). Furthermore, westerly facing roosts become warmest in late afternoons which might aid in arousal before their nightly emergence (Vaughan and O'Shea 1976).

Vegetative characteristics surrounding roosts, such as canopy cover, may affect bats use of available roost sites (Vohnof and Barclay 1996; Betts 1998). Canopy cover in the Red Hills was sparse around the identified roosting locations of pallid bats. If trees were present at roost sites they were distant, or at least not touching cliff faces. This may indicate the use of more open cliff faces or passive selection of available cliff faces; however, I did not assess disproportional avoidance of tree cover by roosting pallid bats. For similar reasons stated above, open cliff faces with no obstructing vegetation might benefit thermoregulation or predator avoidance. Roosts away from trees may increase the amount of protection from terrestrial predators by limiting direct access of terrestrial predators to the roost (Vaughan and O'Shea 1976; Kunz 1982) and allowing quick entrance or exit of these bats to avoid aerial predators (Vohnof and Barclay 1996).

Distances from roost sites to location of initial capture varied. However, most roost sites appeared to be relatively close to a water sources (within 50 m) (JCM, *pers. observ.*). Water sources proximate to roosting sites may be an important habitat characteristic for roosting bats (Tuttle 1976; Walsh and Harris 1996). Insect activity is also associated with riparian areas and has been identified as key foraging habitat by bats (Walsh and Harris 1996), and survivorship of newly volant young decreases with distance from such foraging areas (Ransome 1990; Tuttle 1976).

The pallid bat has been described as the most endangered bat in Kansas (Sparks and Choate 2000). Here I have reported multiple roost locations and descriptions of roosting habitat used by pallid bats. While this information may be useful for pallid bat conservation in the Red Hills, further investigations of the distributional extent of this species and its abundance in the region are warranted.

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CHAPTER 4

RECOVERY PLAN FOR TWO BAT SPECIES IN KANSAS: THE PALLID BAT, *Antrozous pallidus* AND TOWNSEND'S BIG-EARED BAT, *Corynorhinus townsendii*.

SUMMARY The two vespertilionid bat species of focus, *Antrozous pallidus* and *Corynorhinus townsendii*, occur throughout the western United States. Because Kansas occurs at the eastern peripheries of the ranges of these species within the United States, representing only small portions of these bats' populations, they both are considered Species in Need of Conservation (SINC) by the Kansas Department of Wildlife and Parks and Tourism. The two species reside only within the Red Hills region of south-central Kansas, along with other western bat species, due to the region's geological make up of caves and cliff-face crevices which these bats depend on for roosting. Additionally, the Red Hills is becoming a region of management concern for wildlife, due to woody encroachment, wind development, and the prospect for white-nose syndrome (WNS) in bat populations. Riparian corridors may be key foraging habitat for many species of bats in this landscape as they contain water and insects, important to these species' diets, as well as tree cover for shelter during nocturnal commutes. Land alteration, such as clearing of woodlands, construction of wind facilities, electrical transmission lines, and row-crop conversion may have adverse effects on certain bat populations. Additionally, WNS might too be an emerging threat to these and other bat populations in the Red Hills. I recommend that the Kansas Department of Wildlife and Parks and Tourism, and its conservation partners, continue to monitor and study these bat species in the Red Hills. In

addition, I suggest the following prioritized goals in attempts to further conserve these bat populations in Kansas:

Protection of roosting habitat. Protection of roosting habitat. Because many bat populations have been shown to decline due to human disturbance, caves and crevices of known roosting bats need to remain unharmed and undisturbed. The transmission of diseases (e.g., WNS) by humans can also be prevented by the limiting access to bat roosts. The disturbance of roosting sites, especially during maternity season, can have serious negative impacts on bat populations. Therefore, in consideration of ongoing efforts for monitoring bat populations, entering caves occupied by roosting bats should only be done during the hibernating season and by professional biologists and experienced spelunkers.

Protection of diverse foraging habitat. Bats readily depend on riparian habitat for foraging and obtaining water. Many studies have indicated these areas harbor greater numbers of foraging bats, which may be attributed to an increase in insect abundance and water availability. Heterogeneity of tree species in these riparian corridors could provide a mixture of forageable insects for different bat species. Trees also provide some bats with protection from wind and predators. However, tree encroachment in the region has negative consequences for other wildlife species. Additionally, salt cedar (*Tamarix* sp.) might reduce riparian water availability and thus bat drinking and foraging habitat. The conversion of prairie to row-crop agriculture may have negative effects on certain bat populations by limiting the diversity of forageable insects within prairie habitat.

Improve knowledge of distribution and abundance of SINC bats. By better understanding the distribution and abundance of the SINC bats in the Red Hills, we can better assess the status of the local populations of these bats and spatial overlap with potential threats from landscape changes. Increased knowledge of foraging and roosting habitats will also help conservation efforts of key bat habitats in the region.

***Monitoring of white nose syndrome* (*WNS*).** Monitoring of WNS could be important for predicting the viability of the SINC bat populations as well as the entire bat community. Routine monitoring of hibernating individuals, and necropsies from winter-killed bats, for the presence of the *Geomyces destructans* fungus (putative causative agent of WNS) will be important for determining the existence of WNS. Ongoing netting efforts should also monitor the spread of WNS. All species in this region as well as the two SINC should remain under concern as potential victims and vectors of this disease. Migratory bat species occur in Kansas and infected individuals may quickly spread to other regions.

Monitoring of potential wind turbine construction sites. Public interest in green energy and the construction of wind power facilities have greatly increased over the past decade. Unfortunately, so has the number of bat fatalities associated with these wind facilities. The development of wind turbine facilities within Kansas is inevitable; however, proper pre and post-construction monitoring must be in place to measure possible effects on all bat populations including the SINC bats. Current efforts to warn of the biological sensitivity of the Red Hills region to wind power, namely bats, should remain.

***Promote public education about bats*.** Education of the importance of bats within the state of Kansas should be heightened. Organizations, such as the Kansas Speleological Society, may be able to provide some education on responsible caving and general rules for minimizing disturbance. In addition, relevance to human health should be clarified, such as the incidence of rabies. Additionally, collaboration among local organizations concerning potential hazards to bat populations should be instilled.

I. INTRODUCTION

Two bat species, *Antrozous pallidus* and *Corynorhinus townsendii*, are widespread in the western United States. These bats range from southwestern Canada to the south through much of Mexico (Kunz and Martin 1982, Hermanson and O'Shea 1983). These bats are highly adaptable to a range of climatic conditions, which is likely related to their widespread ranges in North America. Both of these bat species are non-migratory and exhibit extended torpor in winter months (i.e., these bats are year round residents in Kansas).

Although these two SINC have a very large longitudinal range in the western region of North America, the eastern latitudinal extent of these species' ranges lies in the Red Hills region of Kansas (Kunz and Martin 1982, Hermanson and O'Shea 1983). The Red Hills region of Kansas is unique compared to the rest of the state. The geology of this region has given it the local name of the "Gypsum Hills" due to the parent materials of gypsum, sandstone, and shale (Young and Beard 1993). The region has over 400 known caves within Kansas and serves as the residence to the largest number of cavernicolous bats in the state, including the two SINC bats (Fig. 2-1). These bats utilize the many natural structures (e. g., crevices and caves) in this region that have been created from mechanical and chemical erosion over thousands of years.

Knowledge of *A. pallidus* and *C. townsendii* in Kansas is incomplete. *A. pallidus* has been observed only occasionally in Kansas through 2009 (Prendergast et al. 2010). Early reports of a colony of ~200 individuals were burned from an overhang near the entrance to May's Cave in 1964 (Sparks and Choate 2000). In addition to this hasty eradication, a large maternity colony was observed in a basement of a barn within the cracks of the underlying foundation (Jones et al. 1967). Since then, small winter hibernating groups have been documented in a crevice near Natural Bridge in Barber County with no significant pattern of change in abundance of the bat at that site (Prendergast et al. 2010). Live-capture of both *A. pallidus* and *C. townsendii* has occurred as recently as 2010 (Chapter 2) includes the location and identification of known roosting sites. As for *C. townsendii*, this bat has only a few isolated populations extending east through the Gypsum Cave Region of Texas, Oklahoma, and Kansas (Kunz and Martin 1982). Small populations within the state of Kansas were diminishing throughout the 1960's and early 70's during which time extensive mark and recapture studies were being conducted (S. Roth, Kansas Biological Survey, personal communication). This was said to have had a detrimental effect on this species (S. Roth, personal communication). Since then, researchers have become more aware of the effects of human disturbance on this species and have begun using less invasive methods for research (S. Roth, personal communication). Yearly hibernating surveys of bat numbers have taken place for the past 46 years within this region; however, *C. townsendii* had shown no significant changes in abundance (Prendergast et al. 2010).

This recovery plan is organized as follows: Detailed natural history accounts are provided for each species highlighting the necessary biological background for understanding these two species. These species accounts document taxonomic descriptions, historic and current distributions, diets, habitat requirements for roosting and foraging, community associates, population sizes and trends, demographic patterns, and conservation statuses and research needs of the two species. Due to the similarity in habitat and ranges of occurrence in Kansas, a common management plan for the two species highlights recommended goals, objectives, and strategies to maintain current populations and perhaps facilitate population growth of these species in the state of Kansas.

II. SPECIES ACCOUNT: PALLID BAT

A. Taxonomy and Physical Description of Antrozous Pallidus:

The first valid description of the pallid bat, *A. pallidus*, was by LeConte in 1856. There are six recognized subspecies of the pallid bat, including: *A. p. bunkeri*, *A. p. koopmani*, *A. p. minor*, *A. p. pacificus*, *A. p. packardi*, and *A. p. pallidus* (Hermanson and O'Shea, 1983). The species was described in Kansas by Hibbard (1934) as *A. bunkeri*, but further investigation showed that it was actually a subspecies of *A. pallidus*, therefore, it was given the subspecies status of *A. p. bunkeri* (Sparks and Choate 2000).

The pallid bat is named for its pale pelage. Along with its notably large ears, the tragus is long, slender, pointed at the tip, and extends more than one-third of the pinna. The muzzle of this bat is said to resemble a pig snout surrounded by several modified hair follicle glands that secrete a musky odor. This particular odor is considered a defensive strategy against predators (Hermanson and O'Shea 1983). Dental formula of the species is 1/2, 1/1, 1/2, 3/3 (Hermanson and O'Shea 1983). The pallid bat is categorized in the following taxonomic groups: class Mammalia; order Chiroptera; suborder Microchiroptera; family Vespertilionidae; subfamily Vespertilioninae (Hermanson and O'Shea 1983).

A. pallidus has a total length ranging from 92 mm to 135 mm, with a weight range of 13.6 g to 28.9 g. Females are heavier than the males for parts of the year during pregnancy, in which young females bats give birth to single offspring and more mature females can have multiple offspring. Males have larger wings and larger mean lengths of the head and body (Williams and Findley 1979). Flight speed for the species averages 14.3 kmh. Echolocation calls are frequency modulated, sweeping from 70 kHz to 25 kHz in 1 to 2 ms (Hermanson and O'Shea 1983).

B. Historical and Current Distributions:

A. pallidus inhabits western North America, ranging from British Columbia south throughout much of Mexico (Fig. 4-1). An isolated subspecies, *A. p. koopmani*, is present on the island of Cuba. Its northeastern limit in the contiguous 48 states reaches Kansas, where it occurred rather infrequently. In Kansas the species only is known from Barber County (Sparks and Choate 2000; Fig. 4-2) within the Red Hills region, where this species utilizes crevices in cliff faces as roosts (Chapter 3).

Distributional trends of this bat are not well understood in Kansas due to the rarity or inconspicuous nature of this nocturnal volant mammal. This species was said to have been burned from an overhang near the entrance to May's Cave in 1964 (Sparks and Choate 2000). After devastation of this colony, small groups of individuals were said to have escaped and redistributed within the region. Additionally, a large maternity colony

Figure 4-1 Range map of *Antrozous pallidus* in North America (Hermanson and O'Shea 1983).

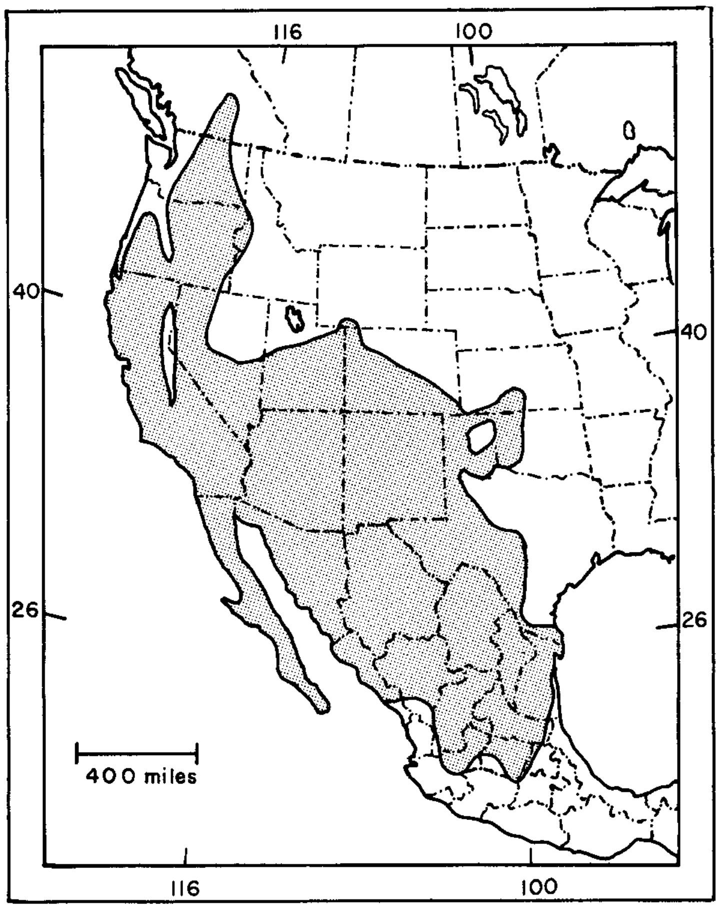
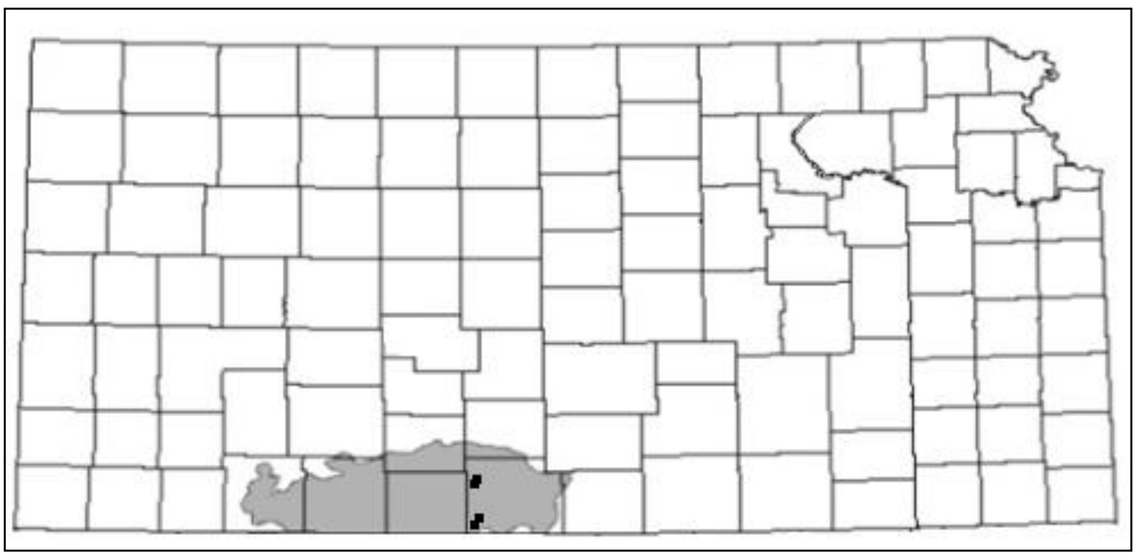

116
100
40
40
26
26
400 miles
116
100

Figure 4-2. Historical distribution of *Antrozous pallidus* from specimens collected in the Red Hills of Barber County, Kansas. (Figure adapted from Sparks and Choate 2000 and Prendergast et al. 2010).



was observed in a basement of a barn within the cracks of the underlying foundation (Jones et al. 1967). Since, small winter hibernating groups of <12 individuals have been documented in a crevice near the “Natural Bridge” in Barber County, though this colony is absent in some years (Prendergast et al. 2010). That hibernaculum remains as the furthest recorded northern distribution of this species in Kansas. Few pallid bats had been captured in nets near Natural Bridge (Sparks and Choate 2000) prior to 2009.

An intensive netting effort (Chapter 3) had live-captured ten pallid bats within the state of Kansas in 2009 and 2010, including two female pallid bats, and one pregnant bat tracked to a roost, in 2010. This suggests the bat is perhaps more abundant in Kansas than previously considered, and that maternity colonies are likely present in the state. The overall distribution of this bat in Kansas still remains unclear.

C. Diet:

A. pallidus typically relies on ground dwelling arthropods for prey, but may occasionally take some insects in flight (Bell 1982). Large arthropods such as scarab beetles (Scarabeidae), ground beetles (Tenebrionidae), short-horned grasshoppers (Acrididae), ground crickets (Gryllacrididae), and scorpions (Vejoridae) make up a large percentage of this bat’s diet (Hermanson and O’Shea 1983). Prey is also gleaned from vegetation such as cicadas (Cicadidae), katydids (Tettigoniidae), praying mantids (Mantidae), and sphingid moths (Sphingidae) (Vaughan and O’Shea 1983). Prey items are typically larger than 17 mm in length (Sparks and Choate 2000). This bat is considered an insectivorous bat, but they are in no way limited to these food types and will take a variety of prey including the occasional small lizards (*Phrynosoma douglassi*) and small rodents, and *Perognathus flavus*) (Bell 1982, O'Shea and Vaughan 1977) other bats in captivity (Engler 1943). This bat often feeds at night roosts apart from other members where they will protect and consume their food (Sparks and Choate 2000).

D. Habitat Description:

Roosting Habitat

A. pallidus typically roosts in rocky crevices and outcroppings (Orr 1954, Twente 1955, Hermanson and O'Shea 1983). Although this bat may use caves for roosting habitat (Dalquest and Walton 1970); however, little evidence has shown this to be the case. Crevices within caves and cliff faces are most often used for roosting (Orr 1954, Twente 1955). This bat may be opportunistic in the use of many different types of summer roosts including buildings (Jones et al. 1967), bat boxes (Tuttle and Hensley 1993), stone piles (Racey 1933), tree hollows (Orr 1954), and even stacks of burlap sacks (Beck and Rudd 1960). Both summer and winter roosts have typically been identified as crevices (Twente 1955, Vaughan and O'Shea 1976).

During summer months maternal colonies consist of primarily females and their offspring (Twente 1955, Vaughan and O'Shea 1976); although, other summer colonies of mixed gender have been documented (Orr 1954, Packard and Judd 1968, Vaughan and O'Shea 1976). During summer months when females and males are roosting apart (e.g., bachelor colonies) these gregarious males can cohabitate in groups of up to 60 individuals (Dalquest 1947).

Several roost sites of pallid bats during summer in the Red Hills of Kansas and Oklahoma have recently been identified (Chapter 3). These were described as cracks within a cliff walls running perpendicular into cliff faces. Most crevices were predominately horizontal. Exfoliations of hollowed domes protruding from—and parallel to—cliff face were also used by *A. pallidus*. These bats have been documented to roost solitarily in small aggregations within the Red Hills as well as other locations within its range (Chapter 3). The only known wintering roost location in Kansas is a crevice near Natural Bridge (Sparks and Choate 2000, Prendergast et al. 2010).

Foraging Habitat

This species is considered a desert bat, prefers open habitat and is less abundant in evergreen and mixed forests (Hermanson and O'Shea 1983). These bats are common in arid regions with rocky outcrops particularly near water (Hermanson and O'Shea 1983). It commonly forages on the ground and gleans insects from vegetation (Hermanson and O'Shea 1983). This bat hunts mainly by listening passively to the footsteps and other sounds their prey is emitting (Bell 1982, Fuzessery et al. 1992). Open ground with exposed rock and dirt and woody edge near these habitats may be primary hunting grounds for these bats (Hermanson and O'Shea 1983, Fuzessery et al. 1992, Ball 2002). Such habitats improve the odds for capturing their preferred prey with little obstruction. *A. pallidus* with its white pelage may be well camouflaged in its foraging habitat. In riparian areas of the Red Hills of Kansas and Oklahoma, *A. pallidus* was regularly captured in nets often near wooded vegetation offering some canopy cover; however, capture attempts were not made in uplands. It was not known whether these areas were used for foraging or merely as travel lanes (Chapter 3). The home range of this species has been investigated by Ball (2002) showing consistent flight away from roosts to foraging areas 6.5 and 8.5 km away; additionally, movements between caves have been recorded up to 30 km (Hermanson and O'Shea 1983). In 2009 and 2010, eight pallid bats were tracked to roost locations in Kansas (Chapter 3). These distances from roosts to nets (suspected foraging areas) ranged from 120 m to 1200 m. A total of seven summer roosting locations were identified and described in that study (Chapter 3).

E. Associated Species and Community:

The distribution of *A. pallidus* is wide spread and associated with the Chihuahuan Faunal Element (Armstrong et al 1986). *A. pallidus* has been shown to share its roosts with other species of bats; however, only two species have been recorded roosting among pallid bats: *Tadarida brasiliensis* and *Myotis yumanensis* (Hermanson and O'Shea 1983). *A. pallidus* has many known commensals and parasites over its entire range; but, there are only 2 species of parasites known to occur on this bat species in Kansas. These parasites include the chiggers (Trombidiformes) *Trombicula twenti* and *T. hoplai* and the bat tick (Ixodida) *Ornithodorus kelleyi* (Sparks and Choate 2000). This species is very vulnerable to predators, especially due to its roosting and foraging methods. Snakes and owls have been documented to prey upon this species (Hermanson and O'Shea 1983).

F. Population Sizes and Trends:

In Kansas the population of *A. pallidus* has always been rare. Yet in 1964, a colony of around 200 pallid bats was said to have been burned out from an overhang near the entrance to May's Cave in Barber County (Jones et al. 1967, Barbour and Davis 1969). Only a few of these survived and were later reported to be roosting in a rock crevice below a Natural Bridge until 1980 (Sparks and Choate 2000). *A. pallidus* were observed by S. D. Roth during winters at the crevice near Natural Bridge periodically from 1976 to 2005 (Prendergast e t al. 2010). This was the only place pallid bats have been regularly observed in Kansas since the early 1960's (Prendergast et al. 2010). Abundance data from that crevice exhibited no trend in numbers over time in that single known hibernaculum (Prendergast et al. 2010). The latest occupied hibernaculum was observed in the winter of 2009 (J. C. Miller, Emporia State University, personal observation).

G. Reproduction and Survival:

Copulation occurs somewhere between the months of October and December (Orr 1954). The sperm acquired during this copulation is stored within the reproductive tract of the female until spring when ovulation occurs (Hermanson and O'Shea 1983). In *A. pallidus,* maternal colonies begin to form in early April. Embryonic development is subject to environmental temperatures, and gestation periods average 63 days starting as early as May (Hermanson and O'Shea 1983). Parturition occurs in late June or early July where females give birth to one or two pups; although, there are some cases of three embryos have been recorded (Orr 1954). Pups at very early stages emit localized isolation calls to mothers for easy location (Brown 1976). This plays an important role in the mother's identification of her pup among other bat young at maternity colonies. Neonates develop their ability to hear low frequency sounds in less than 24 days, unlike other bat species of similar size and age (Brown et al. 1978). Pups are generally volant by the time they reach six weeks (Sparks and Choate 2000). Normal flight is possible at 42 days of age, but has been observed as early as 33 days of age with short flights beginning at four to five weeks of age. At birth the sex ratio is 1:1. Individuals of this species have been recorded surviving up to nine years in captivity (Brown et al. 1978).

H. CONSERVATION STATUS

Potential Threats to Population Viability:

The pallid bat has been described as the most endangered bat in the state of Kansas (Sparks and Choate 2000). Disturbance from human interaction and the loss of roosting and foraging habitat might be the greatest threats to this bat in Kansas. The largest known colony of pallid bats in Kansas was virtually destroyed by ranch hands, when individuals were burned form their roosting location (Sparks and Choate 2000). Female pallid bats have shown to select horizontal crevices for maternity roosting, likely for thermoregulation and retrieval of fallen offspring (Vaughan and O'Shea 1976), and it is these maternity roosts may need to receive greatest protection. The spread of white nose syndrome (WNS) in nearby states (Sleeman 2010) may threaten bat species in the Red Hills. Human activities that could facilitate the spread of *Geomyces destructans* should be limited, this includes use of sterile methods while conducting field research.

Other factors such as the loss of roosting and foraging habitat (Racey and Entwistle 2002, Kunz and Lumsden 2003), disturbance to roosts (Tuttle 1979), and the construction of local wind-power facilities (Arnett et al. 2010), could also affect population viability of bats in the Red Hills. Alteration to foraging habitat and nearby water sources may also threaten this species by increasing commuting distances to suitable foraging sites, decreasing survivorship of newly volant young (Ransome 1990; Tuttle 1976), increasing rates of predation (Lewis 1996), and perhaps abandonment of preferred roost sites closer to suitable foraging habitat (Tuttle 1979). This gleaning bat may also have potential threats from the encroachment of excessive aerial clutter, such as trees, near roosting and foraging sites, which may limit mobility at these locations (Norberg and Rayner 1987, Walsh and Harris 1996). Additionally, with recent advancement in alternative energy, many more wind power facilities are being built across the Kansas landscape, and many scientists have noted an alarming number of bat mortalities from spinning wind turbine blades (Arnett et al. 2010, Barclay et al. 2007, Kunz et al. 2007). Construction of wind turbine facilities, within or adjacent to the Red Hills might have deleterious effects on all bat species including this SINC. Many bat mortalities have been associated with migratory species (Arnett et al. 2008); though, local hibernating bat species have also been affected (Arnett et al. 2008). With already low numbers of SINC in the Red Hills, wind harnessing facilities may have much more of an effect on these smaller populations. It is not known how vulnerable *A. pallidus* is to wind-turbine fatality.

Protective Laws or Special Conservation Status:

Federal:

A. pallidus is offered no protection under federal law.

State:

In Kansas the *A. pallidus* is an eleventh-ranked, tier 1 species in the state's comprehensive wildlife conservation plan (Wasson et al. 2005) and is listed as a SINC by

KDPWT. Under the latter listing the species is provided no legal protection. The listing does, however, inform those who may be working around or interacting with the species that there is a reason to be concerned with how their actions may affect the species.

Research Needs:

Although recent research has resulted in more information about *A. pallidus* in Kansas (Chapter 2), I suggest more research in areas such as mating behavior, patterns of dispersion while foraging, social organization and behavior, age-specific survival rates and life expectancy, and seasonal and lifetime fecundity. Improved home range estimates (Ball 2002) would allow us to estimate possible use of caves and foraging regions that may be critical for *A. pallidus* colonies. A better understanding of the number of females and maternity roosts and detailed demographic information would allow for more robust population modeling. The susceptibility of *A. pallidus* to WNS and its association with the fungus *Geomyces destructans* needs better understanding. The potential effects from wind energy developments is also poorly understood for this species. This information is very important for understanding population viability of this species in the Red Hills. Such research needs are partly the subject of the management plan below.

III. SPECIES ACCOUNT: TOWNSEND'S BIG-EARED BAT

A. Taxonomy and Physical Description of *Corynorhinus townsendii*:

Cooper in 1837 made the first valid description of this species at which time it was given the name *Corynorhinos townsendii* in honor of Dr. John K. Townsend (Schwartz and Schwartz 2001). The bat was moved into the genus *Plecotus,* consisting of bats in the

Americas and Europe, and *Corynorhinos* was viewed as a subgenus. Although, further phylogenetic studies (Frost and Timm 1992, Tumilson and Douglas 1992, Bogdanowicz et al. 1998) revealed that the bats thought to comprise the genus *Plecotus* actually represented three genera. Therefore, the original genus for the species was re-established to present us with the current name *Corynorhinus townsendii* (Sparks and Choate 2000). There are four known subspecies, two considered eastern and two considered western subspecies. The two eastern subspecies are *C. t. virginianus* and *C. t. ingens*, both of which are endangered. The two western subspecies are *C. t. pallescens* and *C. t. townsendii*, which are of special concern (Harvey et al. 1999). The only subspecies that has been recorded occurring within Kansas is *C. t. pallescens* (S. Roth, personal communication).

The very large ears are the most conspicuous feature of *C. townsendii*. The tragus has a length that is approximately one half the length of the ear. The tragus is very slender, but is rounded near the tip. Both the membranes of the tail and wings are hairless. The fur that is present on the body is long and soft. The color of the bat on top is a buff tan to brown while underneath it is a pinkish buff color. The dental formula of the species is 2/3, 1/1, 2/3, 3/3 (Schwartz and Schwartz 2001). Townsend's big-eared bat is categorized in the following taxonomic groups: class Mammalia; order Chiroptera; suborder Microchiroptera; family Vespertilionidae; subfamily Vespertilioninae (Kunz and Martin1982).

The species has a total length between 90 mm to 112 mm, with a weight ranging between 5 g and 13 g. The weight of females increases during the fall and winter months. Females are said to be larger in size than males (Kunz and Martin 1982) and significant differences in forearm length were reported in New Mexico (Williams and Findley 1979). The flight speed of individuals of the species was recorded between 2.9 and 5.5 m/s (~6 mph to 12 mph). Echolocation calls are frequency modulated, and are emitted at sweeping frequencies of 20-90 kHz, at a rate of 1 to 2 ms (Kunz and Martin 1982).

B. Historical and Current Distributions:

C. townsendii occurs throughout the western part of North America, extending from the southwestern Canada southward throughout much of Mexico (Fig. 4-3). There are a few isolated populations extending east through the Gypsum Cave region of Texas, Oklahoma, and Kansas and the Limestone Cave region through Arkansas, Missouri, Oklahoma, and the disjunct *C. t. ingens* in the central Appalachians (Kunz and Martin 1982). There has been no obvious change in distribution of *C. townsendii* in the last 300 years (Sparks and Choate 2000). In Kansas, the species only occupies three counties: Barber County, Comanche County, and Kiowa County, (Fig. 4-4) Sparks and Choate (2000) within the Red Hills region, where the species utilizes Gypsum Caves as roosts (Prendergast et al. 2010).

C. Diet:

C. townsendii relies primarily on members of Lepidoptera (moths) for food, but will also take beetles, leaf hoppers, and small flies (Kunz and Martin 1982). The primary foraging grounds for the species lies on the edge of riparian vegetation (Fellers and Pierson 2002). Upon catching prey the bats will often land at a night roost to feed (Sparks and Choate 2000).

Figure 4-3 Range map of *Corynorhinus townsendii* in North America (Kunz and Martin 1982)

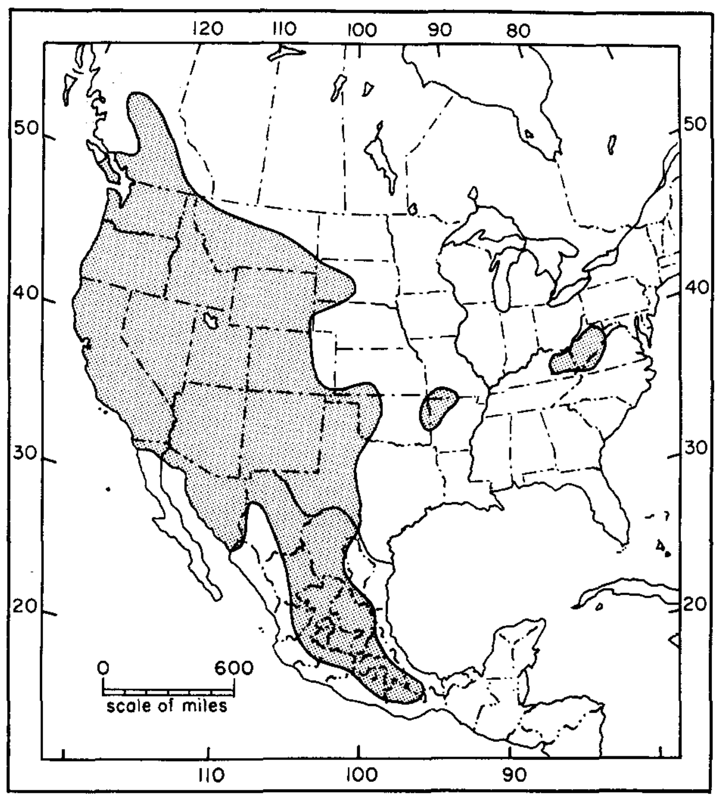
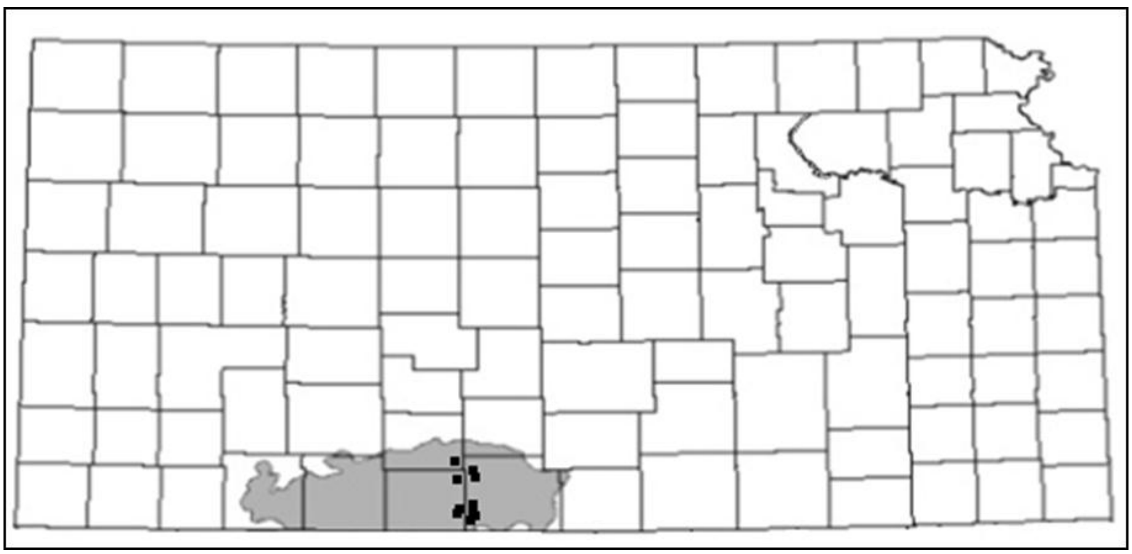

120
110
100
90
80
50
40
30
20
0
600
scale of miles
110
100
90

Figure 4-4 Historical distributions of *Corynorhinus townsendii* from specimens collected in the Red Hills of Barber, Comanche, and Kiowa Counties, Kansas. (Figure adapted from Sparks and Choate 2000 and Prendergast et al. 2010)



D. Habitat Description:

Roosting Habitat

C. townsendii relies on caves for roosting habitat. Different roost types have been used by *C. townsendii* including caves, mines and buildings (Humphrey and Kunz 1976), Twente 1955).

During summer months, maternal colonies consist of only females and their offspring, and generally utilize warmer areas of the caves, typically near openings to assist in thermoregulation and rapid development of offspring. Other colonies (e.g., bachelor colonies) will often disperse to utilize a variety of roosts (Schwartz and Schwartz 2001).

During the winter months this bat has been reported to hibernate singly and in small and large clusters in Kansas (Humphrey and Kunz 1976, Prendergast et al. 2010). These clusters range from a few bats to a few dozen, rarely exceeding 100 individuals (Humphrey and Kunz 1976). During winter, this bat tends to utilize the coldest, but most climatically labile regions of caves (Twente 1955, Humphrey and Kunz 1976); although reports of responding to temperature changes within caves may cause them to move to more stable regions of a cave if temperatures are not suitable (Humphrey and Kunz 1976). Additionally, this species has been reported to feed in, as well as move to, different hibernacula during wintering months (Kunz and Martin 1982, Clark et al. 2002). These bats also exhibit a large degree of site fidelity in returning to the same hibernacula year after year (Pearson et al. 1952).

Foraging Habitat

C. townsendii is a very strong and agile flyer that is often seen flying near wooded areas (Caire et al. 1984, Fellers and Pierson 2002). Key foraging habitat for this species consists mainly of woodland edge habitat within riparian corridors (Caire et al. 1984, Fellers and Pierson 2002). These bats have also been reported using edge habitat for transient movements and to avoid open grazed pastureland, which may reduce the threat of predation (Fellers and Pierson 2001). This bat forages for insects during flight as well as gleaning insects form vegetation. These riparian corridors may provide this bat with high quality foraging habitat and may also provide shelter from heavy winds (Caire et al. 1984) and potential aerial predators (Verboom and Spoelstra 1999).

In a recent study in the Red Hills (Chapter 2) *C. townsendii* was found more commonly in more heavily wooded portions of riparian corridors. Distances traveled from roosts to foraging areas by this species were within a few km (Brigham 1991, Entwistle et al. 1996) to over 30 km (Pearson et al. 1952). In 2009, I captured and radioed one male *C. townsendii*; it was tracked 546 m away from the netting site (J. C. Miller, unpubl. data).

Home ranges for this species in Kansas are poorly understood. However, other studies of the subspecies *C. rafinesquii* have shown average home ranges in South Carolina at 93.1 ha (Menzel et al. 2001) and in Kentucky at 160.6 ha (Hurst and Lacki 1999). This species has been described to be a relatively sedentary species that does not migrate (Barbour and Davis 1969, Humphrey and Kunz 1976).

E. Associated Species and Communities:

The distribution of *C. townsendii* is so wide spread it was not associated to a faunal element (Choate et al. 1994). It was suggested that it be included in the Chihuahuan Faunal Element like that of *A. pallidus* (Sparks and Choate 2000); however, this holds true if only the three western subspecies are considered (Sparks and Choate 2000). Three species of bats can be regularly observed occupying similar areas within gypsum caves of the Kansas Red Hills, including cave myotis (*Myotis velifer*), big brown bat (*Eptesicus fuscus*), and the tri-colored bat (*Perimyotis subflavus*) (Prendergast et al. 2010). Other bats associated with the species in the western portion of its range include *Myotis leibii* and *Myotis californicus* (Kunz and Martin 1982). There are also many commensal and parasitic organisms known to be associated with the species. Only two are known for *C. townsendii* in Kansas, which are the bat flies *Trichobias cornorhini* and *T. major* (Sparks and Choate 2000).

F. Population Sizes and Trends:

In Kansas the population of *C. townsendii* was diminishing through the 60's and early 70's during which time extensive mark and recapture studies were ongoing, apparently having a negative effect on the species (S. Roth, personal communication). Since this time, researchers have become more aware of the effects of human disturbance on this species, and have begun using less invasive methods for research. This species has maintained regular population sizes within Kansas (Adams 1995) and there appears to be no serious decline in this species from a long-term hibernation survey in Red Hills caves (Prendergast et al. 2010).

G. Reproduction and Survival:

In *C. townsendii* mating can take place in fall, winter, or spring. Sperm is stored by females until they awake from hibernation (Weyandt et al. 2005). The gestation occurs during spring and lasts between 56-100 days, depending on how the maternal colony is arranged (Kunz and Martin 1982). Gestation is shorter when females cluster together because they are able to maintain a higher body temperature (Schwartz and Schwartz 2001). These maternal colonies can range from as few as 15 to as many as 550 females (Sherwin et al. 2000). Females give birth sometime between May and June to a single pup and rarely twin pups (Hermanson and O'Shea 1983). During parturition the females hang upside down and spread the wing and tail membranes to catch emerging young (Schwartz and Schwartz 2001). These neonates weigh 1/10 ounce at birth. Pups are left behind at the maternity roost during the night while the mother forages, but returns each day to provide milk (Schwartz and Schwartz 2001). The young bats can produce vocal sounds within a few hours after birth, which play an important role in the mother’s identification of her pup among the masses. Within one week, the pups produce a call that is very adult-like (Kunz and Martin 1982). Young can fly at three weeks of age, but do not hunt until they are fully weaned at six weeks of age. Even though females become sexually mature by the first autumn the males do not (Kunz and Martin 1982). When these female maternity colonies start forming, the males and non-breeding females start forming bachelor colonies. At this time the males become solitary (Weyandt et al. 2005).

Bachelor colonies are typically made up of one or two bats, but can be as large as seven (Sherwin et al. 2000). Life expectancy for this bat has been recorded up to 16 years in the wild (Schwartz and Schwartz 2001).

H. CONSERVATION STATUS

Potential Threats to Population Viability:

The greatest threat to *C. townsendii* may be human disturbance (Humphrey and Kunz 1986, Sparks and Choate 2000, Schwartz and Schwartz 2001); although, changes to foraging and roosting habitat may also detrimental to this bat species. Habitat loss, degradation, and fragmentation can have a profound impact on the wellbeing of bat species (Tuttle 1979, Racey and Entwistle 2002, Kunz and Lumsden 2003). *C. townsendii* have been documented avoiding open areas (Fellers and Pierson 2002) and to use riparian forested regions for foraging (Caire et al. 1984, Fellers and Pierson 2002). Increased distance between anthropogenically fragmented foraging habitats and roosting habitats may decrease survivorship of young at maternal roosts (Tuttle 1979). Therefore, habitat alteration via removal of vegetative cover may be detrimental to this bat species. Construction of local or adjacent wind facilities could cause mortality to this bat species (Kunz et al. 2007, Arnett et al. 2008).

Disturbance to roosting habitat during the summer months make this species particularly vulnerable when females have formed maternal colonies (Humphrey and Kunz 1976). Disruptions of these colonies may cause the mothers to abort embryos, delay development, inhibit first year breeding, or abandon roosts and therefore young (Humphrey and Kunz 1976). Additionally, disturbance of *C. townsendii* during hibernation may cause abandonment of roost sites (Humphrey and Kunz 1976). Flight during such relocations is metabolically expensive because it may cause individuals to use stored energy reserves that are needed to complete the hibernation cycle (Humphrey and Kunz 1976, Clark et al. 1997). It has been noted by researchers that continual banding projects of the species most likely was one cause of the decrease in the species population for the state during the 1960's and 1970's (S. Roth, personal communication). When this practice was ceased and less invasive methods of monitoring were used, an increase in the population trends was observed (S. Roth, personal communication). In addition to direct disturbance by humans, the vectoring of WNS by humans or other bats into hibernacula from surrounding locations is of concern. For example, the migratory species *Tadarida brasiliensis* utilizes a large cave proximate to the Kansas border, just south of many *C. townsendii* roosting sites. Less invasive monitoring of these bats and the use of sterile methods when visiting these areas must be put into place (USFWS 2011).

With recent advancement in alternative energy, many more wind power facilities are being built across the Kansas landscape. As stated above, many scientists have noted an alarming number of bats mortalities by the direct and indirect contact of spinning wind turbine blades (Barclay et al. 2007, Kunz et al. 2007, Arnett et al. 2010). Increased construction of wind turbine facilities adjacent to or within this region could have deleterious effects on all bat species including the SINC species *C. townsendii*. Many bats succumbing to wind-power mortalities have been migratory species; although few in comparison, sedentary bats also are killed by these structures such as *E. fuscus* and *M. lucifugus* (Arnett et al. 2008). More research is needed on the vulnerability of *C.*

townsendii to wind turbine mortality; however, Caire et al. (1984) reported flight heights for *C. townsendii* in Oklahoma at 20 to 60 m.

Protective Laws or Special Conservation Status:

Federal:

C. townsendii in Kansas is offered no protection under federal law. The two eastern subspecies of *C. townsendii* are listed as endangered by the U.S. Fish and Wildlife Service (FWS).

State:

In Kansas, *C. townsendii* is a 12th ranking, tier 1 species in the state's comprehensive wildlife conservation plan (Wasson et al. 2005) and is listed as a SINC by KDWPT . Under this listing the species is provided no legal protection. The listing does however inform those who may be working around, or interacting with the species that there is a reason to be concerned with how their actions may affect the species in the state of Kansas.

Research Needs:

There is much knowledge about the life history of the species (Humphrey and Kunz 1976, Kunz and Martin 1982); still, there are certain areas that appear to contain gaps within this knowledge. Perhaps the largest unknown aspect of the bats lives are of males in bachelor colonies. Questions arise about male roosting bats forming bachelor colonies after they leave females. These males often disperse and create difficulties in research. For this reason I have little information about the behavior and ecology of the males during summer months. Furthermore, the use of nocturnal and feeding roosts of this bat remains limited. Other pertinent information for this species concerns predation on these organisms, home range sizes, age-specific survival rates and life expectancy, and seasonal and lifetime fecundity. Identification of predators and predation rates may give insight into threats not directly related—or related—to human activity. Home range estimates would allow us to estimate possible use of caves and foraging regions that may be critical for certain colonies of bats. The susceptibility of *C. townsendii* to WNS and its association with the fungus *G. destructans* needs better understanding. The potential for impacts from wind energy developments is also poorly understood for this species. This information is very important for understanding population viability of this species in the Red Hills. Such research needs are partly the subject of the management plan below.

IV. RECOVERY OF THE PALLID AND TOWNSEND'S BIG-EARED BATS IN KANSAS

There has been a perpetual concern about listing species with peripheral populations in limited political geographies, such as states. Arguments for the protection of such peripheral populations can be made based on an observation that the ranges of many endangered mammal species have collapsed toward the edges of their historic range distributions, rather than toward range cores (Lomolino and Channel 1995). The natural rarity of *A. pallidus* and *C. townsendii* within Kansas has contributed to their SINC designation in the state, a status that might not—and likely should not—change. Prevention of more dire listing statuses of these species within the state should be the goal, though some (Sparks and Choate 2000) have recently argued for upgrading listings of these species as state-level threatened (or *A. pallidus* as state endangered). An aim for recovery of *A. pallidus* and *C. townsendii* in Kansas should be the conservation of at least representative distributions and abundances of these species within the state of Kansas. It is unlikely that their ranges will expand within the state, but such expansions should not be hindered. However, "pre-settlement" ranges and population sizes of either species within Kansas are not precisely known, and in most cases it is uncertain how previous human disturbance has affected these species (Humphrey and Kunz 1976, Clark et al. 1997, Sparks and Choate 2000). These bat species might be affected by continuous changes in the Red Hills landscape, such as woody encroachment into prairies (Coppedge et al. 2001, Briggs et al. 2002), removal of wooded vegetation, wind power development, and emerging wildlife diseases (e.g., WNS). By limiting human disturbance to roosting crevices and caves, and cautiously managing landscape changes, we may allow these species to continue to maintain healthy populations.

"Recovery" of *A. pallidus* and *C. townsendii* populations within Kansas might be maintenance of status quo, if their populations have not undergone significant changes. However "recovery" may be defined, continuous monitoring of the distribution and abundance of these species is strongly recommended. Continuous summer netting data as well as surveys at hibernacula could be used to represent population trends (Prendergast et al. 2010) and perhaps distributional limits of these bats within Kansas. All monitoring of bat species anywhere in North America should only be done by professional biologists informed about protocols to minimize the spread of WNS and having knowledge and proper training of animal capture and handling.

Below are listed general goals, objectives, and strategies for achieving those conservation objectives, to address the overall goal of preventing the further endangerment of *A. pallidus* and *C. townsendii* in Kansas. "20___" in objective statements indicate uncertain deadlines to be determined by KDWPT upon adoption of the plan by that agency.

Goals, Objectives, and Strategies:

Goal 1. Ensure the stability of current populations by protecting roosting and foraging habitat.

Objective 1.1. Implement protections of existing roosting habitat known to support these species by 20___.

Strategy1.1.1. Limit access to all known roost caves and crevices during most sensitive periods of each species' annual cycle, first and foremost during maternal colony periods and also during hibernation. Gates could be used at openings of caves to restrict human access. Gate types, and possible disturbance to bats during gate construction, must be considered before implementation. Internal gates described by Martin et al. (2000) appear to have no negative impact on Ozark big-eared bats (*C. townsendii ingens*). Additionally, attention should be given to the placement of gates with concern toward the soft parent material (gypsum) in the Red Hills that could deteriorate during or after gate construction and change microclimatic conditions within caves, or cave accessibility to bats. Also, temporary disturbance due to the construction of internal gates described by Martin et al. (2000) appeared to have no negative impacts on the inhabiting colonies. Additionally or alternatively, placing warning signs at openings of caves is recommended. Incentives to landowners for the above alterations might be provided through an applicable conservation easement or project funds. Access to caves by chiroptologiocal and speleological researchers and other conservation professionals should be allowed, pending landowner permission, if strict protocols are followed for limiting disturbance and vectoring WNS.

Strategy 1.1.2 Alternate uses of existing caves for guano harvesting or gypsum mining should be discouraged. Spelunking expeditions or other activities that are not research or conservation based should also be discouraged at caves that are known rooting sites of SINC bats. Cautions regarding spelunker activity have already been made by KDWPT regarding spread of WNS (http://www.kdwp.state.ks.us/news/KDWPT-Info/News/Weekly-News/6-3-2010/RARE-FUNGUS-COULD-INFECT-KANSAS-BATS- Accessed 21 July 2011). Similar cautionary statements could be made more generally to include bat guano and gypsum mining. Harvesting of guano or any materials that would facilitate cave visitation should also be halted at known roosting sites. Limiting these activities within these cave systems would decrease human disturbance and perhaps the spread of the WNS.

Strategy 1.1.3. State and federal agencies should purchase land or obtain conservation easements on land with gypsum caves with known roost locations to prevent development such as mining projects which could destroy bat roosting habitat. This is a larger scale strategy than Strategy

1.1.1 which pertains specifically to cave entrances. Applicable easement programs should be sought.

Objective 1.2. Limit loss of riparian habitat adjacent to and surrounding known roosting locations for SINC bats, this includes woody vegetation, bank vegetation and avoiding disruption to flow regimes; protections should be implemented by 20___.

Strategy 1.2.1. Conservation officials should limit complete clearing of riparian woodland vegetation when implementing programs that control of target woody encroachment. Such control of woody encroachment in uplands is desirable for other biological reasons (e.g., grassland birds); however, riparian habitat is important for many bats species and these areas were historically wooded to some degree. Mechanical removal of woody encroachment in uplands should make minimal disturbance to soil and hydrology to maintain biotic integrity of streams used by bats for drinking and foraging. Invasive salt cedar (*Tamarix*) should be removed completely from riparian zones.

Strategy 1.2.2. Land owners should be encouraged by the conservation community to maintain heterogeneous amount of cover and open space as well as all live or dead deciduous tree species within riparian corridors, as diversity of plant life creates a diversity of insects (Murdoch et al .1972) and cover for bat species.

Strategy 1.2.3. Land owners should limit reservoir inundation of ephemeral streams that likely contribute to insect populations and sheltered drinking habitat for bats. Key foraging habitat for bats consist of both water and surrounding riparian vegetation. Promoting regular flow regimes, increased insect diversity and density, as well as healthy vegetation, will ensure that these areas remain key foraging habitats for bats.

Objective 1.3. Continue to warn developers of prospective wind-power facilities of the occurrence of SINC and other bats in the Red Hills region.

Strategy 1.3.1. Continue to support the Kansas Natural Resource Planner (http://www.kars.ku.edu/maps/naturalresourceplanner/ - Accessed 30 June 2011), administered by the Kansas Biological Survey, which notes the Red Hills region as a biological sensitive area, largely due to the region's bat fauna.

Goal 2. Improve biological knowledge of *A. pallidus* and *C. townsendii.*

Objective 2.1. Determine and monitor continuously the abundance and extent of distribution of SINC bats during summer months starting May 20___. This will constitute a long-term survey to investigate trends in distribution and abundance that will inform conservation of the SINC bats.

Strategy 2.1.1. Mist net surveys should be designed and carried out regularly by state, federal, and/or universities during summer months within the Red Hills region of Kansas, in cooperation with land owners. Easements and other financial support may be offered in return for landowner cooperation, given available funding. Netting should take place within riparian corridors where bat activity is highest for most species. All bat specimens during summer that are clearly symptomatic of WNS should be collected for necropsy and routine scoring observations of WNS should be made on all bats captured (Reichard 2008).

Strategy 2.1.2. Roost selection should be further studied using radio telemetry by individuals involved with netting surveys in the Red Hills. By attaching radio transmitters onto selected individuals and following individuals for the life of the transmitter, the identification and characterization of roosts—including maternity—can be done.

Strategy 2.1.3. Acoustic monitoring stations can be established and carried out regularly by state, federal, and/or universities during summer months within the Red Hills region of Kansas, in cooperation with land owners. Easements and other financial support may be offered in return for landowner cooperation, given available funding. This acoustic collection may take place in uplands and lowlands within areas of interest including within riparian habitat to supplement mist-net monitoring of bat species.

Objective 2.2. Continue winter hibernation surveys and monitoring for WNS. This will also allow for monitoring of changes in distribution and abundance.

Strategy 2.2.1. Continue and expand surveys (used for Prendergast et al. 2010) for bat numbers in hibernacula (e.g., caves, crevices, and buildings) during winter months to investigate population trends and distributional shifts. Researchers from universities, agencies, or other cooperating institutions, should continue to positively develop working relationship with landowners and follow recommended survey protocols that limit the spread of WNS (USFWS 2011). Visits to caves should not occur more than once every two years to minimize disturbance to hibernating bats.

Strategy 2.2.2. Those monitoring bats in hibernacula should collect all bat specimens during winter that are clearly symptomatic of WNS and submit the specimens for tests of WNS and *G. destructans.* (Reichard 2008) using observations made during surveys. Soil samples could also be routinely taken to test for the presence and distribution of the fungus *G. destructans* (putative agent of WNS).

Objective 2.3. Surveys of bat activity should be made at prospective and probable wind power sites by 20___.

Strategy 2.3.1. State, federal, university biologists, or environmental consulting firms should deploy acoustic detectors on towers representing heights of wind turbine blades within areas highlighted as potential wind sites by Kansas Natural Resource Planner (http://www.kars.ku.edu/maps/naturalresourceplanner/).

Objective 2.4. Determine the genetic distinctiveness of the SINC bats in Kansas by 20___.

Strategy 2.4.1. Biopsy wing punches collected during mist net surveys could be used for molecular data to perform phylogeographic comparisons of *A. pallidus* and *C. townsendii* to conspecifics in other regions of the western U.S. Similar tissue samples could be obtained from cooperating biologists in other states.

Goal 3. Foster public appreciation of *A. pallidus* and *C. townsendii* and other bats in the Red Hills.

Objective 3.1. Implement programs to educate the general public, landowners, and law enforcement about the SINC bats, *A. pallidus* and *C. townsendii*, as well as other bats in the Red Hills by Aug. 20___.

Strategy 3.1.1.State conservation officials and other biologists give public seminars of ongoing research on these species and importance of their protection. These might include use of captive bats for hands-on experiences.

Strategy 3.1.2. Create artificial roosting and foraging exhibits for live-bat species of Kansas including *A. pallidus* and *C. townsendii*, at local zoos (e.g., Wichita) for research and educational purposes. Specimens could be transported from wildlife rehabilitation centers in Kansas or cooperating centers from other states where these SINC species are more common.

Strategy 3.1.3. State affiliates should provide education programs to children, such as boy scouts, girl scouts, 4-H, etc. to engender interest and awareness in SINC bats.

Strategy 3.1.4. Conservation affiliates should further educate the conservation community in Kansas on bat biology and their concerns through regional conferences, such as the Kansas Natural Resource Conference (KNRC), Kansas Academy of Science conference, and other public events.

Strategy 3.1.5. Encourage education programs for individuals gaining access to the caves in which information on WNS-prevention protocol is communicated. This could involve members of the Kansas Speleological Society.

Strategy 3.1.6.Create a pocket pamphlet on *A. pallidus* and *C. townsendii* and other bats in the Red Hills (e.g., similar to those produced through the Great Plains Nature Center) and widely distribute these and current publications, such as the Bats of Kansas. Recipients of the publications should include schools, nature centers, and offices of agencies frequented by the public (e.g., KDWPT, FWS, and U.S. Army Corps of Engineers).

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CHAPTER 5

SUMMARY

In Chapter 2, Acoustic and netting data were collected for bats in the Red Hills to help describe habitat use by these organisms. According to our data, *M. velifer* was the only species showing relationships with measured habitat variables, where it was more common in areas of higher canopy cover and at lower elevations. The occurrences of other bat species were determined not to be reliably influenced by any habitat variable measured. Although eight different species were captured in nets, netting data was analyzed for only three species *M. velifer*, *C. townsendii*, and *A. pallidus* (net captures > 10) in the Red Hills. My analyses revealed that canopy cover was important in positively predicting capture rates of both *M. velifer* and *C. townsendii*. Our data corroborates to the findings of Caire et al. (1984) and Fellers and Pierson (2002) indicating that these species appear to use heavier vegetated regions for foraging.

Chapter 3 describes the roost characterization of *A. pallidus* in the Red Hills. Little was known about summer roost-site characteristics of the pallid bat (*Antrozous pallidus*) in the Red Hills region of Kansas and Oklahoma. With this species listed as a Species in Need of Conservation (SINC) within the state of Kansas it is critical that more information be gathered for this organism (Sparks and Choate 2000). Ten pallid bats were radioed and 11 roost sites were identified in the state of Kansas and Oklahoma. The largest colony size that was visually confirmed at least 10 individuals. Roost structures consisted of vertical or horizontal crevices or exfoliated cliff faces. Cliff faces where roosts occurred had a generally westerly aspect with approximate lengths of roosting crevices ranging from 0.3 m to 3.2 m and approximate widths from 3 cm to 20 cm.

Approximate roost heights above talus piles ranged from 0 m to13 m. Most roost sites (*n* = 8) had no surrounding tree canopy cover or heavy vegetation.

Chapter 4 is a species recovery plan for both *A. pallidus* and *C. townsendii*. These two species ranges in Kansas represent only small portions of these bats' populations, and have the official listing as SINC in the state (Sparks and Choate 2000, Prendergast et al. 2010). The Red Hills is becoming a region of management concern for wildlife, including woody encroachment, wind development, and the prospect for white-nose syndrome (WNS) in bat populations (Coppedge et al. 2001, Briggs et al. 2002, Kunz et al. 2007, Sleeman 2010). Recommendations were made for the Kansas Department of Wildlife, Parks, and Tourism, United States Fish and Wildlife Service and others in the conservation community to research and monitor these bat species in the Red Hills and implement strategies to achieve goals to further conserve these bat populations in Kansas.

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