Original Article

Abundance and Density of Lesser Prairie-Chickens and Leks in Texas

JENNIFER M. TIMMER,[1,2] *Department of Natural Resources Management, Texas Tech University, P.O. Box 42125, Lubbock, TX 79409, USA*
MATTHEW J. BUTLER, *United States Fish and Wildlife Service, P.O. Box 1306, Albuquerque, NM 87103, USA*
WARREN B. BALLARD,[3] *Department of Natural Resources Management, Texas Tech University, P.O. Box 42125, Lubbock, TX 79409, USA*
CLINT W. BOAL, *United States Geological Survey Texas Cooperative Fish and Wildlife Research Unit, Texas Tech University, Agricultural Sciences 218, Lubbock, TX, 79409, USA*
HEATHER A. WHITLAW,[4] *United States Fish and Wildlife Service, P.O. Box 42125, Lubbock, TX 79409, USA*

ABSTRACT Lesser prairie-chickens (LEPCs; *Tympanuchus pallidicinctus*) have experienced population declines due to both direct and indirect habitat loss, including conversion of native rangeland to cropland and disturbance from energy development. Our objectives were to 1) determine the current density of LEPC leks and LEPCs within the Texas (USA) occupied range, including areas with high potential for wind-energy development; and 2) find new leks. To estimate lek and LEPC density, we employed a line-transect-based aerial survey method using a Robinson 22 helicopter to count leks. We surveyed 26,810.9 km of transect in the spring of 2010 and 2011 and we detected 96 leks. We estimated a density of 2.0 leks/100 km^2 (90% CI = 1.4–2.7 leks/100 km^2) and 12.3 LEPCs/100 km^2 (90% CI = 8.5–17.9 LEPCs/100 km^2) and an abundance of 293.6 leks (90% CI = 213.9–403.0 leks) and 1,822.4 LEPCs (90% CI = 1,253.7–2,649.1 LEPCs) for our sampling frame. Our best model indicated that lek size and lek type (AIC$_c$ wt = 0.235) influenced lek detectability. Lek detectability was greater for larger leks and natural leks versus man-made leks. Our statewide survey efforts provide wildlife managers and biologists with population estimates, new lek locations, and areas to target for monitoring and conservation.

KEY WORDS abundance, aerial survey, detectability, distance sampling, lek density, lesser prairie-chicken, Texas, *Tympanuchus pallidicinctus*.

The lesser prairie-chicken (LEPC; *Tympanuchus pallidicinctus*) was recently proposed for protection as a threatened species under the Endangered Species Act (U.S. Fish and Wildlife Service [USFWS] 2012) because its occupied range had been reduced by >90% (Taylor and Guthery 1980, Applegate and Riley 1998). Lesser prairie-chicken population and distribution declines are attributed to a variety of factors, including an increase in oil, natural gas, and wind-energy development; reversion of Conservation Reserve Program grassland to cropland; overgrazing; herbicide use in shinnery oak (*Quercus havardii*) habitat; mesquite (*Prosopis glandulosa*) and juniper (*Juniperus virginiana*) encroachment; and habitat fragmentation (Taylor and Guthery 1980, Applegate and Riley 1998, Hagen et al. 2004, USFWS 2012).

Due to the LEPC's conservation status, McRoberts et al. (2011*b*) identified a need for effective monitoring and efficient techniques for finding new leks. Lek surveys and lek counts from the ground have traditionally been used to monitor population trends in prairie grouse (*Centrocercus* spp. and *Tympanuchus* spp.) populations and have been incorrectly used to estimate population size (Applegate 2000, Walsh et al. 2004). In addition, lek surveys are often conducted from roads, a convenience-based sample that can yield biased conclusions (Anderson 2001). Recent studies have evaluated the use of aerial surveys and distance sampling to estimate avian density (Butler et al. 2007, 2008; Rusk et al. 2007, McRoberts et al. 2011*b*). Aerial distance sampling provides a better density estimate than do the traditional ground-based techniques by allowing for probabilistic sampling of potential habitat and adjusting for incomplete detectability (Buckland et al. 2001). Compared with traditional ground surveys, aerial surveys allow a larger area to be sampled in less time, and allow access to remote or privately owned land (Butler et al. 2007, McRoberts et al. 2011*b*).

Texas currently produces the most wind power in the United States (American Wind Energy Association 2012) and 5 Competitive Renewable Energy Zones (CREZs) were designated in West Texas to encourage further wind-energy development (Electric Reliability Council of Texas [ERCOT] 2006). Transmission lines are already being constructed to deliver electricity generated in these zones to customers in large Texas cities (ERCOT 2006). Two of the CREZs overlap approximately 27% of the occupied LEPC

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[1]*E-mail: timmerj3@gmail.com*
[2]*Present address: Colorado State University, 1499 Campus Delivery, Fort Collins, CO 80525, USA*
[3]*Deceased*
[4]*Present address: United States Fish and Wildlife Ecological Services, 2609 Anderson Avenue, Manhattan, KS 66502, USA*

range in Texas (Davis et al. 2008). However little is known about how this anthropogenic disturbance could affect LEPC density, which has demonstrated steady declines during the past 100 years (Sullivan et al. 2000, Kuvlesky et al. 2007). To better inform conservation and management decisions, we conducted the first randomized line transect-based distance sampling aerial survey of the Texas occupied LEPC range. Our objectives were to estimate LEPC and LEPC lek density and abundance in the Texas occupied range (including areas with high potential for wind-energy development) and to find new leks.

STUDY AREA

Currently LEPCs inhabit 2 portions of the Texas Panhandle: the northeastern and southwestern portions; a few birds are thought to be scattered throughout the central portion (Davis et al. 2008). Our sampling frame encompassed 86.9% of the Texas occupied LEPC range that was delineated by Davis et al. (2008). We excluded portions that were not LEPC habitat, such as riparian woodlands and cotton fields. Approximately 27% of the Texas occupied range intersected the 2 CREZs (Fig. 1). The southwestern region of the study

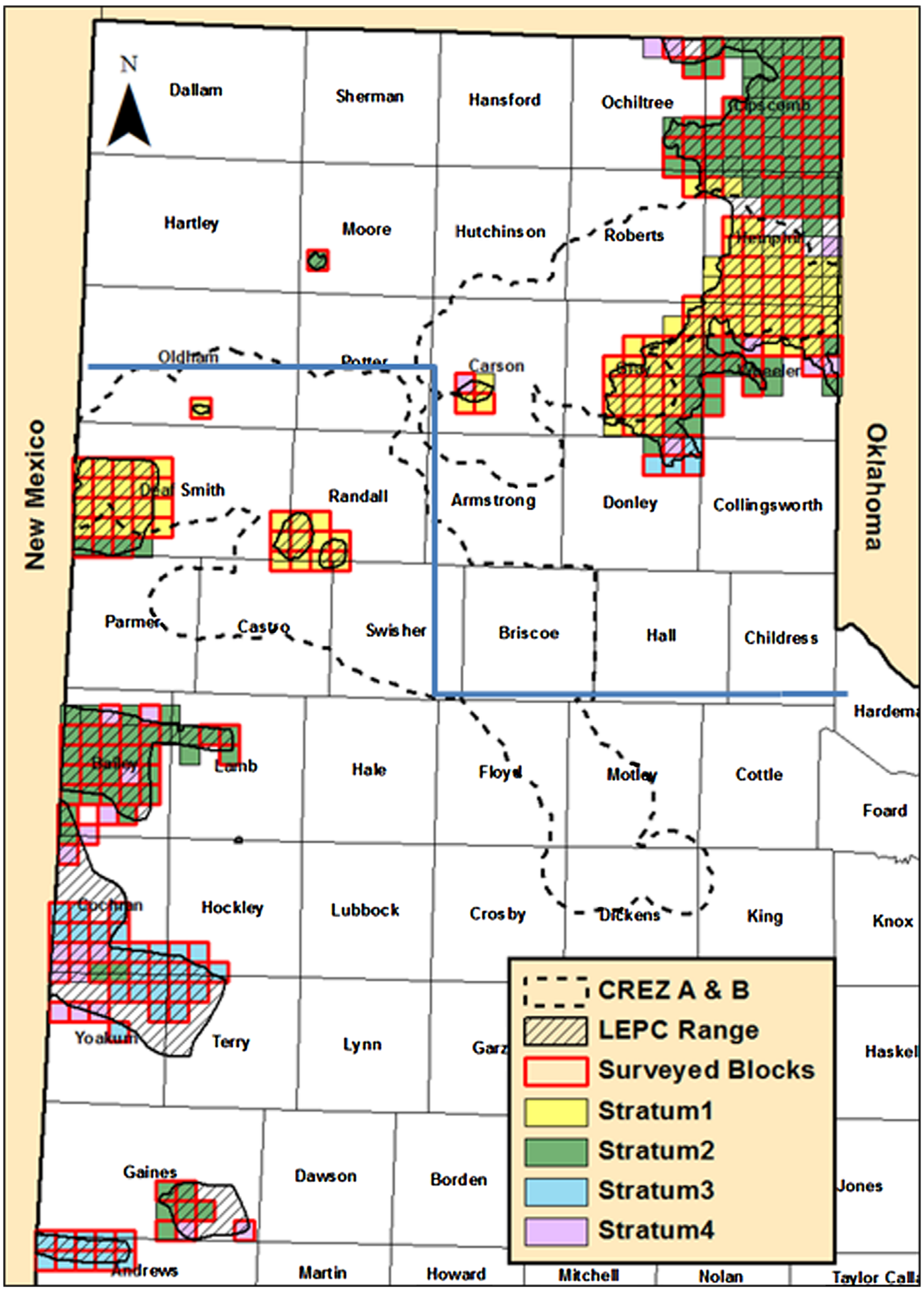


Figure 1. Sampling frame of 285 lesser prairie-chicken (LEPC) aerial survey blocks in Texas for spring 2010 (northeast and central region) and 2011 (southwest and west-central region) with 2 Competitive Renewable Energy Zones (CREZ) and 4 strata. The 2 survey regions are delineated by a blue line. White areas inside the occupied range were classified as non-LEPC habitat and were not included in the sampling frame.

area was a short-grass prairie dominated by little bluestem (*Schizachyrium scoparium*) and shinnery oak with some mesquite. The northeastern region of the study area was a mixed-grass prairie. The dominant grass was little bluestem and the dominant shrub was sand sagebrush (*Artemisia filifolia*). The main crops grown in the Panhandle region were cotton, winter wheat, and grain sorghum (U.S. Department of Agriculture [USDA] 2008). The climate of the Panhandle was for the most part dry and the majority of the precipitation occurred during the autumn and spring (PRISM Group 2011). The southwestern region of the Panhandle received an average of 40–51 cm of precipitation yearly and the northeastern region received an average of 50–61 cm of precipitation yearly (PRISM Group 2011).

METHODS

We stratified our sampling frame based on vegetation characteristics believed to influence LEPC density (e.g., grassland, shrubland, agriculture, and a mosaic) and regions with high potential for wind-energy development. We used ArcGIS 9.3 to create 7.2-km $\times$ 7.2-km survey blocks covering the occupied LEPC range in Texas (Fig. 1). We re-classified the Texas cropland data layer (USDA 2008) into 8 categories (e.g., cotton, grains, other crops, grassland or idle pasture, shrubland, woodland, open water, and barren or developed areas). We combined these vegetation types with the 2 CREZs in the Panhandle and assigned survey blocks to 1 of 4 strata (Table 1) and randomly selected blocks from each stratum. We did not include survey blocks that did not meet a stratum specification.

The first stratum was composed of survey blocks that were within a CREZ and $\geq$50% grassland, the second stratum was composed of survey blocks that were $\geq$50% grassland but not within a CREZ, the third stratum was composed of survey blocks with >50% shrubland, and the fourth stratum was composed of survey blocks with a $\geq$75% combination of grassland–shrubland–grain field. Of the 329 survey blocks covering the LEPC-occupied range in Texas, we did not include 44 blocks in any strata because they were primarily urban, open water, or woodland. Thus, our sampling frame consisted of 285 survey blocks (Fig. 1).

Because we were interested in examining LEPC density in areas subject to wind-energy development, we prioritized the strata based on the greatest potential for wind-energy development to impact lek distribution. Thus, survey blocks in the first stratum received the most survey effort, while survey blocks in the fourth stratum received the least survey effort. We randomly selected 72 survey blocks in the first stratum, 54 in the second stratum, 36 in the third stratum, and 18 in the fourth stratum (Table 1). We also selected some additional blocks from each stratum in case we were able to survey more blocks than planned. We surveyed sampled blocks from each stratum opportunistically based on pilot availability and local weather.

We divided our sampling frame into 2 regions. We surveyed blocks in the northeastern and central regions of the Panhandle (hereafter, northeastern region) between 17 March and 3 June 2010, and we surveyed blocks in the southwestern and west-central regions (hereafter, southwestern region; Fig. 1) between 1 March and 4 May 2011. We conducted our surveys from an R-22 helicopter (Robinson Helicopter Co., Torrance, CA) and also trained technicians from an R-44 helicopter (Robinson Helicopter Co.) early in each field season. We followed the survey protocol developed by McRoberts et al. (2011*b*; i.e., transects spaced 400 m apart and oriented north–south, target altitude of 15 m above ground-level, target speed of 60 km/hour, survey for approximately 2.5 hours after sunrise, and observers search within 200 m of the side on which they are seated). When LEPCs were detected, the pilot deviated from transect and flew over the center of the group of birds or the center of the location from where birds flushed. We used a GPS unit to record the location of detected LEPCs and a track log of the flight path for actual distance surveyed. We examined $\geq$50% of the aerial detections from the ground to confirm lek activity and location. We arrived at detected leks $\geq$60 minutes before sunrise to listen for male vocalizations and watch for male displays from a nearby parked vehicle or blind. We also looked around the point within a 100-m radius for evidence of lek activity (e.g., feathers, scat, flattened grass, etc.) and classified the detection as non-lek if no evidence of lek activity was found.

Data Analysis

We analyzed all detections that included leks and non-leks. Both males and females attending leks, plus males and females in non-lek locations, were detected, which enabled us to estimate total LEPC abundance. Detections that were confirmed leks were analyzed as a subset (i.e., leks-only data

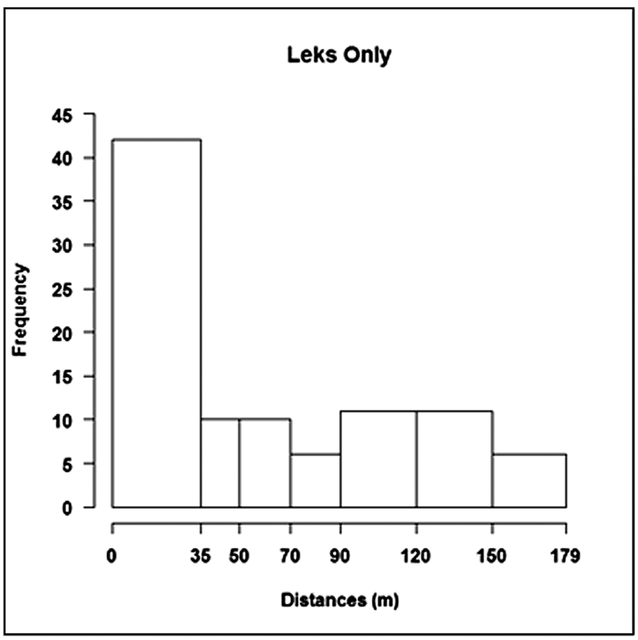
Table 1. Sample stratification and survey effort allocation for lesser prairie-chicken lek surveys in the Texas (USA) occupied range during spring 2010 and 2011.

Stratum[a]	CREZ[b]	Land-cover type	Total available blocks/stratum	Initial allocation of survey blocks[c]	No. of blocks surveyed[d]
Priority 1	Yes	$\geq$50% Grassland	97	72	76
Priority 2	No	$\geq$50% Grassland	125	54	73
Priority 3	No	>50% shrubland	39	36	39
Priority 4	Either	$\geq$75% grassland–shrubland–grain field mix	24	18	20

[a] Priority ranges high to low: 1–4.
[b] Competitive Renewable Energy Zone.
[c] One hundred eighty blocks selected to be surveyed during 2010 and 2011.
[d] Two hundred eight blocks actually surveyed during 2010 and 2011.

set), which enabled us to estimate LEPC lek abundance. For the data set of all detections, each detection was an object of interest and we analyzed our observations as groups of LEPCs. To analyze the leks-only data set, the individual lek was our object of interest. We used Program R 2.13.0 (R Development Core Team 2011) to perform 2-way analysis of variance tests with the strata and region as explanatory covariates and either average group size or average encounter rate as the response variable to determine whether the data should be further stratified by region ($\alpha = 0.10$).

We grouped our distance data into 7 distance intervals, 0–35 m, 35–50 m, 50–70 m, 70–90 m, 90–120 m, 120–150 m, and 150–179 m, for both data sets (Fig. 2). We chose our truncation distance based on the furthest detection observed from the transect. We determined our grouping based on recommendations by Buckland et al. (2001) to reduce spiking around the centerline, produce an improved shoulder on the detection function, and provide better model fit.



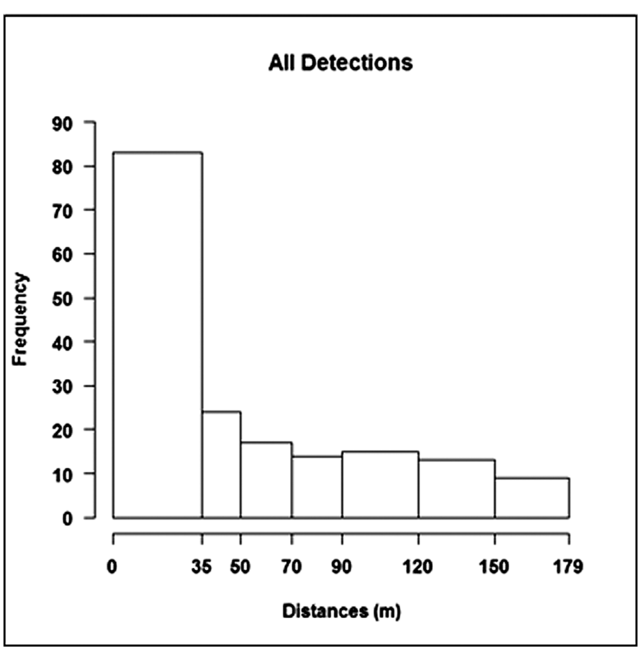


Figure 2. Grouped distance data for leks only ($n = 96$) and all detections ($n = 175$) during 2010 and 2011 lesser prairie-chicken aerial surveys in the Texas occupied range.

We used the multiple-covariate and conventional distance-sampling engines in Program Distance 6.0 (Thomas et al. 2010) to analyze our data and Akaike's Information Criterion corrected for small sample size (AIC_c) to select competitive models (Burnham and Anderson 2002). We considered models competitive if $\Delta AIC_c \leq 2$, and we excluded models with uninformative parameters (Arnold 2010). We pooled detections across strata for modeling the detection function. For the leks-only data set, our covariates included lek size, lek type, and survey date. We included lek size and lek type (i.e., man-made or natural) in our models because McRoberts et al. (2011*b*) determined that lek detectability was greater for man-made leks and larger leks. For our analysis, man-made leks included leks located in grain or plowed fields. We used a binary classification for lek type by assigning man-made leks a 1 and natural leks a 0. We included lek size as a numerical variable because accurate LEPC counts were possible when flying over a lek to mark it. Following McRoberts et al. (2011*b*), we included a standardized survey date among our covariates by assigning our earliest survey date, 2 March, a value of 0 and consecutively numbering the following survey dates. Because lek attendance peaks in the middle of the spring (Haukos and Smith 1999) and the birds are less likely to flush during this period, we modeled a quadratic relationship for standardized date (McRoberts et al. 2011*a*).

For the all-detections data set, our covariates included detection type, lek confirmation, and survey date. We included detection type and lek confirmation as categorical covariates and also included a standardized survey date with a quadratic term. For detection type, detections observed in a manipulated landscape (e.g., oil pad, grain field, or next to a stock tank) were assigned a 1 and detections observed in a natural landscape (e.g., grassland or shrubland) were assigned a 0. Detections that were confirmed leks were assigned a 1 and non-lek detections were assigned a 0, which allowed us to account for differential detection between leks and non-leks. Rather than include group size as a covariate, we regressed natural log of group size against detection probability to correct for size-biased detection (Buckland et al. 2001). We assumed significance at $\alpha < 0.15$ for size-biased regression (Buckland et al. 2001). In addition, lek confirmation was similar to including group size as a covariate because we expected confirmed leks to have more LEPCs per group than non-lek detections.

We examined several key function and series expansion combinations in Program Distance as recommended by Buckland et al. (2001) to determine which model(s) best described detectability. These models included combinations of the half-normal, hazard rate, and uniform key functions and the cosine, hermite polynomial, and simple polynomial adjustment terms (Table 2). We model-averaged among our

Table 2. Candidate lek detection functions for lesser prairie-chickens from aerial surveys in Texas, USA, during spring 2010 and 2011 ($n = 96$). For each candidate model, we give $-2 \times$ log-likelihood (-2LL), number of parameters (K), second-order Akaike's Information Criterion (AIC$_c$), difference in AIC$_c$ compared with lowest AIC$_c$ of the model set (Δ_i), AIC$_c$ weight (w_i), value of the probability density function of perpendicular distances at 0 m ($f(0)$), detection probability (P), and coefficient of variation for detection probability (CV(P)).

Model[a]	-2LL	K	AIC$_c$	Δ_i	w_i	$f(0)$	P[b]	CV(P)
Half-normal (size + type + date)	304.568	5	315.235	0.000	0.403	0.012	0.482	0.109
Half-normal (size + type)	310.057	3	316.318	1.083	0.235	0.011	0.510	0.099
Half-normal (size)	313.266	2	317.395	2.160	0.137	0.011	0.532	0.097
Half-normal (size + date)	309.441	4	317.880	2.645	0.107	0.011	0.505	0.107
Hazard-rate (size)	312.399	3	318.660	3.425	0.073	0.016	0.355	0.135
Hazard-rate (size + type)	311.657	4	320.096	4.861	0.035	0.012	0.468	0.103
Hazard-rate (size + type + date)	310.423	6	323.367	8.132	0.007	0.013	0.446	0.113
Hazard-rate	323.773	2	327.902	12.667	0.002	0.016	0.355	0.452
Half-normal + cosine	323.858	2	327.987	12.752	0.001	0.013	0.437	0.119
Uniform + cosine	322.585	3	328.845	13.610	<0.000	0.013	0.416	0.123
Hazard-rate (type)	325.492	3	331.753	16.518	<0.000	0.012	0.481	0.087
Hazard-rate (size + date)	321.778	5	332.444	17.209	<0.000	0.012	0.471	0.086
Hazard-rate (date)	325.380	4	333.820	18.585	<0.000	0.012	0.467	0.103
Half-normal (date)	328.476	3	334.737	19.502	<0.000	0.010	0.578	0.073
Half-normal (type + date)	326.415	4	334.854	19.619	<0.000	0.010	0.570	0.076
Half-normal (type)	331.052	2	335.181	19.946	<0.000	0.010	0.587	0.068
Hazard-rate (type + date)	324.728	5	335.394	20.159	<0.000	0.012	0.460	0.099

[a] Covariates include: size = size of lek, type = lek type (man-made or natural), date = quadratic function of standardized survey date. Models are represented as key function + series expansion (covariates).

[b] Detection probability based on truncation distance of 179 m.

competing models (ΔAIC$_c \leq 2$) to account for model selection uncertainty (Burnham and Anderson 2002, Anderson 2008).

To allow density estimates to vary among the strata, we did not pool encounter rates across strata. However for the all-detections data set, we pooled group sizes among the strata because the number of detections was too small for reliable estimation of average group size for some of the strata. We estimated the abundance of LEPCs as the product of the average group size (or size-bias corrected average group size) and the total number of detections (Buckland et al. 2001). We tested for differences in lek and LEPC density estimates between strata with a z-test (Buckland et al. 2001).

RESULTS

We inventoried 105 survey blocks (90 from an R-22 and 15 from an R-44 helicopter) during spring 2010 and 103 survey blocks (92 from an R-22 and 11 from an R-44 helicopter) during spring 2011 (Fig. 1). In spring 2010 (northeastern region), we flew 233.7 hours (2.2 hr/block) at an average speed of 63.3 km/hour (SE = 0.679) and in spring 2011 (southwestern region), we flew 241.3 hours (2.3 hr/block) at an average speed of 60.8 km/hour (SE = 0.388). We surveyed a total distance of 13,403.4 km in the northeast and 13,407.5 km in the southwest and covered 88.6% of our sampling frame and 61.6% of the Texas LEPC occupied range. We detected LEPCs within 160.5 m of transect in the northeast and 178.3 m of transect in the southwest.

We detected 66 LEPC groups in the northeast; 35 were confirmed as leks, 25 were new leks, 1 detection was outside of the occupied range in Texas, and 13 detections were within a CREZ. In the southwest, we detected 109 LEPC groups; 61 were confirmed as leks, 46 were new leks, 4 detections were outside of the occupied range, and 10 detections were within a CREZ. We pooled our detections from the R-22 and the R-44 for 2010 and 2011. The average number of LEPCs observed attending leks was 4.5 (SE = 0.670) and 5.2 (SE = 0.525) in the northeast and southwest region, respectively.

We did not detect a difference in average encounter rate between strata and region for the leks-only data set ($F_{3,\ 200} = 1.008$, $P = 0.390$) and we also did not detect differences between strata and region for average group size and average encounter rates for the all-detections data set ($F_{2,\ 168} = 0.295$, $P = 0.745$; $F_{3,\ 200} = 0.794$, $P = 0.499$, respectively). Therefore, we did not post-stratify the analysis by region for either data set.

We found one model that was competitive and parsimonious for the leks-only data set—the half-normal key function with lek size and lek type included as covariates (AIC$_c$ wt [w_i] = 0.235; Table 2). Detectability was greater for natural leks and larger lek sizes (Fig. 3). Although the model including lek size, lek type, and date appeared top-ranked, the 2 coefficients associated with the quadratic of date were not significant. We found 2 competitive, parsimonious models for the all-detections data set—the half-normal key function and cosine adjustment term ($w_i = 0.211$) and the hazard rate key function with no adjustment ($w_i = 0.203$; Table 3). Although the hazard-rate model with covariate for lek confirmation appeared top-ranked, the coefficient for lek confirmation was not significant. Our lek and LEPC density estimates for our sampling frame were 2.0 leks/100 km^2 (90% CI = 1.4–2.7 leks/100 km^2) and 12.3 LEPCs/100 km^2 (90% CI = 8.5–17.9 LEPCs/100 km^2), respectively (Table 4). We estimated 1.0 lek/100 km^2 (90% CI = 0.6–1.7 leks/100 km^2) for the first stratum; we estimated 2.4 leks/100 km^2 (90% CI = 1.5–3.8 leks/100 km^2), 2.7 leks/100 km^2 (90% CI = 1.6–4.3 leks/

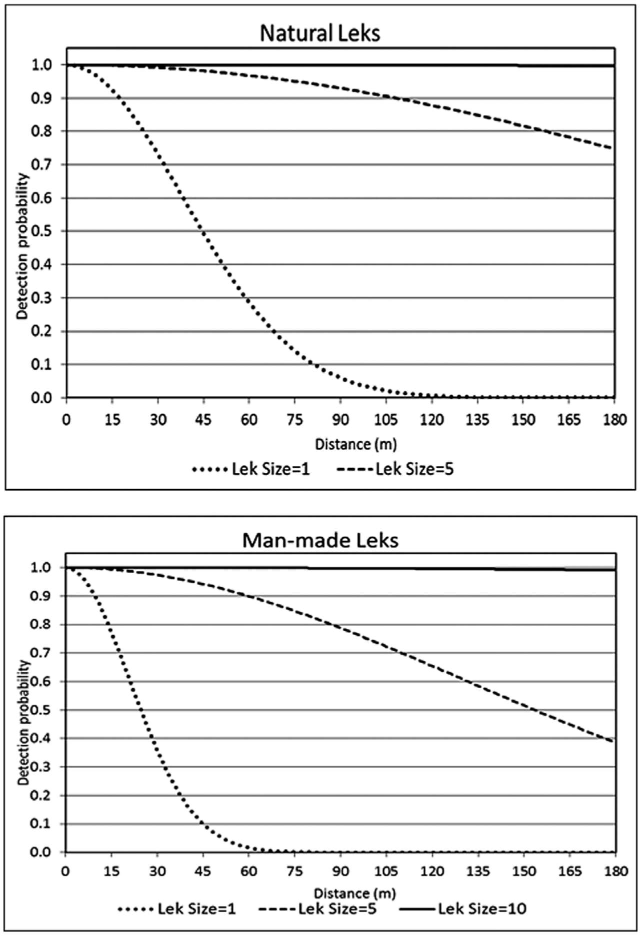


Figure 3. Predicted detectability for lesser prairie-chicken leks ($n = 96$) from 2010 to 2011 aerial surveys in the Texas occupied range.

100 km^2), and 2.7 leks/100 km^2 (90% CI = 1.3–5.7 leks/100 km^2) for the second, third, and fourth strata, respectively (Table 4). Our lek and LEPC abundance estimates for our sampling frame were 293.6 leks (90% CI = 213.9–403.0 leks) and 1,822.4 LEPCs (90% CI = 1,253.7–2,649.1 LEPCs; Table 4).

We detected a difference in lek density between strata 1 and 2 ($Z = -1.972$, $P = 0.024$), strata 1 and 3 ($Z = -1.951$, $P = 0.026$), and strata 1 and 4 ($Z = -1.293$, $P = 0.098$). We also detected a difference in LEPC density between strata 1 and 2 ($Z = -1.775$, $P = 0.038$) and strata 1 and 3 ($Z = -1.677$, $P = 0.047$). We did not detect a difference in lek density between strata 2 and 3 ($Z = -0.236$, $P = 0.407$), strata 2 and 4 ($Z = -0.197$, $P = 0.422$), or strata 3 and 4 ($Z = -0.030$, $P = 0.488$). We also did not detect a difference in LEPC density between strata 1 and 4 ($Z = -1.193$, $P = 0.116$), strata 2 and 3 ($Z = -0.425$, $P = 0.335$), strata 2 and 4 ($Z = -0.142$, $P = 0.444$), or strata 3 and 4 ($Z = 0.197$, $P = 0.578$).

DISCUSSION

We conducted the first randomized line transect-based distance sampling survey of the LEPC range in Texas. Overall, we detected 71 new leks, 25 known leks, and expanded the estimated occupied range by detecting 5 observations of LEPCs outside the area delineated by Davis et al. (2008). The new leks probably would not have been detected by traditional road-based lek surveys that many wildlife managers and biologists have implemented in the past (Butler et al. 2010, McRoberts et al. 2011*b*). We were able to provide estimates of precision for our unbiased density and abundance estimates, which many previous population monitoring efforts have not done (Applegate 2000, McRoberts et al. 2011*b*). Additionally, we estimated

Table 3. Candidate detection functions (all detections including leks and non-leks) for lesser prairie-chickens from aerial surveys in Texas, USA, during spring 2010 and 2011 ($n = 175$). For each candidate model, we give $-2 \times$ log-likelihood (-2LL), number of parameters (K), second-order Akaike's Information Criterion (AIC$_c$), difference in AIC$_c$ compared with lowest AIC$_c$ of the model set (Δ_i), AIC$_c$ weight (w_i), value of the probability density function of perpendicular distances at 0 m ($f(0)$), detection probability (P), and coefficient of variation for detection probability (CV(P)).

Model[a]	-2LL	K	AIC$_c$	Δ_i	w_i	$f(0)$	P[b]	CV(P)
Hazard-rate (lek)	562.443	3	568.584	0.000	0.256	0.016	0.354	0.102
Half-normal + cosine	564.894	2	568.964	0.380	0.211	0.015	0.379	0.078
Hazard-rate	564.977	2	569.047	0.463	0.203	0.016	0.350	0.210
Hazard-rate (lek + type)	561.302	4	569.537	0.954	0.159	0.016	0.342	0.094
Uniform + cosine	564.705	3	570.845	2.261	0.083	0.015	0.375	0.081
Hazard-rate (lek + date)	562.713	5	573.068	4.484	0.027	0.013	0.426	0.064
Hazard-rate (lek + type + date)	560.939	6	573.439	4.855	0.023	0.013	0.421	0.065
Hazard-rate (type)	567.383	3	573.523	4.940	0.022	0.013	0.439	0.059
Hazard-rate (date)	567.360	4	575.595	7.011	0.008	0.013	0.432	0.060
Half-normal (lek)	573.270	2	577.340	8.756	0.003	0.011	0.497	0.056
Hazard-rate (type + date)	567.395	5	577.750	9.166	0.003	0.013	0.437	0.060
Half-normal (lek + date)	570.647	4	578.882	10.299	0.001	0.011	0.492	0.057
Half-normal (lek + type)	573.079	3	579.219	10.635	0.001	0.011	0.496	0.056
Half-normal (lek + type + date)	569.966	5	580.321	11.737	0.001	0.011	0.490	0.057
Half-normal (date)	577.571	3	583.711	15.127	<0.001	0.011	0.503	0.055
Half-normal (type + date)	577.273	4	585.508	16.924	<0.001	0.011	0.503	0.055
Half-normal (type)	581.440	2	585.509	16.926	<0.001	0.011	0.510	0.053

[a] Covariates include: lek = detection is confirmed lek or not, type = detection was observed in natural or man-made landscape, date = quadratic function of standardized survey date. Models are represented as key function + series expansion (covariates).
[b] Detection probability based on truncation distance of 179 m.

Table 4. Density and abundance estimates and average encounter rate for lek detections and for all detections (i.e., lek and non-lek detections) from lesser prairie-chicken (LEPC) aerial surveys in the Texas (USA) occupied range during spring 2010 and 2011.

	Density			Encounter				Abundance	
Data set	*D*[a]	CV(*D*)	CI[b]	*n*[c]	L[d]	*n*/L	CV(*n*/L)	*N*[e]	CI
Leks-only									
Stratum 1[f]	1.0	0.34	0.6–1.7	18	9,923.8	0.002	0.32	49.9	29.2–85.4
Stratum 2[g]	2.4	0.28	1.5–3.8	41	9,288.5	0.004	0.26	156.6	99.8–245.5
Stratum 3[h]	2.7	0.31	1.6–4.3	25	5,161.5	0.005	0.29	53.6	32.8–87.7
Stratum 4[i]	2.7	0.48	1.3–5.7	12	2,437.0	0.005	0.47	33.5	15.9–70.8
State-wide [j]	2.0	0.19	1.4–2.7	96	26,810.8	0.004	0.41	293.6	213.9–403.0
All detections[k]									
Stratum 1	7.0	0.34	4.1–12.0	37	9,923.8	0.004	0.29	352.6	205.5–604.8
Stratum 2	14.4	0.30	8.9–23.1	71	9,288.5	0.008	0.24	931.6	579.3–1,498.0
Stratum 3	17.1	0.36	9.6–30.5	47	5,161.5	0.009	0.32	346.2	194.1–617.6
Stratum 4	15.4	0.46	7.5–31.9	20	2,437.0	0.008	0.43	192.0	93.0–396.4
State-wide	12.3	0.23	8.5–17.9	175	26,810.8	0.007	0.36	1,822.4	1,253.7–2,649.1

[a] Density estimates (*D*) measured in leks/100 km^2 for the leks-only data sets and LEPCs/100 km^2 for the all-detections data sets.
[b] Ninety percent CIs for density and abundance estimates.
[c] No. of confirmed lek detections for the leks-only data set and no. of all observations for the all-detections data set.
[d] Transect length in km.
[e] Abundance estimates (*N*) measured in leks for the leks-only data set and LEPCs for the all-detections data set.
[f] Stratum 1 includes survey blocks within a Competitive Renewable Energy Zone (CREZ) and composed of $\geq$50% grassland.
[g] Stratum 2 includes survey blocks not within a CREZ and composed of $\geq$50% grassland.
[h] Stratum 3 includes survey blocks not within a CREZ and composed of >50% shrubland.
[i] Stratum 4 includes survey blocks not within a CREZ and composed of $\geq$75% grassland–shrubland–grain field mix.
[j] Includes the estimated occupied LEPC range for Texas.
[k] The half-normal + cosine and hazard-rate models were model-averaged for the LEPC density and abundance estimates.

LEPC and lek density in areas with high potential for wind-energy development.

Lek size and lek type were the most influential covariates on lek detectability. McRoberts et al. (2011*b*) also observed an increase in lek detectability with lek size, but they observed a higher detection probability for man-made leks. Our lek detectability was greater for natural leks, but mainly evident at small lek sizes (Fig. 3). It seems intuitive that displaying LEPCs would be easier to spot on manipulated landscapes void of vegetation, such as abandoned oil pads, and that windmills or stock tanks would provide a visual cue for observers looking for leks (McRoberts et al. 2011*b*). However, Schroeder et al. (1992) concluded that lek detectability could be negatively influenced by landscape features that distract observers. Two greater prairie-chicken (*T. cupido*) leks that were undetected on their helicopter surveys were located near a power line or windmill. Our most competitive, parsimonious model for leks only did not include the covariate "date." McRoberts et al. (2011*b*) similarly found that date played a small role in lek detectability and concluded that an increase in lek detectability with date may have been due to observers developing a search image for leks.

For comparability with previous research efforts, our lek detection probability scaled to a 200-m strip width was 45.7%, which was lower than lek detectability reported by Schroeder et al. (1992) and McRoberts et al. (2011*b*; 67% and 72.3%, respectively). One possible explanation for our lower detection rate is that our survey sampled the entire occupied range in Texas; whereas, Schroeder et al. (1992) and McRoberts et al. (2011*b*) repeatedly surveyed areas with known active leks, which potentially introduced bias in their estimates. We also flew more surveys outside the peak lekking period in order to complete our sampling effort. Lastly, our average lek sizes were smaller than those observed by Schroeder et al. (1992; 5.0 birds compared with 6.7 birds) and smaller leks are less detectable than large leks.

The abundance and density estimates from the literature differ from our estimates due to the techniques used to survey and estimate LEPC and lek density. We accounted for incomplete detectability of individuals within our sampling frame and provided probabilistic sampling of potential habitat. In contrast, other abundance and density estimates are usually derived from convenience-based sampling of higher quality habitat that does not account for undetected individuals within the sampling frame, such as females not attending leks (e.g., Davis et al. 2008). For example, Olawsky and Smith (1991) estimated LEPC densities in the southwestern Texas Panhandle and southeastern New Mexico, USA, that were >150 times more than our LEPC density estimates. They used a line-transect procedure to estimate lek density within their sampling frame, but transects were restricted to roads and their surveys were conducted in some of the highest-quality LEPC habitat. Davis et al. (2008) estimated a Texas LEPC abundance of 15,730 (range = 6,077–24,132 LEPCs), but LEPC density was assumed constant across the entire range for the state and their study areas were some of the best habitat in the state. In contrast, Hamilton and Manzer (2011) used a modified point count design with distance sampling to estimate sharp-tailed grouse (*T. phasianellus*) lek density in east-central Alberta, Canada, and their regional density estimate was comparable to ours (2.6 leks/100 km^2; 95% CI = 1.6–4.3 leks/100 km^2).

We observed a difference in lek density between strata 1 and 2, strata 1 and 3, and strata 1 and 4 and a difference in LEPC density between strata 1 and 2 and strata 1 and 3. We anticipated having higher LEPC and lek density estimates in strata 1 and 2 because LEPCs primarily use native and Conservation Reserve Program grasslands for breeding, nesting, and brood-rearing (Taylor and Guthery 1980, Applegate and Riley 1998); therefore, we allocated more survey effort to strata 1 and 2. However, our greatest LEPC and lek density estimates were in strata 3 and 4, which were composed of survey blocks with <50% native grassland. Although we did not observe a difference in lek or LEPC density between strata 2 and 3 or strata 2 and 4, our results suggest that low-growing shrubs and a source of grain may be important components of LEPC habitat in Texas, given that stratum 3 was composed of primarily shrubland and stratum 4 was composed of a mix of grassland, shrubland, and grain fields. Other studies have reached a similar conclusion. Declining LEPC populations in New Mexico, Oklahoma, and Texas were associated with a greater loss of shrubland cover types (Woodward et al. 2001). Patten et al. (2005) observed radiomarked LEPCs in a survival study in southeastern New Mexico and northwestern Oklahoma occupying sites with a greater density of shrubs, and broods in southeastern New Mexico selected sites with greater shinnery oak cover (Bell et al. 2010). Crawford and Bolen (1976) found the greatest lek density and populations in the southwestern Texas Panhandle on sites with limited cultivation (e.g., 5–37%) as compared with sites with no cultivation.

The potential threats to declining prairie grouse populations require more effective population monitoring, such as aerial lek surveys. There are several ways to improve lek detectability from aerial surveys, as identified by McRoberts et al. (2011*b*), such as using helicopters instead of fixed-winged aircraft and restricting surveys to clear sunny mornings when visibility of LEPCs is greatest. We further suggest not flying on windy mornings (e.g., wind speed >32 km/hr) because it is more difficult to control aircraft speed along the transect and navigating over tall structures is more dangerous. Schroeder et al. (1992) observed a decrease in lek detection with an increase in helicopter speed, so flying transects at a lower speed should increase detection rate. McRoberts et al. (2011*b*) further recommended flying surveys during the peak lekking season when female lek attendance is greatest and displaying and fighting males are most visible to observers. Disturbance to LEPC breeding activity is also minimal during this period because the males are less likely to flush when females are present at leks (McRoberts et al. 2011*a*). We observed LEPCs flushing more frequently later in the morning in response to the helicopter, so restricting surveys to approximately 2.5 hours post-sunrise should minimize this disturbance response.

If distance sampling and aerial surveys are used to estimate lek density, we recommend a few precautions to ensure quality data and accurate estimates. Critical assumptions must be met, such as complete detectability on the transect (Buckland et al. 2001), which is difficult with a fixed-winged aircraft (Butler et al. 2007, McRoberts et al. 2011*b*). It is important to mark where the birds flushed from, and the direction and distance that the birds flushed, to avoid re-counting (Buckland et al. 2001). To prevent spiking of data at the center line (e.g., distances are erroneously allocated to on or just off the transect), pilots need to stay on the transect line until the helicopter is perpendicular to the detected lek rather than flying toward the lek to mark it when it is spotted in front of the helicopter. We found that deviating from the flight transect to a detection was more effective for obtaining an accurate location of a lek and a count of LEPCs than estimating the distance from the helicopter to a detection. The distance data should be examined while the data are being collected so that problems, such as heaping or spiking on transect, can be corrected in the beginning of a field season (Buckland et al. 2001, Thomas et al. 2010). Finally, we included covariates that could have affected lek detectability, such as lek size, in order to improve precision of our density estimates (Marques et al. 2007).

MANAGEMENT IMPLICATIONS

Species of conservation concern, such as LEPCs, require effective monitoring and management efforts. Aerial lek surveys can provide wildlife managers and biologists with unbiased density and abundance estimates, as well as distribution information. For example, we detected 23 LEPC groups in the 2 CREZs in the Texas Panhandle, but the CREZs overlap low-density portions of the LEPC range and overall LEPC abundance in Texas is lower than previously thought. Wind-energy developers and biologists can utilize our techniques to identify and monitor LEPC populations that occur in potential wind resource areas.

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