The over-winter ecology of lesser prairie-chickens (*Tympanuchus pallidicinctus*) in the northeast Texas Panhandle

by

Curtis A. Kukal, B.S.

A Thesis

In

WILDLIFE SCIENCE

Submitted to the Graduate Faculty
of Texas Tech University in
Partial Fulfillment of
the Requirements for
the Degree of

MASTER OF SCIENCE

Approved

Warren B. Ballard
Co-Chairperson of the Committee

Mark C. Wallace
Co-Chairperson of the Committee

Matthew J. Butler

Phillip S. Gipson

Heather A. Whitlaw

Ernest B. Fish

Ralph Ferguson
Acting Dean of the Graduate School

December, 2010

ACKNOWLEDGMENTS

I would like to take this opportunity to acknowledge several people who were instrumental in my research and this thesis. First and foremost, I would like to thank my wife Brittany. She made me coffee when I could barely move, kept me company while trapping, and helped me through all the stressors of being a graduate student. She married me and then immediately moved to the prairie to support me in my research, and I am so grateful to her.

Second, I would like to thank my major professors: Dr. Warren Ballard and Dr. Mark Wallace. These men gave me the opportunity to develop my scientific mind. They allowed me the academic freedom to discover things for myself. They asked me questions to which there is no easy answer. They supported me all the way and gently kept me on track.

Third, I would like to acknowledge the Texas Tech University Department of Natural Resources Management graduate students. These scientists challenged my mind every time we talked about science, natural resource management, and life. They helped me with fieldwork and with statistical techniques. I would especially like to thank Doug Holt for his help in this regard.

Finally, I would like to thank my committee. Heather Whitlaw taught me more about lesser prairie-chickens than any other person. I especially want to thank Dr. Matt Butler for furthering my understanding of statistics and research, as well as supporting all aspects of the research logistics.

TABLE OF CONTENTS

ACKNOWLEDGMENTS	ii
LIST OF TABLES	v
LIST OF FIGURES	viii
CHAPTER	
I. INTRODUCTION	1
LITERATURE CITED	4
II. SPACE AND HABITAT USE DYNAMICS OF OVER-WINTERING LESSER PRAIRIE-CHICKENS IN THE NORTHEAST TEXAS PANHANDLE	9
ABSTRACT	9
INTRODUCTION	9
STUDY AREA	12
METHODS	13
Capture and Radiomarking	13
Radiotelemetry	14
Accuracy of Locations	14
Landcover Determination	15
Data Analysis	16
RESULTS	19
DISCUSSION	22
MANAGEMENT IMPLICATIONS	25
LITERATURE CITED	27

III. OVER-WINTER SURVIVAL OF LESSER PRAIRIE-CHICKENS IN THE NORTHEAST TEXAS PANHANDLE IN RELATION TO LANDSCAPE CHARACTERISTICS 47

ABSTRACT 47

INTRODUCTION 47

STUDY AREA 49

METHODS 50

Capture and Radiomarking 50

Radiotelemetry 50

Landcover Determination 51

Home Range and Landscape Metrics 52

Data Analysis 53

RESULTS 53

DISCUSSION 55

MANAGEMENT IMPLICATIONS 56

LITERATURE CITED 58

APPENDIX

A. OVER-WINTER RELOCATION SAMPLE SIZES 68

B. PATCH CHARACTERISTICS OF LANDCOVER MAP 71

C. GROUND-TRUTH STUDY SUMMARY 73

LIST OF TABLES

2.1. Landcover types used for delineation of landcover patches in our Geographic Information System (GIS) coverage. 33

2.2. Home range sizes, minimum daily movements, distances to leks-of-capture, and distances to nearest known leks for male lesser prairie-chickens in the northeast Texas Panhandle during the over-winter of 2008–2009. 35

2.3. Home range sizes, minimum daily movements, distances to leks-of-capture, and distances to nearest known leks for male lesser prairie-chickens in the northeast Texas Panhandle during the over-winter of 2009–2010. 36

2.4. Home range sizes, minimum daily movements, distances to leks-of-capture, and distances to nearest known leks for female lesser prairie-chickens in the northeast Texas Panhandle during the fall of 2008. 37

2.5. Home range sizes, minimum daily movements, distances to leks-of-capture, and distances to nearest known leks for female lesser prairie-chickens in the northeast Texas Panhandle during the over-winter of 2009–2010. 38

2.6. Ranking matrix of habitat selection for over-wintering male lesser prairie-chickens in the northeast Texas Panhandle; use defined as the proportion of locations within patches of a certain landcover type. Triple signs represent significant deviation from random at $P < 0.1$. 39

2.7. Ranking matrix of habitat selection for over-wintering male lesser prairie-chickens in the northeast Texas Panhandle; use defined as proportions of landcover types within the core area home range. Triple signs represent significant deviation from random at $P < 0.1$. 40

2.8. Ranking matrix of habitat selection for over-wintering male lesser prairie-chickens in the northeast Texas Panhandle; use defined as proportions of landcover types within a buffered area of 116.1 m from locations. Triple signs represent significant deviation from random at $P < 0.1$. 41

2.9. Ranking matrix of habitat selection for female lesser prairie-chickens (n = 4) in the northeast Texas Panhandle during the over-winter of 2009–2010; use defined as the proportion of locations within patches of a certain landcover type. Triple signs represent significant deviation from random at $P < 0.1$. 42

2.10. Ranking matrix of habitat selection for female lesser prairie-chickens (n = 4) in the northeast Texas Panhandle during the over-winter of 2009–2010; use defined as proportions of landcover types within the core area home range. Triple signs represent significant deviation from random at $P < 0.1$. 43

2.11. Ranking matrix of habitat selection for female lesser prairie-chickens (n = 4) in the northeast Texas Panhandle during the over-winter of 2009–2010; use defined as proportions of landcover types within a buffered area of 116.1 m from locations. Triple signs represent significant deviation from random at $P < 0.1$. 44

3.1. Landcover types used for delineation of habitat patches within our study areas in the northeast Texas Panhandle for use in habitat-dependant survival analyses. 63

3.2. Description of metrics comprising the a priori candidate model set used in habitat-dependant survival analyses for over-wintering lesser prairie-chickens in the northeast Texas Panhandle, 2008–2011. 65

3.3. Ranking of a priori candidate models predicting survival hazard for over-wintering lesser prairie-chickens in the northeast Texas Panhandle between 1 September 2008 and 28 February 2010. For each model, we display –2 × log-likelihood (–2LL), the second order Akaike's Information Criterion (AICc) value, the difference between model AICc value and the lowest value of AICc (ΔAICc) in the candidate set, and the model probability (w_i) (n = 17). 66

A.1. Summary of the total number of locations collected for radiomarked lesser prairie-chickens in the northeast Texas Panhandle during the over-winter of 2008–2009. 69

A.2.	Summary of the total number of locations collected for radiomarked lesser prairie-chickens in the northeast Texas Panhandle during the over-winter of 2009–2010.	70
B.1.	Number of patches, mean patch sizes (m^2), and standard errors for each cover type in our Geographic Information System (GIS) coverage.	72
C.1.	Summary of the number of randomly generated points and the classification accuracy within each of the three native prairie landcover subtypes.	74

LIST OF FIGURES

1.1.	Approximate boundary of study sites where lesser prairie-chickens were trapped and monitored from 1 September 2008 to 28 February 2010.	8
2.1.	Percent of lesser prairie-chicken locations in the northeast Texas Panhandle plotted against the distance to leks-of-capture (km) during the over-winters of 2008–2009 and 2009–2010 combined.	45
2.2.	Percent of lesser prairie-chicken locations in the northeast Texas Panhandle plotted against the distance to the nearest known lek (km) during the over-winters of 2008–2009 and 2009–2010 combined.	46
3.1.	Bar chart displaying the frequencies of cause-specific mortality classifications (n = 17 mortality events) for over-wintering lesser prairie-chickens in the northeast Texas Panhandle between 1 September 2008 and 28 February 2010.	67

CHAPTER I

INTRODUCTION

The lesser prairie-chicken (*Tympanuchus pallidicinctus*; LPC) is a gallinaceous bird occurring on portions of the Southern Great Plains of Colorado, Kansas, New Mexico, Oklahoma, and Texas (Davis et al. 2008). Since the 1800s, LPC populations have declined across their range (Taylor and Guthery 1980*a*). This decline prompted a petition to the U.S. Fish and Wildlife Service (USFWS) in 1995 to list the species as "threatened". In 1998, the USFWS concluded that this listing was "warranted but precluded" because of higher-priority species and the LPC was subsequently added to the "candidate species" list (USFWS 1998). Recently, the species was upgraded to Priority Number 2 (USFWS 2008), indicating that listing may be imminent. Potential threats to the LPC include habitat loss and change (Crawford and Bolen 1976*b*, Woodward et al. 2001), habitat fragmentation (Wu et al. 2001, Patten et al. 2005), poor rangeland management (Jackson and DeArment 1963), periodic droughts (Schwilling 1955, Jackson and DeArment 1963), energy development (Hunt 2004, USFWS 2008), and competition with sympatric ring-necked pheasants (*Phasianus colchicus*; Sullivan et al. 2000, Hagen et al. 2002, Holt et al. 2010). Historically, conversion of native rangeland was likely the primary driver of range-wide population declines (Taylor and Guthery 1980*a*).

In Texas, the occupied range of the LPC decreased by an estimated 78% between 1940 and 2000 (Sullivan et al. 2000). Texas has not been exempt from the habitat loss and degradation occurring throughout the LPC's range (Crawford and Bolen 1976*b*, Taylor and Guthery 1980*a*, Peterson and Boyd 1998, Sullivan et al. 2000). Furthermore, Conservation Reserve Program (CRP) plantings in the Texas Panhandle have historically been of non-native grasses (Sullivan et al. 2000), which may be of less value to LPC than native rangeland (Jamison 2000, Toole 2005). Increased woody cover and fragmentation of non-woody cover types at large spatial scales contributed to habitat degradation in the Rolling Plains (Wu et al. 2001). Recent surveys in the northeastern Panhandle (i.e., Gray, Hemphill, and Wheeler counties) indicated declining LPC populations between 1998 and 2007 (Davis et al. 2008). Currently, the estimated occupied range of LPCs in Texas is isolated in 2 disjunct populations: one in each of the northeast and southwest portions of the Panhandle (Davis et al. 2008).

Winter can be an especially important time for grouse. Nutritionally, late winter is a critical period for ruffed grouse (*Bonasa umbellus*; Norman and Kirkpatrick 1984), and the availability of high-quality food may limit population densities in parts of that species' range (Servello and Kirkpatrick 1987). In Colorado, Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) engage in substantial directional and elevational winter movements that clearly influence the scale of management (Boisvert et al. 2005).

The LPC has been understudied during the over-winter period. Of the limited research that has been completed during the over-winter period, much has been conducted at study sites with high availability of irrigated agriculture at large spatial scales (e.g., Crawford and Bolen 1976*a*, Salter et al. 2005), or in the western portion of the species' geographic range (e.g., Taylor and Guthery 1980*b*, Riley et al. 1993). Clearly, a more complete understanding of LPC ecology during all stages of its life history is needed to better inform management decisions in the northeastern Texas Panhandle.

We conducted research in the northeast Texas Panhandle (Figure 1.1) from 1 September 2008 to 28 February 2010 during 2, 6-month field seasons (1 Sep to 28 Feb). Our research sought to better understand several aspects of LPC ecology during the over-winter period. Our objectives were to 1) better understand movement and home range dynamics of over-wintering LPC in an area where grain agriculture was rare, 2) quantify LPC habitat selection at the spatial scale of the home range, and 3) relate landscape composition and configuration to LPC over-winter survival.

I formatted the content of this thesis according to the guidelines for the Journal of Wildlife Management (Chamberlain and Johnson 2008). Chapters II and III have coauthors that were determined according to the guidelines proposed by Dickson et al. (1978). Authorship is:

Chapter I. Kukal, C. A.

Chapter II. Kukal, C. A., W. B. Ballard, M. J. Butler, R. D. Holt, H. A. Whitlaw, and M. C. Wallace.

Chapter III. Kukal, C.A., W. B. Ballard, M. J. Butler, R. D. Holt, H. A. Whitlaw, and M. C. Wallace.

LITERATURE CITED

Boisvert, J. H., R. W. Hoffman, and K. P. Reese. 2005. Home range and seasonal movements of Columbian sharp-tailed grouse associated with Conservation Reserve Program and mine reclamation. Western North American Naturalist 65:36–44.

Chamberlain, M. J., and C. Johnson. 2008. Journal of Wildlife Management guidelines. <http://www.wildlifejournals.org/pdf/author_instructions.pdf>. Accessed 30 September 2010.

Crawford, J. A., and E. G. Bolen. 1976*a*. Fall diet of the lesser prairie-chicken in west Texas. Condor 78:142–144.

Crawford, J. A., and E. G. Bolen. 1976*b*. Effects of land use on lesser prairie chickens in Texas. Journal of Wildlife Management 40:96–104.

Davis, D. M., R. E. Horton, E. A. Odell, R. D. Rogers, and H. A. Whitlaw. 2008. Lesser prairie-chicken Conservation Initiative. Unpublished Report. Lesser Prairie Chicken Interstate Working Group, Colorado Division of Wildlife, Fort Collins, USA.

Dickson, J. G., R. N. Conner, and K. T. Adair. 1978. Guidelines for authorship of scientific article. Wildlife Society Bulletin 6:260–261.

Hagen, C.A, B. E. Jamison, R. J. Robel, and R. D. Applegate. 2002. Ring-necked pheasant parasitism of lesser prairie-chicken nests in Kansas. Wilson Bulletin 114:522–524.

Holt, R. D., M. J. Butler, W. B. Ballard, C. A. Kukal, and H. Whitlaw. 2010. Disturbance of lekking lesser prairie-chickens (*Tympanuchus pallidicinctus*) by ring-necked pheasants (*Phasianus colchicus*). Western North American Naturalist 70:241–244.

Hunt, J. L. 2004. Investigation into the decline of populations of the lesser prairie-chicken (*Tympanuchus pallidicinctus* Ridgway) in southeastern New Mexico. Dissertation, Auburn University, Auburn, Alabama, USA.

Jackson, A. S., and R. DeArment. 1963. The lesser prairie chicken in the Texas Panhandle. Journal of Wildlife Management 27:733–737.

Jamison, B. E., J. A. Dechant, D. H. Johnson, L. D. Igl, C. M. Goldade, and B. R. Euliss. 2002. Effects of management practices on grassland birds: Lesser prairie-chicken. Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

Norman, G. W., and R. L. Kirkpatrick. 1984. Food, nutrition and condition of ruffed grouse in southwestern Virginia. Journal of Wildlife Management 48:183–187.

Patten, M. A., D. H. Wolfe, E. Shochat, and S. K. Sherrod. 2005. Habitat fragmentation, rapid evolution, and population persistence. Evolutionary Ecology Research 7:1–15.

Peterson, R. S., and C. S. Boyd. 1998. Ecology and management of sand shinnery communities: a literature review. U.S. Forest Service General Technical Report RMRS-GTR-16. Rocky Mountain Research Station, Fort Collins, Colorado, USA.

Riley, T. Z., C. A. Davis, and R. A. Smith. 1993. Autumn-winter habitat use of lesser prairie-chickens (*Tympanuchus pallidicinctus*, Tetraonidae). Great Basin Naturalist 53:409–411.

Salter, G. C., R. J. Robel, and K. E. Kemp. 2005. Lesser prairie-chicken use of harvested corn fields during fall and winter in southwestern Kansas. Prairie Naturalist 37:1–9.

Schwilling, M. D. 1955. Study of the lesser prairie chicken in southwest Kansas. Kansas Fish and Game 12:10–12.

Servello, F. A., and R. L. Kirkpatrick 1987. Regional variation in the nutritional ecology of ruffed grouse. Journal of Wildlife Management 51:749–770.

Sullivan, R. M., J. P. Hughes, and J. E. Lionberger. 2000. Review of the historical and present status of the lesser prairie-chicken (*Tympanuchus pallidicinctus*) in Texas. Prairie Naturalist 32:178–188.

Taylor, M. A., and F. S. Guthery. 1980*a*. Status, ecology, and management of the lesser prairie-chicken. U.S. Forest Service General Technical Report RM-77. Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado, USA.

Taylor, M. A., and F. S. Guthery. 1980*b*. Fall-winter movements, ranges, and habitat use of lesser prairie-chickens. Journal of Wildlife Management 44:521–524.

Toole, B. E. 2005. Survival, seasonal movements, and cover use by lesser prairie chickens in the Texas Panhandle. Thesis, Texas A&M University, College Station, USA.

U.S. Fish and Wildlife Service. 1998. Endangered and threatened wildlife and plants; 12-month finding for a petition to list the lesser prairie-chicken as threatened and designate critical habitat. Federal Register 63:31400–31406.

U.S. Fish and Wildlife Service. 2008. Review of native species that are candidates for listing as Endangered or Threatened; annual notice of findings on resubmitted petitions; annual descriptions of progress on listing actions; proposed rule. Federal Register 73:75175–75244.

Woodward, A. J. W., S. D. Fuhlendorf, D. M. Leslie Jr., and J. Shackford. 2001. Influence of landscape composition and change on lesser prairie-chicken (*Tympanuchus pallidicinctus*) populations. American Midland Naturalist 145:261–274.

Wu, X. B., N. J. Silvy, F. E. Smeins, and R. C. Maggio. 2001. Landscape changes in lesser prairie chicken habitat in the Texas panhandle. Final Report to Texas Parks and Wildlife Department. Texas A&M University, College Station, USA.

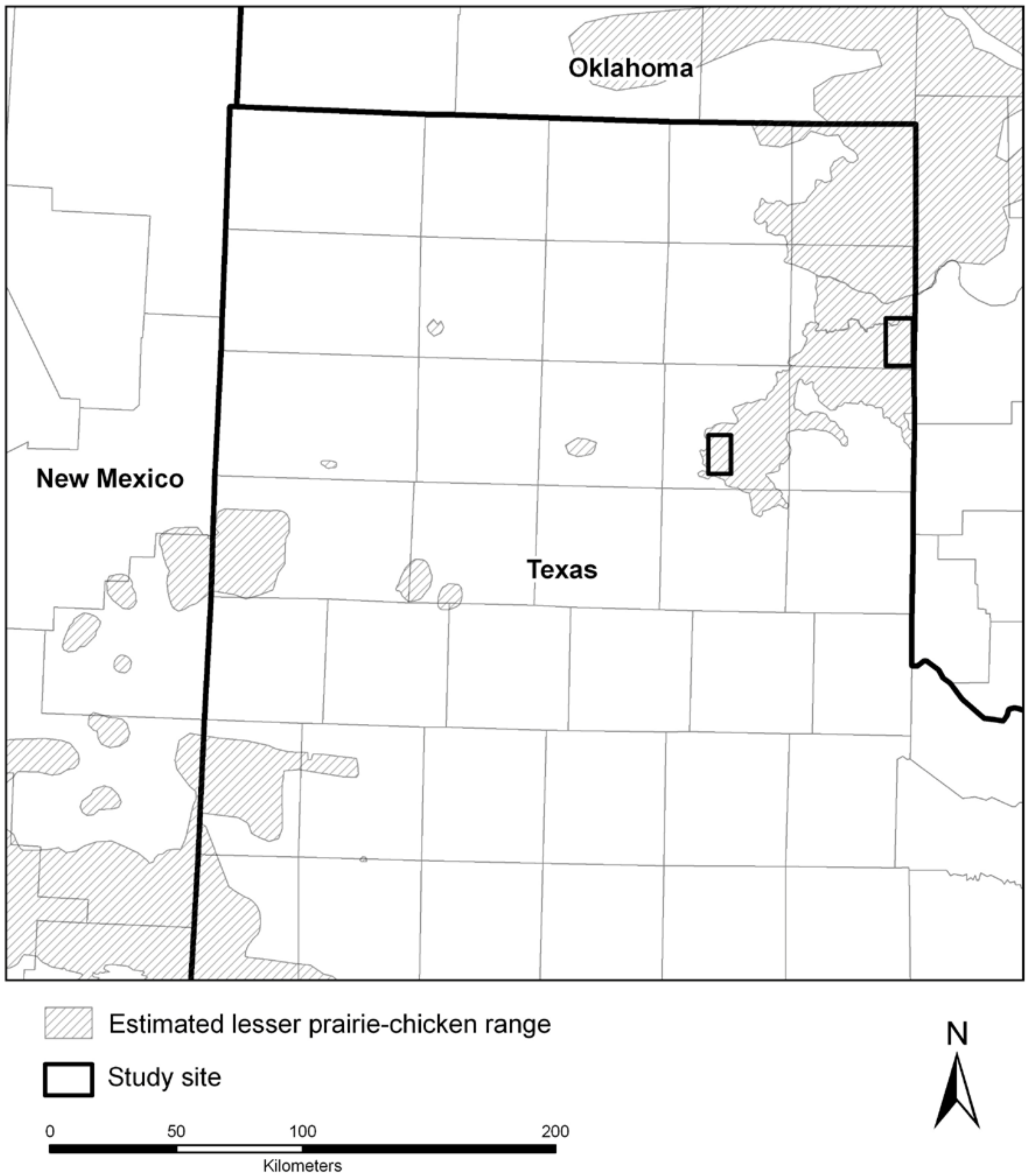

Figure 1.1. Approximate boundary of study sites where lesser prairie-chickens were trapped and monitored from 1 September 2008 to 28 February 2010.

CHAPTER II

SPACE AND HABITAT USE DYNAMICS OF OVER-WINTERING LESSER PRAIRIE-CHICKENS IN THE NORTHEAST TEXAS PANHANDLE

ABSTRACT

Over-winter space-use and habitat selection behavior by lesser prairie-chickens (*Tympanuchus pallidicinctus*; LPC) in the northeast Texas Panhandle is poorly understood. We investigated home range dynamics, movement patterns, and habitat selection for over-wintering LPCs between 1 September 2008 and 28 February 2010. We observed that ≥98% of LPC locations were within 5.0 km of their leks-of-capture and ≥98% were within 2.4 km of a known lek. We did not observe LPCs utilizing agricultural fields, possibly because most agriculture near leks was dominated by wheat (*Triticum aestivum*). Both genders consistently selected grassland (<15% canopy coverage of shrubs) landcover over shrubland landcover types. Our results underscore the need to conserve grassland landcover for over-wintering LPCs. We agree with previous management recommendations that rangelands within 5.0 km should be managed for over-wintering LPCs, but we further recommend prioritizing rangeland within 2.4 km of all leks in an area.

INTRODUCTION

Understanding a species' home range and movement dynamics is critically important to wildlife managers. This information is particularly useful in defining the appropriate scale of management activities (e.g., Boisvert et al. 2005, Ginter and

Desmond 2005, Mei-Hsiu Hwang et al. 2010), and can elucidate fundamental aspects of a species' ecology (e.g., Shriver et al. 2010).

Taylor and Guthery (1980), Jamison (2000), and Toole (2005) have previously investigated the home range dynamics of lesser prairie-chickens (*Tympanuchus pallidicinctus*; LPC) during the over-winter period. Taylor and Guthery (1980) observed that monthly minimum convex polygon (MCP; Mohr 1947) home range sizes of male LPCs in west Texas ranged from 50 ha to 1,945 ha between November and February. They did not report the minimum number of locations used to calculate MCPs. Toole (2005) calculated the MCP home range size of 7 individuals during the over-winter period in the northeast Texas Panhandle using a minimum of 15 locations. Calculating MCPs with sample sizes this low may be problematic since MCPs are sensitive to the number of locations used to estimate the home range, as well as to outliers (Seaman et al. 1999, Kernohan et al. 2001). Minimum convex polygons are also unable to identify multiple centers of activity (Kernohan et al. 2001). Jamison (2000), using 95% fixed kernel home ranges, observed that median monthly home range sizes of LPC males in Kansas were relatively small (77 ha–144 ha) during the summer (Jun–Sep) and then rose to an annual peak during October (229 ha–409 ha) when birds began to use harvested grain fields. Jamison also observed a smaller second peak in median monthly home range area during February.

The over-winter movement patterns of LPCs have also been investigated. Jamison (2000) observed an annual peak in median daily movements during March (435 m/day–786 m/day) and a smaller second peak in October. Taylor and Guthery (1980*c*) observed increased movements coincident with the end of the false-lekking period in the fall and the beginning of sunflower field usage, and calculated that about 50% of locations were within 1.6 km of the lek. Pitman et al. (2006) investigated dispersal movements of juvenile (hatch-year to following spring) LPCs in Kansas. They observed a bimodal pattern of dispersal movements; a fall peak of dispersal movements for both genders occurred between late October and early November, though female movements were much greater during spring (late March). Toole (2005) estimated mean movements of LPCs in the Rolling Plains of the Texas Panhandle (Hemphill, Lipscomb, and Wheeler counties) during the over-winter period, but his data were constrained by sample size.

We are not aware of any studies that rigorously investigated either over-winter space use or movement patterns in the northeast Texas panhandle, an area that was characterized by low availability of grain agriculture at large spatial scales during the course of this study. Because current management paradigms are based on assumptions inferred from studies which may not apply to the northeast Panhandle, it is clear that a more complete understanding of space use and movement patterns by over-wintering LPCs in the northeast Texas panhandle is needed to inform conservation activities there.

An understanding of resources used by a species is critically important for effective wildlife habitat management. For LCPs, resource selection studies have generally indicated that shrubs were an important habitat component at ecological sites where they are supported. Patten et al. (2005) and Bell et al. (2010) suggested that LPCs display positive selection for shrubs at small spatial scales. In west Texas, Taylor and Guthery (1980) observed that the shinnery oak (*Quercus havardii)*/sand sagebrush (*Artemisia filifolia*) and shinnery oak/little bluestem (*Schizachyrium scoparium*) vegetation types were used during fall and winter at a level greater than availability would otherwise predict. During the breeding season in New Mexico, Johnson et al. (2004) observed that female LPCs were found closer to untreated shinnery oak than random locations. However, Johnson et al. (2004) used euclidean distance analysis, which has recently been criticized as unreliable (Bingham et al. 2010). Haukos and Smith (1989) observed that hens captured in tebuthiuron-treated shinnery rangelands in west Texas nested in untreated areas at a level greater than expected. In shinnery oak dominated landscapes in Oklahoma, Cannon et al. (1982) observed a negative correlation between the density of displaying males on leks and the proportion of the landscape in brush. Riley et al. (1993) investigated over-winter habitat use for LPCs in southeastern New Mexico. That study found that grasses dominated foraging and roosting sites, but inference was constrained by sample size (n = 8 males). Furthermore, it is clear that some LPC populations use agriculture fields when they are available (e.g., Schwilling 1955, Copelin 1963, Campbell 1972, Taylor and Guthery 1980, Salter et al. 2005), but habitat selection by over-wintering LPCs in the eastern portion of the species' range where populations do not have ready access to grain agriculture is poorly understood.

STUDY AREA

We conducted research in the Rolling Plains Ecoregion (Bender et al. 2005) of the northeast Texas Panhandle in Gray and Hemphill counties. At the Hemphill county study site (National Weather Service Cooperative Station ID. 411408, 0 km from the study area), there was 80.9 cm of annual precipitation in 2008 (National Climatic Data Center [NCDC] 2008) and 66.9 cm of annual precipitation in 2009 (NCDC 2009). At the Gray County study site (National Weather Service Cooperative Station ID. 416776, ≈25 km from study area), there was 54.3 cm of annual precipitation in 2008 (NCDC 2008) and 61.7 cm of annual precipitation in 2009 (NCDC 2009).

Sand sagebrush, shinnery oak, and grassland communities characterized the vegetation of the study area. A description of common flora at the study site can be found in Jackson and DeArment (1963). Conservation reserve program (CRP) fields of primarily monospecific pastures of non-native grasses such as weeping lovegrass (*Eragrostis curvula*), yellow bluestem (*Bothriochloa ischaemum*), and kleingrass (*Panicum coloratum*) were interspersed in native rangeland. Land-use in the area included cattle grazing, oil and natural gas exploration and extraction, and row-crop agriculture (primarily wheat; *Triticum aestivum*). Anthropogenic features included improved and unimproved roads, scattered buildings, agricultural infrastructure, transmission lines of various capacities, barbed-wire fences, and oil and natural gas extraction pads. All study leks were located on private property.

METHODS

Capture and Radiomarking

We used walk-in traps with leads (Schroeder and Braun 1991, Salter and Robel 2000) and rocket-nets (Haukos et al. 1990) to capture LPCs on leks during the fall (early-Oct to mid-Nov) and spring (mid-Mar to late-May). Immediately following removal from a trap or net, we affixed a 12-g to 16-g necklace-style radio transmitter (≤3% of total body mass) operating at a unique frequency between 150.000–151.999 MHz. Transmitters were equipped with a 12-hour mortality sensor. We affixed a uniquely numbered leg band (size 12, National Band and Tag, Newport, KY) to LPCs before releasing them at the site of capture. Capture was conducted under the Texas Tech Institutional Animal Care and Use Committee (IACUC) approval number 07050-08.

Radiotelemetry

We relocated LPCs using a 3-element handheld Yagi antenna and a radio-receiver (R2000, Advanced Telemetry Systems, Inc., Isanti MN). We triangulated the signal source from geo-referenced base-stations stored in hand-held Global Positioning System (GPS) units (76CX, Garmin International Inc., Olathe, KS). We traveled between base-stations using all terrain vehicles or trucks. We collected all azimuths for a triangulation event within at least 20 min to minimize error. We used program LOAS (Ecological Software Solutions, Hegymagas, Hungary) to estimate triangulated LPC locations. We systematically rotated sampling throughout the diel period as to include locations from the first third of daylight hours, the middle third of daylight hours, the last third of daylight hours, and over-night (2400 hr to 1 hr before sunrise). We attempted to collect over-night locations 1 time per week at the Hemphill County study site. We were unable to collect over-night locations at the Gray County study site because of logistical constraints. We collected only survival status when we were unable to triangulate due to inclement weather, logistic or time constraints, or limited access.

Accuracy of Locations

We conducted a beacon study to estimate the linear accuracy of triangulated locations. First, we placed several beacons approximately 10 cm above ground in areas frequented by LPCs. We then conducted triangulation under field conditions. All observers received similar radiotelemetry training. The linear distances (m) between locations estimated in program LOAS and the known locations of the beacons were calculated.

Landcover Determination

We imported aerial imagery (National Aerial Imagery Program [NAIP], 1-m resolution, 2008 imagery) into ArcMap 9.3 (ArcInfo, Environmental Systems Research Institute, Redlands, CA). We then delineated patches of 12 pre-determined landcover types (see Table 2.1 for a list and description) into a polygon-based coverage (see Table B.1). These land cover classifications were somewhat arbitrary, but were chosen specifically to 1) allow results to be comparable to previous LPC research (Woodward et al. 2001, Fuhlendorf et al. 2002), 2) reflect the landcover diversity of the study area, 3) reflect the resolution of available aerial imagery, and 4) be useful for subsequent habitat analyses.

We ground-truthed 130 randomly generated points using a handheld GPS unit (76CX, Garmin International Inc., Olathe, KS) in early November 2010. We generated random points 1) within 2.5 km of a known lek, 2) on properties for which we had access permission, and 3) ≥10 m from a landcover edge. Because the majority (69.1%) of the Gray County study site within 2.5 km of known leks was classified as landcover type 12 (native prairie regenerating following a wildfire) which could not be accurately ground-truthed in November 2010, we tested our classification methodology at the Hemphill County study site. An observer stood at a point, and then classified the landcover within an area approximately 10 m from the point in all directions using the same classification types as the landcover map. To avoid bias, the observer did not have access to the landcover map or the map's classification of that point. We classified 110 random points

(84.62%) as the same type classified by the landcover map (Table C.1). Additionally, we ground-truthed ≥5 areas that were representative of landcover types 4, 5, 6, 7, 8, 9, and 11 during data collection activities during the over-winters of 2008–2009 and 2009–2010. All landcover classified as type 10 (improved roads) were ground-truthed.

Data Analysis

We identified 2 time intervals reflecting periods that were biologically relevant for over-wintering LPCs. The beginning of the study period (1 September) roughly corresponded to the average date of brood break-up observed in Kansas (Pitman et al. 2006). The latest we observed fall lekking behavior during the course of the study was 11 November 2009. The earliest we observed lekking behavior in the spring was 10 February 2009. To allow for possible observer error, we buffered these dates by 1-week. We therefore compared 1 September–18 November (fall hereafter) to 19 November–3 February (winter hereafter).

We used the package adehabitat (Calenge 2006) in program R (R Development Core Team 2008) to compute 95% fixed kernel home ranges (Worton 1989). Seaman et al. (1999) recommended a minimum of 30 locations per individual when calculating kernel home ranges. We collected 28 or 29 locations for several birds for a given season, so we used 28 as the minimum number of locations to compute home ranges to avoid sacrificing data.

We estimated the daily movement as the linear distance between 2 triangulated locations on consecutive days. We averaged the minimum daily movement for male LPCs with 10 or more such movements. Because this estimate likely does not reflect the actual total daily movements of an individual (Laundré et al. 1987), it should be viewed as an index. We calculated the overall gender-specific percentages of locations within various distances of leks using ArcMap. We calculated the 90% exact binomial confidence intervals for these proportions.

We used a 2-factor analysis of variance (ANOVA) to compare the minimum daily movements of male LPCs by year and season. Inspection of histograms indicated male home range sizes (ha), distances from known leks (m), and distances from leks-of-capture (m) were right-skewed. We could not transform the data satisfactorily, so we used Kruskal-Wallace tests to compare these distributions, with season as treatments (fall 2008, winter 2008–2009, fall 2009, winter 2009–2010). We made comparisons only for male LPCs because of low female sample size (but see Tables 2.4 and 2.5 for summaries for female LPCs during fall 2008 and over-winter 2009–2010 respectively). Hypotheses were rejected at p-values ≤ 0.1. Tests of significance were performed in program R (R Development Core Team 2008).

We compared daytime locations to those that were sampled during the over-night period (roosting) for over-wintering male LPCs. We paired roosting locations with randomly selected daytime, non-lekking locations for that individual during the previous 7 days (or during the period between over-night sampling events if that period was <7 days). We used a one-tailed Wilcoxon signed-rank test to compare the median distances between locations and known leks (m), with years and seasons pooled. We rejected hypotheses at p-values ≤ 0.1. Tests of significance were performed in program R (R Development Core Team 2008).

We conducted a compositional analysis (Aebischer et al. 1993) to investigate habitat selection by over-wintering LPCs. This methodology allowed us to consider the individual as the sampling unit instead of each location and permitted an empirically-derived and objective definition of habitat use. Furthermore, managers can easily interpret the output of this methodology, which is relatively consistent in its ranking unlike euclidean distance analysis (Bingham et al. 2010). Since LPC home ranges are at least somewhat tied to leks, we evaluated selection within the home range (Johnson's third-order selection; Johnson 1980). We considered the over-winter 95% fixed kernel home range as "available" habitat, and evaluated "use" using 3 methodologies. First, we divided the number of LPC locations within a landcover type by the total number of locations for that individual for each individual. Second, we determined the proportion of an individual's over-winter core home range (Wilson et al. 2010) in each landcover type and considered these proportions "use" (e.g., Chamberlain et al. 2003). When there was evidence for multi-scale cores, we used the outer-most core to delineate the core's boundary. Finally, we buffered locations by our average telemetry error and determined the proportion of each landcover type within this area. We considered these proportions "use".

Recent radiotelemetry studies in the eastern portion of the LPC's range indicated that LPCs generally selected native landcover over non-native grassland (Toole 2005) and non-indigenous landcover types (Jamison 2000). We observed that for over-wintering LPCs in Hemphill County, native prairie landcover (landcover types 1, 2, and 3) averaged >94% of available habitat within the 95% fixed kernel home range in over-winters. Furthermore, >96% of estimated LPC locations in Hemphill County were within these landcover types. Approximately 2% of LPC locations in Hemphill County were within a 116.1-m buffer (our average telemetry error) of landcover types 4 or 5, and just

1% estimated as being within types 4 or 5 (and the majority of these were due to a single adult male). We therefore evaluated only landcover types 1–3 using compositional analyses. Compositional analyses were conducted using the package adehabitat (Calenge 2006) in program R (R Development Core Team 2008). To reduce the probability of making type I errors, we substituted 0.3% when habitat-use was zero (Bingham and Brennan 2004). Following the recommendations of Leban et al. (2001), we censored individuals with <50 locations for an over-winter season. Habitat selection was evaluated for the over-winter period (1 Sep–28 Feb) for both years of the study. Null hypotheses were rejected at *p*-values ≤ 0.1.

RESULTS

We captured and monitored 41 LPCs (34 males and 7 hens) from 8 leks. We collected 1,229 locations from 19 LPCs during the over-winter of 2008–2009, and 1,984 locations from 29 LPCs during the over-winter of 2009–2010. We were unable to hear a radio signal 3.9% of the days that we checked for one, however 50.4% of those events were due to a single adult female that temporarily left the study area during both years of the study. At the Hemphill County study area, 405 of the 3,040 locations we collected were sampled during the over-night period.

Three observers averaged 116.1 m (SE = 13.48, *n* = 54, range = 12–462 m) error between known beacon locations and triangulated locations that were estimated in program LOAS. We found 98.0% (90% Exact Binomial CI = 97.5–98.4) of male LPC locations ≤2.3 km from a known lek and 97.8% (90% Exact Binomial CI = 97.3–98.3) ≤5.0 km from leks-of-capture. We found 97.5% (90% Exact Binomial CI = 96.0–98.6) of female LPC locations ≤2.4 km from a known lek, and 97.8% (90% Exact Binomial CI = 96.2–98.8) ≤3.8 km from leks-of-capture (Fig. 2.1 and 2.2).

Minimum daily movements (summarized in Tables 2.2 and 2.3 for the over-winters of 2008–2009 and 2009–2010 respectively) for male LPCs were greater in the fall compared to winter ($F = 13.553$, df = 1, 61; $P < 0.001$). There was little evidence for a year effect ($F = 0.043$, df = 1, 61; $P = 0.837$) or for an interaction between season and year ($F = 0.057$, df = 1, 61; $P = 0.812$).

Distances between locations and the nearest known lek (summarized in Tables 2.2 and 2.3 for the over-winters of 2008–2009 and 2009–2010 respectively) for male LPCs differed by season ($H = 11.727$, df = 3, $P = 0.008$). Multiple comparisons indicated that distances during the two fall seasons did not differ from each other, distances during the two winter seasons did not differ from each other, and that distances during the fall seasons were greater than the winter seasons. In Hemphill County, 29.4% of the area within 5.0 km of a known lek was also within 2.4 km of a known lek. In Gray County, 32.4% of the area within 5.0 km of a known lek was also within 2.4 km of a known lek.

Distances between locations and leks-of-capture (summarized in Tables 2.2 and 2.3 for the over-winters of 2008–2009 and 2009–2010 respectively) for male LPCs differed by season ($H = 6.886$, df = 3, $P = 0.076$). Multiple comparisons indicated that distances during the winter seasons did not differ from each other, distances during the fall of 2008–2009 were greater than the winter seasons, and that distances during fall of 2009–2010 did not differ from any other season.

We found 95% fixed kernel home range sizes (summarized in Tables 2.2 and 2.3 for the over-winters of 2008–2009 and 2009–2010 respectively) for male LPCs differed by season (H = 6.806, df = 3, P = 0.078). Multiple comparisons indicated that home range sizes during the winter seasons did not differ from each other, home range sizes during the fall of 2008–2009 were greater than during either winters, and that the fall of 2009–2010 did not differ from any other season.

Distances between locations and known leks did not differ between over-night and daytime sampling periods (V = 34,504, P = 0.154) for over-wintering male LPCs. Locations sampled during the day had a median distance of 613.5 m (SE = 26.06, range = 41.0 m–3,831.9 m), and locations sampled during the over-night period had a median distance of 587.5 m (SE = 25.18, range = 88.3 m–3,588.6m).

All LPCs with >50 locations showed evidence of a core home range. Core home range isopleths ranged from 30% to 75% during the over-winter of 2008–2009 and 28% to 76% during the over-winter of 2009–2010. Over-wintering male LPCs showed a consistent selection pattern across years and definitions of use (Tables 2.6, 2.7, and 2.8). Male LPCs consistently selected grassland>other prairie>shinnery oak landcover types. During the over-winter of 2008–2009 using the location methodology to evaluate habitat use, other prairie and shinnery showed no evidence for differential selection (ranking is interchangeable) though the grassland cover type was selected over the other two. This pattern of habitat selection was also observed during the over-winters of 2008–2009 and 2009–2010 using the buffered location methodology.

Female LPC habitat-use during the over-winter of 2009–2010 did not appear to be non-random using the location methodology (Λ = 0.110, P = 0.139), the core home range methodology (Λ = 0.114, P = 0.149), or the buffered location methodology (Λ = 0.410, P = 0.491) for defining use. However, ranking matrices consistently ranked grassland>other prairie>shinnery oak landcover types, even though these differences were not always significant (see Tables 2.9, 2.10, and 2.11).

DISCUSSION

Our data concurred with previous studies (Copelin 1963, Taylor and Guthery 1980) in indicating that LPCs have a strong tendency to remain within 5.0 km of their lek-of-capture. However, our data also suggest that over-wintering LPCs have a strong tendency to remain <2.4 km from a known lek. We do not believe this result is an artifact of lek spacing. If LPCs randomly occupied the area within 5.0 km of known leks, then based on the lek spacing at our study sites we would expect approximately a third of locations to be <2.4 km of a known lek. We observed approximately 98% of locations within 2.4 km of a known lek, enforcing the inference that this area is frequented more than probability alone would predict. The observation that locations were so proximal to leks may be related to the fact that we did not observe LPCs making long movements to grain fields during the course of the study. Reporting the distance to lek-of-capture may be misleading if a bird is far away from its lek-of-capture, but proximal to a neighboring lek, as our data suggests. Although we did not observe LPCs displaying on multiple leks (except for a satellite lek 455 m away that replaced the main lek over the course of the study), we estimated locations for several birds that were near (<1 km) leks other than their lek-of-capture.

The 95% fixed kernel fall home range sizes we observed were larger than anything we could find in the literature for over-wintering male LPCs using this methodology, even though we never observed LPC utilizing grain agriculture fields or making flights to them. If we had observed LPCs consistently making long flights between loafing and agricultural habitats, this would have likely inflated home range area. It is unlikely that the larger home ranges and longer movements we observed in the fall were due to dispersal movements because our sample was biased to adult males, which exhibit high lek fidelity (Hagen et al. 2005). It is also unlikely that these results were due to males attending multiple leks because only ≈3% of male locations represented lekking locations and we did not observe lek switching (but see above). Previous studies have observed relatively large fall home ranges, though this dynamic was implicitly attributed to use of agricultural areas (Taylor and Guthery 1980, Jamison 2000). Even though our results suggested that home range size was larger in the fall when compared to the winter, the effect was relatively small. We can offer limited comparisons to other home range estimates during the over-winter, as these studies utilized MCPs estimated with a minimum number of points (≥15 locations per bird; Taylor and Guthery 1980, Toole 2005) or calculated monthly home range sizes (Jamison 2000).

The roosting behavior of LPCs is poorly understood. Copelin (1963) observed that LPCs in Oklahoma roosted on ridges, in draws, and in ravines and did not roost in locations with overhead cover >3 feet high. Riley et al. (1993) noted that LPC over-winter roosting sites in New Mexico were dominated by grass and suggested that LPCs may have roosted near foraging areas. Neither of these studies investigated roost location proximity to the nearest known lek. We did not detect a difference in proximity to nearest lek between roost and day locations as one might expect with a central-place species like the LPC.

While previous LPC habitat selection studies have indicated selection for shrubby habitat (Jamison 2000, Patten et al. 2005, Bell et al. 2010), our results strongly suggested that over-wintering LPCs in our study area consistently selected for landcover with <15% canopy coverage of shrubs. This ranking was consistent across years and methodologies for defining habitat use. Recent research in Texas has indicated that survival is lower for LPCs in landscapes dominated by shinnery oak as compared to those dominated by sandsage (Lyons et al. 2009). This could have influenced habitat selection by LPCs at our study area. Our results must be considered with some caution because of our low sample size for female LPCs (n = 4 for only 1 over-winter). The fact that we did not observe LPCs using agricultural fields is likely related to the type of agriculture near study leks. Most agricultural fields near our study leks were planted in wheat. Previous laboratory research on greater prairie-chickens (*Tympanuchus cupido*) indicated they strongly avoided eating winter wheat grass (Heffron and Parrish 2005).

We censored individuals with <50 locations during the over-winter period from compositional analyses (Leban et al. 2001). If habitat selection affects survival at the scale of the home range, then it is possible that these results are fundamentally biased since LPCs that die early will have fewer locations (see Tables A.1 and A.2). However, since individuals that were censored were those that died before we could relocate them at least 50 times, any bias would be toward those that selected habitat that fundamentally increased survival.

The tests we used for data analyses assume independence. Excluding lekking behavior, LPCs are known to be gregarious during the over-winter period (e.g., Schwilling 1955, Copelin 1963, Taylor and Guthery 1980, Salter et al. 2005). During the

2 years of our study, radiocollared male LPCs that were accidentally flushed during triangulation (for which the observer recorded an accurate number of LPC that flushed) were more likely to be alone than with another LPC (54%, $n = 68$; assumes a complete flush). Less than 3% of male LPC locations during the study were locations on leks. Finally, we never observed LPCs utilizing or flying to grain fields in groups, which would have further violated the assumption of independence. Because we only sampled individuals one time per day and systematically rotated sampling time, we assumed that daily locations for each individual were independent. Taken together, we feel that the assumption of independence was not seriously violated during this study.

MANAGEMENT IMPLICATIONS

Our results indicated that LPCs tended to remain within 5.0 km their leks-of-capture and within 2.4 km of a known lek. Previous conservation and management guidelines (Applegate and Riley 1998, Jamison et al. 2002) have suggested that management should take place within 4.8 km of LPC leks. This is desirable because processes at larger spatial scales are likely important to LPCs (Westemeier 1998, Fuhlendorf et al. 2002). However, if management resources are limited our data also indicated that native prairie within 2.4 km of all leks should receive the highest priority for LPC over-winter conservation and management activities in the northeast Texas Panhandle. Determining the area necessary to maintain LPC population will depend on several factors including the number of leks in an area and their degree of overlap. If populations regularly use agriculture fields this must also be taken into consideration. Our data suggested that the assumption that over-wintering male LPCs have an equal opportunity to select resources within 4.8 km of a lek might be untenable for some populations. Our results also suggest that the over-winter period should be treated as at least 2 seasons because we observed differences in multiple space-use variables between the fall and winter seasons.

Our results underscore the need to conserve landcover with <15% canopy coverage of shrubs and <50% canopy coverage of decadent little bluestem for over-wintering LPC in the northeast Texas Panhandle. These results must be interpreted tentatively because of low sample sizes for females. We urge future resource selection studies for LPCs to investigate habitat selection using home ranges as the available habitat to offer comparisons to this population. Finally, if LPC populations in different parts of the species' range select habitat differentially, a more regional approach to habitat management may be necessary.

LITERATURE CITED

Aebischer, N. J., P. A. Robertson, and R. E. Kenward. 1993. Compositional analysis of habitat use from animal radio-tracking data. Ecology 74:1313–1325.

Applegate, R. D., and T. Z. Riley. 1998. Lesser prairie-chicken management. Rangelands 20:13–15.

Bell, L. A., S. D. Fuhlendorf, M. A. Patten, D. H. Wolfe, and S. K. Sherrod. 2010. Lesser prairie-chicken hen and brood habitat use on sand shinnery oak. Rangeland Ecology and Management 63:578–486.

Bender, S., S. Shelton, K. C. Bender, and A. Kalmbach, editors. 2005. Texas comprehensive wildlife conservation strategy: 2005–2010. Texas Parks and Wildlife Department, Austin, USA.

Bingham, R. L., and L. A. Brennan. 2004. Comparison of type I error rates for statistical analyses of resource selection. Journal of Wildlife Management 68:206–212.

Bingham, R. L, L. A. Brennan, and B. M. Ballard. 2010. Discrepancies between euclidean distance and compositional analyses of resource selection data with known parameters. Journal of Wildlife Management 74:582 –587.

Boisvert, J. H., R. W. Hoffman, and K. P. Reese. 2005. Home range and seasonal movements of Columbian sharp-tailed grouse associated with Conservation Reserve Program and mine reclamation. Western North American Naturalist 65:36–44.

Calenge, C. 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling 197:516-519.

Campbell, H. 1972. A population study of lesser prairie-chickens in New Mexico. Journal of Wildlife Management 36:689–699.

Cannon, R. W., F. L. Knopf, and L. R. Pettinger. 1982. Use of LANDSAT data to evaluate lesser prairie chicken habitats in western Oklahoma. Journal of Wildlife Management 46:915–922.

Chamberlain, M. J., B. D. Leopold, and L. M. Conner. 2003. Space use, movements, and habitat selection of adult bobcats (*Lynx rufus*) in central Mississippi. American Midland Naturalist 149:395–405.

Copelin, F. F. 1963. The lesser prairie chicken in Oklahoma. Technical Bulletin 6, Oklahoma Wildlife Conservation Department. Oklahoma City, USA.

Fuhlendorf, S. D., A. J. W. Woodward, D. M. Leslie, and J. S. Shackford. 2002. Multi-scale effects of habitat loss and fragmentation on lesser prairie-chicken populations of the US Southern Great Plains. Landscape Ecology 17:617–628.

Ginter, D. L., and M. J. Desmond. 2005. Influence of foraging and roosting behavior on home-range size and movement patterns of savannah sparrows wintering in south Texas. Wilson Bulletin 117:63–71.

Hagen, C. A., J. C. Pitman, B. K. Sandercock, R. J. Robel, and R. D. Applegate. 2005. Age-specific variation in apparent survival rates of male lesser prairie-chickens. Condor 107:78–86.

Haukos, D. A, and L. M. Smith. 1989. Lesser prairie-chicken nest site selection and vegetation characteristics in tebuthiuron-treated and untreated sand shinnery oak in Texas. Great Basin Naturalist 49:624–626.

Haukos, D. A., L. M. Smith, and G. S. Broda. 1990. Spring trapping of lesser prairie-chickens. Journal of Field Ornithology 61:20–25.

Heffron, M. B., and J. W. Parrish Jr. 2005. Apparent metabolizable energy of seeds in greater prairie-chickens. Transactions of the Kansas Academy of Science 108:93–98.

Jackson, A. S., and R. DeArment. 1963. The lesser prairie chicken in the Texas Panhandle. Journal of Wildlife Management. 27:733–737.

Jamison, B. E. 2000. Lesser prairie-chicken chick survival, adult survival, and habitat selection and movements of males in fragmented rangelands of southwestern Kansas. Thesis, Kansas State University, Manhattan, USA.

Jamison, B. E., J. A. Dechant, D. H. Johnson, L. D. Igl, C. M. Goldade, and B. R. Euliss. 2002. Effects of management practices on grassland birds: Lesser prairie-chicken. Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65–71.

Johnson, K., B. H. Smith, G. Sadoti, T. B. Neville, and P. Neville. 2004. Habitat use and nest site selection by nesting lesser prairie-chickens in southeastern New Mexico. Southwestern Naturalist 49:334–343.

Kernohan, B. J., R. A. Gitzen, and J. J. Millspaugh. 2001. Analysis of animal space use and movements. Pages 125–166 *in* J. J. Millspaugh and J. M. Marzluff, editors. Radio tracking and animal populations. Academic Press, San Diego, California, USA.

Laundré, J. W., T. D. Reynolds, S. T. Knick, and I. J. Ball. 1987. Accuracy of daily point relocations in assessing real movement of radio-marked animals. Journal of Wildlife Management 51:937–940.

Leban, F. A., M. J. Wisdom, E. O. Garton, B. K. Johnson, and J. G. Kie. 2001. Effect of sample size on the performance of resource selection analyses. Pages 291–307 *in* J. J. Millspaugh and J. M. Marzluff editors. Radio tracking and animal populations. Academic Press, San Diego, California, USA.

Lyons, E. K., B. A. Collier, N. J. Silvy, R. R. Lopez, B. E. Toole, R. S. Jones, and S. J. DeMaso. 2009. Breeding and non-breeding survival of lesser prairie-chickens *Tympanuchus pallidicinctus* in Texas, USA. Wildlife Biology 15:89–96.

Mei-Hsiu, H., D. L. Garshelis, Y. Wu, and Y. Wang. 2010. Home ranges of Asiatic black bears in the Central Mountains of Taiwan: gauging whether a reserve is big enough. Ursus 21:81–96.

Mohr, C. O. 1947. Table of equivalent populations of North American small mammals. American Midland Naturalist 37:223–249.

Patten, M. A., D. H. Wolfe, E. Shochat, and S. K. Sherrod. 2005. Effects of microhabitat and microclimate on adult survivorship of the lesser prairie-chicken. Journal of Wildlife Management 69:1270–1278.

Pitman, J. C., B. E. Jamison, C. A. Hagen, R. J. Robel, and R. D. Applegate. 2006. Brood break-up and juvenile dispersal of lesser prairie-chicken in Kansas. Prairie Naturalist 38:85–99.

R Development Core Team. 2008. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Riley, T. Z., C. A. Davis, and R. A. Smith. 1993. Autumn-winter habitat use of lesser prairie-chickens (*Tympanuchus pallidicinctus*, Tetraonidae). Great Basin Naturalist 53:409–411.

Salter, G. C., and R. J. Robel. 2000. Capturing lesser prairie-chickens on leks during fall. Transactions of the Kansas Academy of Science 103:46–47.

Salter, G. C., R. J. Robel, and K. E. Kemp. 2005. Lesser prairie-chicken use of harvested corn fields during fall and winter in southwestern Kansas. Prairie Naturalist 37:1–9.

Schroeder, M. A., and C. E. Braun. 1991. Walk-in traps for capturing greater prairie-chickens on leks. Journal of Field Ornithology 62:378–385.

Schwilling, M. D. 1955. Study of the lesser prairie chicken in southwest Kansas. Kansas Fish and Game 12:10–12.

Seaman, D. E., J. J. Millspaugh, B. J. Kernohan, G.C. Brundige, K. J. Raedeke, and R. A. Gitzen. 1999. Effects of sample size on kernel home range estimates. Journal of Wildlife Management 63:739–747.

Shriver, W. G., T. P. Hodgman, J. P. Gibs, and P. D. Vickery. Home range sizes and habitat use of Nelson’s and Saltmarsh sparrows. Wilson Journal of Ornithology 122:340–345.

Taylor, M. A., and F. S. Guthery. 1980. Fall-winter movements, ranges, and habitat use of lesser prairie-chickens. Journal of Wildlife Management 44:521–524.

Toole, B. E. 2005. Survival, seasonal movements, and cover use by lesser prairie chickens in the Texas Panhandle. Thesis, Texas A&M University, College Station, USA.

National Climatic Data Center. 2008. Climatological data annual summary: Texas. Volume 113. National Oceanographic and Atmospheric Administration, U.S. Department of Commerce, Asheville, North Carolina, USA.

National Climatic Data Center. 2009. Climatological data annual summary: Texas. Volume 114. National Oceanographic and Atmospheric Administration, U.S. Department of Commerce, Asheville, North Carolina, USA.

Westemeier, R. L., J. D. Brawn, S. A. Simpson, T. L. Esker, R. W. Jansen, J. W. Walk, E. L. Kershner, J. L. Bouzat, and K. N. Paige. 1998. Tracking the long-term decline and recovery of an isolated population. Science 282:1695–1698.

Wilson, R. R., M. B. Hooten, B. N. Strobel, and J. A. Shivik. 2010. Accounting for individuals, uncertainty, and multiscale clustering in core area estimation. Journal of Wildlife Management 74:1343–1352.

Woodward, A. J. W., S. D. Fuhlendorf, D. M. Leslie Jr., and J. Shackford. 2001. Influence of landscape composition and change on lesser prairie-chicken (*Tympanuchus pallidicinctus*) populations. American Midland Naturalist 145:261–274.

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology 70:164–168.

Table 2.1. Landcover types used for delineation of landcover patches in our Geographic Information System (GIS) coverage.

Cover type	Classification[a]	Description
1	Other prairie	Native prairie >15% canopy coverage shrubs, and/or >50% canopy coverage decadent little bluestem (*Schizachyrium scoparium*).
2	Grassland	Native prairie <15% canopy coverage shrub, and <50% canopy coverage decadent little bluestem.
3	Shinnery oak	Native prairie >15% canopy coverage shinnery oak (*Quercus havardii*).
4	Pasture	Introduced grasses (e.g., *Eragrostis curvela*, *Bothriochloa ischaemum, Panicum coloratum)* and heavily-manipulated pasture (e.g., mowed prairie).
5	Cultivation	Cultivated field.
6	Windbreak or tree	Woody vegetation >2m in height.
7	Water	Stock tanks, ponds, streams, wetlands.
8	Prairie-dog town	Active black-tailed prairie-dog (*Cynomys ludovicianus*) colony.
9	Vegetated linear corridor	2-track roads, vegetated pipe scars.

Table 2.1. Continued.

Cover type	Classification[a]	Description
10	Improved road	Paved road.
11	Bare ground or sparsely-vegetated	Unimproved roads, caliche pits, oil pads, portions of highly-eroded slopes.
12	Regenerated burn	Native prairie within the approximate boundaries of the 2006 I-40 wildfire.

[a] Landcover types 1–11 were classified using 1-m National Agriculture Imagery Program (NAIP) aerial imagery taken during the growing season of 2008. Landcover type 12 was classified using 1-m NAIP aerial imagery taken during the growing season of 2006.

Table 2.2. Home range sizes, minimum daily movements, distances to leks-of-capture, and distances to nearest known leks for male lesser prairie-chickens in the northeast Texas Panhandle during the over-winter of 2008–2009.

	Season							
	Fall				Winter			
Estimate	*n*	Mean	SE	Median	*n*	Mean	SE	Median
95% fixed kernel home range area (ha)	11	670.6	98.5	604.2	11	514.5	167.3	348.3
Minimum daily movement (m)	15	613.7	39.8	636.7	12	483.9	40.2	437.2
Distance from lek-of-capture (m)	15	931.3	97.0	811.0	12	840.8	218.5	611.7
Distance from nearest known lek (m)	15	803.3	89.7	663.2	12	738.7	195.7	564.6

Table 2.3. Home range sizes, minimum daily movements, distances to leks-of-capture, and distances to nearest known leks for male lesser prairie-chickens in the northeast Texas Panhandle during the over-winter of 2009–2010.

	Season							
	Fall				Winter			
Estimate	*n*	Mean	SE	Median	*n*	Mean	SE	Median
95% fixed kernel home range area (ha)	18	599.5	181.1	376.9	16	480.8	129.5	248.4
Minimum daily movement (m)	21	630.0	39.34	650.9	17	481.6	29.4	463.4
Distance from lek-of-capture (m)	24	962.3	178.0	711.6	18	1271.4	333.8	672.2
Distance from nearest known lek (m)	24	667.0	40.9	640.7	18	550.0	24.0	555.92

Table 2.4. Home range sizes, minimum daily movements, distances to leks-of-capture, and distances to nearest known leks for female lesser prairie-chickens in the northeast Texas Panhandle during the fall of 2008.

Estimate	*n*	Mean	SE	Median
95% fixed kernel home range area (ha)	3	319.5	50.1	299.4
Minimum daily movement (m)	3	593.2	57.6	552.0
Distance from lek of capture (m)	3	1,923.0	789.3	1,396.1
Distance from nearest known lek (km)	3	1,367.8	274.2	1,358.2

Table 2.5. Home range sizes, minimum daily movements, distances to leks-of-capture, and distances to nearest known leks for female lesser prairie-chickens in the northeast Texas Panhandle during the over-winter of 2009–2010.

	Season							
	Fall				Winter			
Estimate	*n*	Mean	SE	Median	*n*	Mean	SE	Median
95% fixed kernel home range area (ha)	3	760.6	452.0	433.1	4	282.3	74.8	256.8
Minimum daily movement (m)	4	499.4	100.0	489.9	4	390.8	78.5	361.7
Distance from lek of capture (m)	5	1,217.6	181.6	1,329.5	4	1,223.0	482.3	922.0
Distance from nearest known lek (km)	5	1,057.4	199.3	820.6	4	697.5	151.8	613.8

Table 2.6. Ranking matrix of habitat selection for over-wintering male lesser prairie-chickens in the northeast Texas Panhandle; use defined as the proportion of locations within patches of a certain landcover type. Triple signs represent significant deviation from random at $P < 0.1$.

	Cover type			
Cover type	Other prairie	Grassland	Shinnery oak	Rank
2008–2009 (*n* = 12)				
Other prairie	·	− − −	+	1
Grassland	+ + +	·	+ + +	2
Shinnery oak	−	− − −	·	0
2009–2010 (*n* = 20)				
Other prairie	·	− − −	+ + +	1
Grassland	+ + +	·	+ + +	2
Shinnery oak	− − −	− − −	·	0

Table 2.7. Ranking matrix of habitat selection for over-wintering male lesser prairie-chickens in the northeast Texas Panhandle; use defined as proportions of landcover types within the core area home range. Triple signs represent significant deviation from random at $P < 0.1$.

	Cover type			
Cover type	Other prairie	Grassland	Shinnery oak	Rank
2008–2009 (n = 11)				
Other prairie	·	− − −	+ + +	1
Grassland	+ + +	·	+ + +	2
Shinnery oak	− − −	− − −	·	0
2009–2010 (n = 18)				
Other prairie	·	− − −	+ + +	1
Grassland	+ + +	·	+ + +	2
Shinnery oak	− − −	− − −	·	0

Table 2.8. Ranking matrix of habitat selection for over-wintering male lesser prairie-chickens in the northeast Texas Panhandle; use defined as proportions of landcover types within a buffered area of 116.1 m from locations. Triple signs represent significant deviation from random at $P < 0.1$.

Cover type	Cover type: Other prairie	Grassland	Shinnery oak	Rank
2008–2009 (n = 12)				
Other prairie	·	− − −	+	1
Grassland	+ + +	·	+ + +	2
Shinnery oak	−	− − −	·	0
2009–2010 (n = 20)				
Other prairie	·	− − −	+	1
Grassland	+ + +	·	+ + +	2
Shinnery oak	−	− − −	·	0

Table 2.9. Ranking matrix of habitat selection for female lesser prairie-chickens ($n = 4$) in the northeast Texas Panhandle during the over-winter of 2009–2010; use defined as the proportion of locations within patches of a certain landcover type. Triple signs represent significant deviation from random at $P < 0.1$.

	Cover type			
Cover type	Other prairie	Grassland	Shinnery oak	Rank
Other prairie	·	– – –	+	1
Grassland	+ + +	·	+ + +	2
Shinnery oak	–	– – –	·	0

Table 2.10. Ranking matrix of habitat selection for female lesser prairie-chickens (*n* = 4) in the northeast Texas Panhandle during the over-winter of 2009–2010; use defined as proportions of landcover types within the core area home range. Triple signs represent significant deviation from random at *P* < 0.1.

	Cover type			
Cover type	Other prairie	Grassland	Shinnery oak	Rank
Other prairie	·	–	+ + +	1
Grassland	+	·	+ + +	2
Shinnery oak	– – –	– – –	·	0

Table 2.11. Ranking matrix of habitat selection for female lesser prairie-chickens ($n = 4$) in the northeast Texas Panhandle during the over-winter of 2009–2010; use defined as proportions of landcover types within a buffered area of 116.1 m from locations. Triple signs represent significant deviation from random at $P < 0.1$.

	Cover type			
Cover type	Other prairie	Grassland	Shinnery oak	Rank
Other prairie	·	–	+	1
Grassland	+	·	+ + +	2
Shinnery oak	–	– – –	·	0

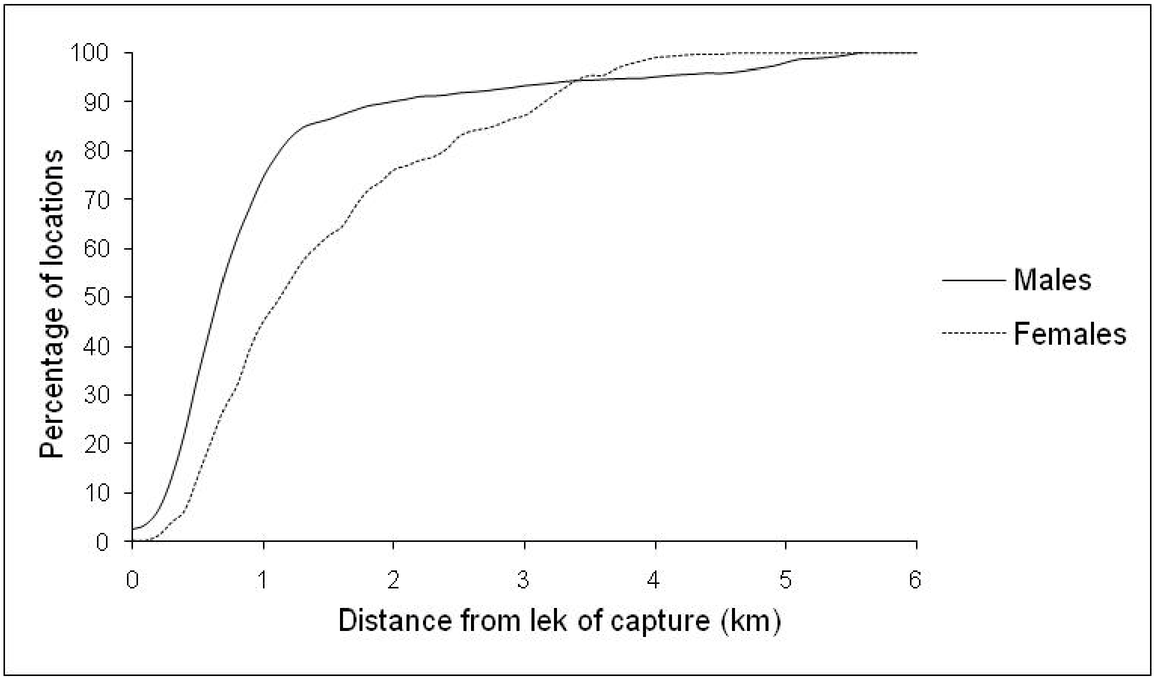

Figure 2.1. Percent of lesser prairie-chicken locations in the northeast Texas Panhandle plotted against the distance to leks-of-capture (km) during the over-winters of 2008–2009 and 2009–2010 combined.

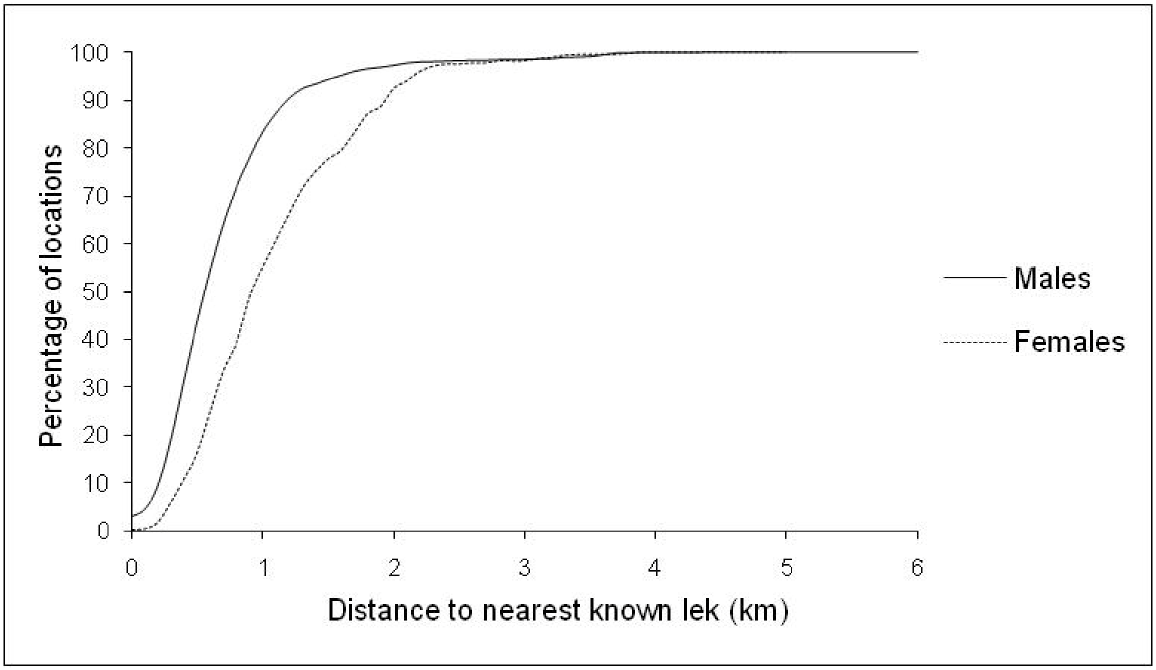

Figure 2.2. Percent of lesser prairie-chicken locations in the northeast Texas Panhandle plotted against the distance to the nearest known lek (km) during the over-winters of 2008–2009 and 2009–2010 combined.

CHAPTER III

OVER-WINTER SURVIVAL OF LESSER PRAIRIE-CHICKENS IN THE NORTHEAST TEXAS PANHANDLE IN RELATION TO LANDSCAPE CHARACTERISTICS

ABSTRACT

For lesser prairie-chickens (*Tympanuchus pallidicinctus*; LPC), the effects of landscape characteristics on over-winter survival are poorly understood. We used habitat-dependant survival modeling to investigate how landscape composition and configuration at the scale of the home range affects the over-winter survival of LPCs in the northeast Texas Panhandle. We found cause-specific mortality rates were equally attributable to mammalian (M = 0.133, SE = 0.056) and avian (M = 0.198, SE = 0.063) predators. We evaluated 22 competing survival models using the second-order Akaike's Information Criterion (AIC_c). That model suggested larger patches of shinnery oak had a negative effect on survival. However, limited sample size likely contributed to uncertainty in our models. Our results suggested that managing for large, contiguous patches of shinnery oak would be counter-productive for LPC over-winter survival.

INTRODUCTION

Prairie grouse biologists and managers need to think "outside the box" and test their assumptions (Applegate et al. 2004). Wildlife habitat management should be informed by knowledge of what habitat species select (or to which individuals are relegated), as well as the survival outcomes associated with that habitat. Traditional wildlife habitat studies typically investigate habitat selection by a species and then assume that selected habitats are of greater quality. For territorial, gregarious, or central-place species, this assumption may be untenable. Grouse may even select habitat that is detrimental to fitness. For black grouse (*Tetrao tetrix*), large-scale fragmentation by agriculture may reduce nest success even though these habitats are regularly utilized by hens with broods (Kurki and Linden 1995).

The various ecological importances of shrublands and grasslands are poorly understood for lesser prairie-chickens (LPC; *Tympanuchus pallidicinctus*). Previous studies have suggested that LPCs may exhibit positive selection for shrubs at large (Taylor and Guthery 1980, Johnson et al. 2004) and small (e.g. Patten et al. 2005, Bell et al. 2010) spatial scales, and Woodward et al. (2001) recommended maintaining shrubland landcover within 4.8 km of leks to maintain LPC populations over time. Lesser prairie-chicken survival has been previously investigated in Kansas (e.g., Hagen et al. 2005, Pitman et al. 2006, Hagen et al. 2007), Texas (Toole 2005, Jones 2009, Lyons et al. 2009), New Mexico (Merchant 1982, Patten et al. 2005, Wolfe et al. 2007), and Oklahoma (Patten et al. 2005, Wolfe et al. 2007). In Texas, Lyons et al. (2009) found that landscapes dominated by shinnery oak (southwest Texas Panhandle) exhibited lower adult survival as compared to those dominated by sand sagebrush (northeast Texas Panhandle) between 2001 and 2005. Conversely, Patten et al. (2005) concluded that percent cover of shrubs at fine spatial scales positively influenced survival for adult LPCs in New Mexico and northwest Oklahoma. The effects of habitat on survival clearly warrant further study. Our objectives were to 1) investigate how landscape characteristics affect over-winter survival and 2) determine cause-specific mortality probabilities for LPCs in the northeast Texas Panhandle.

STUDY AREA

We conducted research in the Rolling Plains Ecoregion (Bender et al. 2005) of the northeast Texas Panhandle in Gray and Hemphill counties. At the Hemphill county study site (National Weather Service Cooperative Station ID. 411408, 0 km from the study area), there was 80.9 cm of annual precipitation in 2008 (National Climatic Data Center [NCDC] 2008) and 66.9 cm of annual precipitation in 2009 (NCDC 2009). At the Gray County study site (National Weather Service Cooperative Station ID. 416776, ≈25 km from study area), there was 54.3 cm of annual precipitation in 2008 (NCDC 2008) and 61.7 cm of annual precipitation in 2009 (NCDC 2009).

Sand sagebrush (*Artemisia filifolia*), shinnery oak (*Quercus havardii*), and grassland communities characterized the landscape of the study area. A description of common flora of the region can be found in Jackson and DeArment (1963). Conservation reserve program (CRP) fields of primarily monospecific pastures of non-native grasses such as weeping lovegrass (*Eragrostis curvula*), yellow bluestem (*Bothriochloa ischaemum*), and kleingrass (*Panicum coloratum*) were interspersed in native rangeland. Land-use in the area included cattle ranching, oil and natural gas exploration and extraction, and row-crop agriculture (primarily wheat; *Triticum aestivum*). Anthropogenic features included improved and unimproved roads, scattered buildings, agricultural infrastructure, transmission lines of various capacities, barbed-wire fences, and oil and natural gas extraction pads. All study leks were located on private property.

METHODS

Capture and Radiomarking

We used walk-in traps with leads (Schroeder and Braun 1991, Salter and Robel 2000) and rocket-nets (Haukos et al. 1990) to capture LPCs on leks during the fall (early-Oct to mid-Nov) and spring (mid-Mar to late-May). Immediately following removal from a trap or net, we affixed a 12-g to 16-g necklace-style radio transmitter (≤3% of total body mass) operating at a unique frequency between 150.000–151.999 MHz. Transmitters were equipped with a 12-hour mortality sensor. We affixed a uniquely numbered leg band (size 12, National Band and Tag, Newport, KY) to LPCs before releasing them at the site of capture. Capture was conducted under the Texas Tech Institutional Animal Care and Use Committee (IACUC) approval number 07050-08.

Radiotelemetry

We relocated LPCs using a 3-element handheld Yagi antenna and a radio-receiver (R2000, Advanced Telemetry Systems, Inc., Isanti, MN). We triangulated the signal source from geo-referenced base-stations stored in hand-held Global Positioning System (GPS) units (76CX, Garmin International Inc., Olathe, KS). We traveled between base-stations using all terrain vehicles or trucks. We collected all azimuths for a triangulation event within 20 min to minimize error. We used program LOAS (Ecological Software Solutions, Hegymagas, Hungary) to estimate triangulated LPC locations. We systematically rotated sampling throughout the diel period as to include locations from the first third of daylight hours, the middle third of daylight hours, the last third of daylight hours, and over-night (2400 hr to 1 hr before sunrise). We attempted to collect over-night locations 1 time per week at the Hemphill County study site. We were unable to collect over-night locations at the Gray County study site because of logistical constraints. We collected only survival status when we were unable to triangulate due to inclement weather, logistic or time constraints, a moving signal source, or poor access (limited availability of roads or trails). When we heard a mortality signal, we tracked to the signal source and classified the cause of mortality according to Dumke and Pils (1973). We classified the cause of mortality for individuals with insufficient evidence as "cause unknown".

Landcover Determination

We imported aerial imagery (National Aerial Imagery Program [NAIP], 1-m resolution, 2008 imagery) into ArcMap 9.3 (ArcInfo, Environmental Systems Research Institute, Redlands, CA). We then delineated patches of 12 pre-determined landcover types (see Table 3.1 for a list and description) into a polygon-based coverage (see Table B.1). These land cover classifications were somewhat arbitrary, but were chosen specifically to 1) allow results to be comparable to previous LPC research (Woodward et al. 2001, Fuhlendorf et al. 2002), 2) reflect the landcover diversity of the study area, 3) reflect the resolution of available aerial imagery, and 4) be useful for habitat-dependant survival analyses.

We ground-truthed 130 randomly generated points using a handheld GPS unit (76CX, Garmin International Inc., Olathe, KS) in early November 2010. We generated random points 1) within 2.5 km of a known lek, 2) on properties for which we had access permission, and 3) $\geq$10 m from a landcover edge. Because the majority (69.1%) of the Gray County study site within 2.5 km of known leks was classified as landcover type 12 (native prairie regenerating following a wildfire) which could not be accurately ground-truthed in November 2010, we tested our classification methodology at the Hemphill County study site. An observer stood at a point, and then classified the landcover within an area approximately 10 m from the point in all directions using the same classification types as the landcover map. To avoid bias, the observer did not have access to the landcover map or the map's classification of that point. We classified 110 random points (84.62%) as the same type classified by the landcover map (Table C.1). Additionally, we ground-truthed ≥5 areas that were representative of landcover types 4, 5, 6, 7, 8, 9, and 11 during data collection activities during the over-winters of 2008–2009 and 2009–2010. All landcover classified as type 10 (improved roads) were ground-truthed in early November 2010.

Home Range and Landscape Metrics

We used the package adehabitat (Calenge 2006) in program R (R Development Core Team 2008) to compute 95% fixed kernel home ranges (Worton 1989). Seaman et al. (1999) recommended a minimum of 30 locations per individual when calculating kernel home ranges. We used 28 as the minimum number of locations to compute home ranges to avoid sacrificing data. We were unable to collect a sufficient number of locations for 4 individuals that died comparatively early (1 during the over-winter of 2008–2009 and 3 during the over-winter of 2009–2010). Because excluding these individuals would have biased our results, we estimated home ranges for these birds by calculating the center of an individual's estimated locations and then buffering that point by a radius such that the area of the resultant circle would equal the gender-specific average over-winter home range area. We clipped our landcover map by the home range for each individual in ArcMap. We then calculated various landscape metrics (see Table

3.2) within each home range using the Patch Analyst extension (Elkie et al. 1999) for ArcGIS.

Data Analysis

We conducted survival analyses using PROC PHREG in Statistical Analysis Software (SAS; v. 9.2, SAS Institute, Cary, NC) using the staggered entry approach (Pollock et al. 1989). When we were unsure of the exact date of a mortality event, we calculated it as the midpoint between the last live encounter date and the first day we heard the mortality signal. We estimated cause-specific mortality ($M = 1 – S \pm SE$) rates by right-censoring competing failure types along with birds with unknown fates (emigrated out of the study area, radio-failure, or survival beyond 28 February). No LPCs died within 14 days of capture during our study, so we did not consider an adjustment period. We assumed that radiomarking did not affect survival (Hagen et al. 2006). We developed 22 a priori models that examined mortality hazard as a function of explanatory variables. Of these models, 3 were categorical (site, year, and gender) and 18 were spatially implicit and continuous (Table 3.2). We also included a model that had no covariates. Because of limited sample size (n = 17 morality events), we compared model parsimony using the second-order Akaike's Information Criterion (AIC_c; Anderson 2008). We tested for proportionality of hazards using PROC CORR in SAS (Kleinbaum and Klein 2005). We considered models to be plausible when the difference between their AIC_c value and the lowest AIC_c value (ΔAIC_c) was <2.

RESULTS

We captured and monitored 41 LPCs (34 males and 7 hens) from 8 leks during the course of the study. We collected 1,229 locations from 19 LPCs during the over-winter of 2008–2009, and 1,984 locations from 29 LPCs during the over-winter of 2009–2010. We were unable to hear a radio signal 3.9% of the days we checked for one, however 50.4% of those events were due to a single adult female that temporarily left the study area during both years of the study.

The estimated over-winter survival probability for LPCs was 0.626 (SE = 0.071). Of the 17 mortality events that we recorded, we attributed 8 to avian predators, 5 to mammalian predators, and 4 to unknown causes (Figure 3.1). Lesser prairie-chickens whose morality was attributed to avian predators exhibited the greatest cause-specific mortality (M = 0.198, SE = 0.063, 90% CI = 0.088–0.295), followed closely by LPCs whose mortality was attributed to mammalian predators (M = 0.133, SE = 0.056, 90% CI = 0.037–0.220). We recovered 4 transmitters in type 1 landcover (“other” native rangeland), 9 in type 2 landcover (grassland), and 2 in type 12 landcover (native prairie regenerating from a wildfire). The location data for 2 mortality locations were lost after collection. One female, whose mortality we classified as “cause unknown”, showed no visible signs of injury or trauma. She was found dead, crouched upright beneath a sandsage bush. No recovered carcasses showed external evidence of collisions with fences or power lines.

The PROC CORR procedure indicated that the assumption of proportionality of hazards was met by all the covariates in our models (p-values >0.05), so we did not stratify any of our models. Model selection (Table 3.3) indicated that our 3 most parsimonious models included mean patch size of shinnery oak within the home range and that those models had a combined weight of 0.998. The model that included only mean patch size of shinnery oak had the lowest AIC_c value (AIC_c = 90.299) and a model weight of 0.702. The 85% confidence interval for the beta parameter estimate of this model overlapped zero ($\beta = 0.104$, 85% CI = $-0.080 \leq 0.104 \leq 0.289$) and the sign of the hazard ratio indicated a negative effect on survival (1.110). No other landscape metrics appeared to influence LPC survival (Table 3.3).

DISCUSSION

Given the relatively small number of mortality events, inference from our cause-specific survival rates should made tentatively. If there was a systematic bias in the “cause unknown” category, this could have substantially affected our results. In Kansas, Hagen et al. (2007) attributed the majority of female LPC mortality events to mammalian predators, though they observed an increase in raptor predation during the early spring (Mar–Apr) and winter (Nov–Feb) as compared to the summer. In Oklahoma and New Mexico, Wolfe et al. (2007) attributed the greatest number of mortality events to predation by raptors, followed by collisions, and then by mammals. That study also observed a peak in raptor predation in the early spring (Mar–Apr) and autumn (Sep–Oct). Wolfe et al. (2007) used a substantially different methodology in that they assumed that any carcass found within 20-m of a fence or power line was killed by that feature. We did not make this assumption. Interpreted in the context of previous studies, it appears that both avian and mammalian predators are important during the over-winter period.

Of the models that we examined, only mean patch size of shinnery oak appeared to influence survival for over-wintering LPCs in the northeast Texas Panhandle. This model suggested that increases in mean patch size of shinnery oak negatively affects survival. The confidence intervals of the beta parameter estimate for this model overlapped zero, but this uncertainty is not unexpected given the small number of mortalities during the course of our study (n = 17). Models including the proportion of home range in shinnery were predictive only when they also included mean patch size of shinnery, indicating this was not an explanatory covariate. Shinnery oak landcover patches often included small mottes, but our model of edge density of trees within the home range was not a competitive model ($w_i < 0.001$). Past research has given contradictory results on the effect of shrubs on survival (Patten et al. 2005, Lyons et al. 2009), although these studies were conducted at very different spatial scales than each other and this study.

Subsequent studies should investigate the abundance and habitat selection dynamics of avian and mammalian predators within shinnery oak rangelands to help elucidate why mean patch size of shinnery oak patches may negatively affect LPC survival, though the experimental design of this study was insufficient to address this. Furthermore, our methodology categorized any landcover with >15% canopy coverage of shinnery oak the same. Subsequent studies need to address the relative quality of shinnery rangelands and move beyond simple presence/absence classifications. Such a study might also clarify why habitat selection studies across the LPC's range have been contradictory

MANAGEMENT IMPLICATIONS

Our data suggested that predation by both avian and mammalian predators should be considered in management plans for over-wintering LPCs. Our data also suggested that managing for large patches shinnery oak would be counter-productive for LPC over-winter survival in the northeast Texas Panhandle. Because of the large amount of uncertainty in our survival models, we recommend further study at the scale of the home range to offer comparisons to our results.

LITERATURE CITED

Anderson, D. R. 2008. Model based inference in the life sciences: a primer on evidence. Springer, New York, New York, USA.

Applegate, R. D., C. K. Williams, and R. R. Manes. 2004. Assuring the future of prairie grouse: dogmas, demagogues, and getting outside the box. Wildlife Society Bulletin 32:104–111.

Bell, L. A., S. D. Fuhlendorf, M. A. Patten, D. H. Wolfe, and S. K. Sherrod. 2010. Lesser prairie-chicken hen and brood habitat use on sand shinnery oak. Rangeland Ecology and Management 63:578–486.

Bender, S., S. Shelton, K. C. Bender, and A. Kalmbach, editors. 2005. Texas comprehensive wildlife conservation strategy: 2005–2010. Texas Parks and Wildlife Department, Austin, USA.

Calenge, C. 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling 197:516–519.

Dumke, R. T., and C. M. Pils. 1973. Mortality of radio-tagged pheasants on the Waterloo Wildlife Area. Wisconsin Department of Natural Resources Technical Bulletin Number 72. Madison, USA.

Elkie, P., R. Rempel, and A. Carr. 1999. Patch Analyst User's Manual. TM-002, Northwest Region Science and Technology, Ontario Ministry Natural Resources. Thunder Bay, Canada.

Fuhlendorf, S. D., A. J. W. Woodward, D. M. Leslie, and J. S. Shackford. 2002. Multi-scale effects of habitat loss and fragmentation on lesser prairie-chicken populations of the US Southern Great Plains. Landscape Ecology 17:617–628.

Hagen, C. A., J. C. Pitman, B. K. Sandercock, R. J. Robel, and R. D. Applegate. 2005. Age-specific variation in apparent survival rates of male lesser prairie-chickens. Condor 107:78–86.

Hagen, C. A., J. C. Pitman, B. K. Sandercock, R. J. Robel, and R. D. Applegate. 2007. Age-specific survival and probable causes of mortality in female lesser prairie-chickens. Journal of Wildlife Management 71:518–525.

Hagen, C. A., B. K. Sandercock, J. C. Pitman, R. J. Robel, and R. D. Applegate. 2006. Radiotelemetry survival estimates of lesser prairie-chickens in Kansas: Are there transmitter biases? Wildlife Society Bulletin 34:1064–1069.

Haukos, D. A., L. M. Smith, and G. S. Broda. 1990. Spring trapping of lesser prairie-chickens. Journal of Field Ornithology 61:20–25.

Jackson, A. S., and R. DeArment. 1963. The lesser prairie chicken in the Texas Panhandle. Journal of Wildlife Management 27:733–737.

Johnson, K., B. H. Smith, G. Sadoti, T. B. Neville, and P. Neville. 2004. Habitat use and nest site selection by nesting lesser prairie-chickens in southeastern New Mexico. Southwestern Naturalist 49:334–343.

Jones, R. S. 2009. Seasonal survival, reproduction, and use of wildfire areas by lesser prairie-chickens in the northeast Texas Panhandle. Thesis, Texas A&M University, College Station, USA.

Kleinbaum, D. G., and M. Klein. 2005. Survival analysis: a self-learning text. Second edition. Springer-Verlag, New York, New York, USA.

Kurki, S., and H. Linden. 1995. Forest fragmentation due to agriculture affects the reproductive success of the ground-nesting black grouse *Tetrao tetrix*. Ecography 18:109–113.

Lyons, E. K., B. A. Collier, N. J. Silvy, R. R. Lopez, B. E. Toole, R. S. Jones, and S. J. DeMaso. 2009. Breeding and non-breeding survival of lesser prairie-chickens *Tympanuchus pallidicinctus* in Texas, USA. Wildlife Biology 15:89–96.

Merchant, S. S. 1982. Habitat-use, reproductive success, and survival of female lesser prairie-chickens in two years of contrasting weather. Thesis, New Mexico State University, Las Cruces, USA.

National Climatic Data Center. 2008. Climatological data annual summary: Texas. Volume 113. National Oceanographic and Atmospheric Administration, U.S. Department of Commerce, Asheville, North Carolina, USA.

National Climatic Data Center. 2009. Climatological data annual summary: Texas. Volume 114. National Oceanographic and Atmospheric Administration, U.S. Department of Commerce, Asheville, North Carolina, USA.

Patten, M. A., D. H. Wolfe, E. Shochat, and S. K. Sherrod. 2005. Effects of microhabitat and microclimate on adult survivorship of the lesser prairie-chicken. Journal of Wildlife Management 69:1270–1278.

Pitman, J. C., C. A. Hagen, B. E. Jamison, R. J. Robel, T. M. Loughin, and R. D. Applegate. 2006. Survival of juvenile lesser prairie-chickens in Kansas. Wildlife Society Bulletin 34:675–681.

Pollock, K. H., S. R. Winterstein, C. M. Bunck, and P. D. Curtis. 1989. Survival analysis in telemetry studies; the staggered entry design. Journal of Wildlife Management 53:7–15.

R Development Core Team. 2008. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Salter, G. C., and R. J. Robel. 2000. Capturing lesser prairie-chickens on leks during fall. Transactions of the Kansas Academy of Science 103:46–47.

Schroeder, M. A., and C. E. Braun. 1991. Walk-in traps for capturing greater prairie-chickens on leks. Journal of Field Ornithology 62:378–385.

Seaman, D. E., J. J. Millspaugh, B. J. Kernohan, G.C. Brundige, K. J. Raedeke, and R. A. Gitzen. 1999. Effects of sample size on kernel home range estimates. Journal of Wildlife Management 63:739–747.

Taylor, M. A., and F. S. Guthery. 1980. Fall-winter movements, ranges, and habitat use of lesser prairie-chickens. Journal of Wildlife Management 44:521–524.

Toole, B. E. 2005. Survival, seasonal movements, and cover use by lesser prairie chickens in the Texas Panhandle. Thesis, Texas A&M University, College Station, USA.

Wolfe, D. H., M. A. Patten, E. Shochat, C. L. Pruett, and S. K. Sherrod. 2007. Causes and patterns of mortality in lesser prairie-chickens *Tympanuchus pallidicinctus* and implications for management. Wildlife Biology 13:95–104.

Woodward, A. J. W., S. D. Fuhlendorf, D. M. Leslie Jr., and J. Shackford. 2001. Influence of landscape composition and change on lesser prairie-chicken (*Tympanuchus pallidicinctus*) populations. American Midland Naturalist 145:261–274.

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology 70:164–168.

Table 3.1. Landcover types used for delineation of habitat patches within our study areas in the northeast Texas Panhandle for use in habitat-dependant survival analyses.

Cover type	Classification[a]	Description
1	Other prairie	Native prairie >15% canopy coverage shrubs, and/or >50% canopy coverage decadent little bluestem (*Schizachyrium scoparium*).
2	Grassland	Native prairie <15% canopy coverage shrub, and <50% canopy coverage decadent little bluestem.
3	Shinnery oak	Native prairie >15% canopy coverage shinnery oak (*Quercus havardii*).
4	Pasture	Introduced grasses (e.g., *Eragrostis curvela, Bothriochloa ischaemum, Panicum coloratum)* and heavily-manipulated pasture (e.g., mowed prairie).
5	Cultivation	Cultivated field.
6	Windbreak or tree	Woody vegetation >2m in height.
7	Water	Stock tanks, ponds, streams, wetlands.
8	Prairie-dog town	Active black-tailed prairie-dog (*Cynomys ludovicianus*) colony.
9	Vegetated linear corridor	2-track roads, vegetated pipe scars.

Table 3.1. Continued.

Cover type	Classification[a]	Description
10	Improved road	Paved road.
11	Bare ground or sparsely-vegetated	Unimproved roads, caliche pits, oil pads, portions of highly-eroded slopes.
12	Regenerated wildfire	Native prairie within the approximate boundaries of the 2006 I-40 wildfire.

[a] Landcover types 1–11 were classified using 1-m National Agricultural Imagery Program (NAIP) aerial imagery taken during the growing season of 2008. Landcover type 12 was classified using 1-m NAIP aerial imagery taken during the growing season of 2006.

Table 3.2. Description of metrics comprising the a priori candidate model set used in habitat-dependant survival analyses for over-wintering lesser prairie-chickens in the northeast Texas Panhandle, 2008–2011.

Metric[a]	Description
%OTHER	Proportion in landcover type 1.
%GRASS	Proportion in landcover type 2.
%SOAK	Proportion in landcover type 3.
%SHRUB	Proportion in landcover types 1 and 3.
ED	Overall edge density.
EDWOOD	Edge density of woody vegetation >2m.
MPS	Overall mean patch size.
MPSOTHER	Mean patch size of landcover type 1.
MPSGRASS	Mean patch size of landcover type 2.
MPSSOAK	Mean patch size of landcover type 3.
SDI	Shannon diversity index.
SEI	Shannon evenness index.

[a] Calculated within the home range.

Table 3.3. Ranking of a priori candidate models predicting survival hazard for over-wintering lesser prairie-chickens in the northeast Texas Panhandle between 1 September 2008 and 28 February 2010. For each model, we display –2 × log-likelihood (–2LL), the second order Akaike's Information Criterion (AIC_c) value, the difference between model AIC_c value and the lowest value of AIC_c (ΔAIC_c) in the candidate set, and the model probability (w_i) (n = 17).

Model	–2LL	*K*	AIC_c	ΔAIC_c	w_i
MPSSOAK	88.032	1	90.299	0.000	0.702
%SOAK + MPSSOAK	88.019	2	92.876	2.577	0.194
%SOAK + MPSSOAK + %SOAK × MPSSOAK	86.306	3	94.152	3.853	0.102
MPSOTHER	101.463	1	103.730	13.431	0.001
%SHRUB	103.014	1	105.281	14.982	0.000
%OTHER	103.036	1	105.303	15.004	0.000
%OTHER + MPSOTHER	101.463	2	106.320	16.021	0.000
%OTHER + MPSOTHER + %OTHER × MPSOTHER	100.526	3	108.372	18.073	0.000
%GRASS	106.810	1	109.077	18.778	0.000
%GRASS + MPSGRASS	105.294	2	110.151	19.852	0.000
%GRASS + MPSGRASS + %GRASS × MPSGRASS	104.774	3	112.620	22.321	0.000
MPSGRASS	111.093	1	113.360	23.061	0.000
No covariates	120.859	0	120.859	30.560	0.000
SITE	119.756	1	122.023	31.724	0.000
EDWOOD	119.773	1	122.040	31.741	0.000
GENDER	120.441	1	122.708	32.409	0.000
YEAR	120.539	1	122.806	32.507	0.000
MPS	120.679	1	122.946	32.647	0.000
ED	120.693	1	122.960	32.661	0.000
%SOAK	120.836	1	123.103	32.804	0.000
SEI	120.854	1	123.121	32.822	0.000
SDI	120.858	1	123.125	32.826	0.000

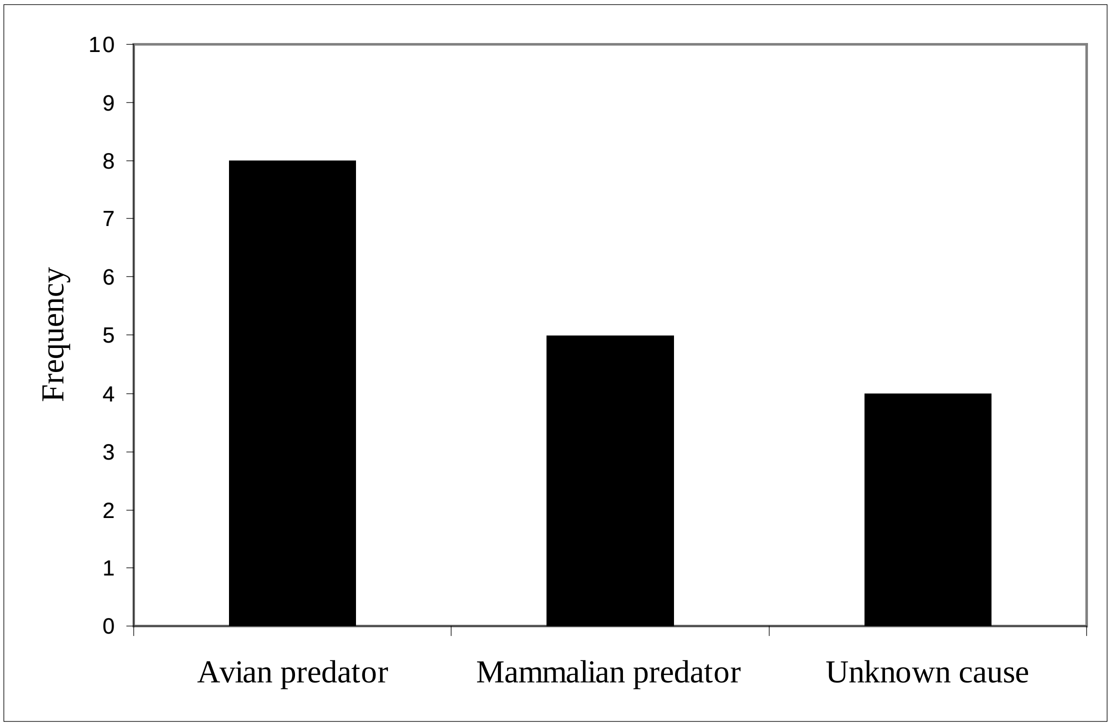

Figure 3.1. Bar chart displaying the frequencies of cause-specific mortality classifications (*n* = 17 mortality events) for over-wintering lesser prairie-chickens in the northeast Texas Panhandle between 1 September 2008 and 28 February 2010.

APPENDIX A

OVER-WINTER RELOCATION SAMPLE SIZES

Table A.1. Summary of the total number of locations collected for radiomarked lesser prairie-chickens in the northeast Texas Panhandle during the over-winter of 2008–2009.

Band	Gender	Number of locations
1013	M	62
1014	M	51
1015	M	55
1102	M	32
1105	M	29
1113	F	43
1115	M	31
1118	F	38
1301	M	85
1302	M	95
1303	M	94
1304	M	6
1306	M	88
2034	M	93
2035	M	96
2036	M	91
2037	M	93
2038	M	94
2039	F	53

Table A.2. Summary of the total number of locations collected for radiomarked lesser prairie-chickens in the northeast Texas Panhandle during the over-winter of 2009–2010.

Band	Gender	Number of locations
1013	M	90
1015	M	86
1017	M	11
1019	F	91
1124	M	92
1128	M	84
1129	M	56
1130	M	53
1142	M	62
1146	M	16
1147	M	87
1151	M	94
1152	F	11
1303	M	96
1306	M	92
1310	M	60
1314	F	62
1317	M	57
1321	F	84
1322	M	39
1323	M	96
1324	M	64
1325	M	28
1326	M	95
1327	M	93
1328	M	57
2034	M	80
2036	M	82
2039	F	66

APPENDIX B

PATCH CHARACTERISTICS OF LANDCOVER MAP

Table B.1. Number of patches, mean patch sizes (m^2), and standard errors for each cover type in our Geographic Information System (GIS) coverage.

Cover type	Number of patches	Mean patch size (m^2)	SE
Other prairie	2,189	22,137.1	2,355.0
Grassland	2,904	11,803.2	1,165.2
Shinnery oak	966	23,359.8	3,349.9
Pasture	85	143,931.0	26,276.7
Cultivation	30	459,312.7	108,077.6
Windbreak or tree	15,351	60.9	6.0
Water	379	1,573.0	377.4
Prairie-dog town	32	49,861.6	25,674.0
Vegetated linear corridor	524	3,467.6	450.6
Improved road	5	62,404.2	33,379.3
Bare ground or sparsely-vegetated	8,602	510.6	83.8
Regenerated wildfire	74	763,273.7	262,938.8

APPENDIX C

GROUND-TRUTH STUDY SUMMARY

Table C.1. Summary of the number of randomly generated points and the classification accuracy within each of the three native prairie landcover subtypes.

Landcover type	Number of points	Percent correctly classified
Other prairie	55	98.2
Grassland[a]	49	63.3
Shinnery oak	26	96.2

[a] Misclassified points in this landcover type were always ground-truthed as other prairie