RANGE-WIDE POPULATION SIZE OF THE
LESSER PRAIRIE-CHICKEN:
2012 AND 2013

Prepared for
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ABSTRACT

We flew aerial line transect surveys to estimate the abundance of lesser prairie-chickens (*Tympanuchus pallidicinctus*) and lesser prairie-chicken leks in four ecoregions in the Great Plains, U.S. in 2012 and 2013. We also estimated the number of mixed species leks which contained both lesser and greater prairie-chickens (*T. cupido*) and the number of hybrid lesser-greater prairie-chickens where these species’ ranges overlap. The study area included the 2011 estimated occupied lesser prairie-chicken range in five States and was divided into four eco-regions. We created a spatially balanced sampling frame over the study area consisting of 536 15- by 15-km grid cells. We flew 512 transects within a probabilistic sample of 256 cells totaling 7,680 km in 2012 and 566 transects within a probabilistic sample of 283 cells totaling 8,490 km in 2013. We estimated a total of 2,930 lesser prairie-chicken leks in 2012 (2,036 in 2013) and 453 lesser and greater prairie-chicken mixed leks in 2012 (356 in 2013) in the study area. We estimated a total of 34,440 individual lesser prairie-chickens in 2012 (17,616 in 2013) and 350 hybrid lesser-greater prairie-chickens in 2012 (342 in 2013) in the study area. We discuss the implications of alternative sampling designs with regard to conservation questions to be addressed.

**KEYWORDS:** helicopter survey, lesser prairie-chicken, lek abundance, bird surveys, line-transect surveys, aerial surveys, detection probability, population estimation, distance methods.
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INTRODUCTION

Ascertaining precise estimates of wildlife population size \( (N) \) is valuable information for natural resource agencies in the management of harvested and non-harvested species (Rabe et al. 2002). Acquiring precise and unbiased estimates of population size requires either a complete census or probabilistic sample of subunits with which to infer population size (Johnson 2002); however, limited funding and staffing have often precluded implementation of these sampling designs. The result had been the development of population indices to monitor population trend or estimate a minimum population size. The limitation of such data is its unknown relationship to population size. Further, it must be assumed that indices track population dynamics (McKelvey and Pearson 2001). These assumptions can be problematic when knowing the population size is critical to decision makers either in the context of harvest or population recovery of sensitive species.

The lesser prairie-chicken (\textit{Tympanuchus pallidicinctus}) has the rare credential of needing a precise population estimate both for setting harvest regulations and managing recovery of populations in different portions of its range (Hagen et al. 2004). Currently, lesser prairie-chickens (LEPC hereafter) are proposed for protection under the Endangered Species Act as a threatened species (USFWS 2012) because of long-term declining population trends and ongoing threats to the species across the 5 state range. The LEPC currently occupies short-grass prairies of northwestern Kansas, sand sagebrush (\textit{Artemesia filifolia}) of southeastern Colorado and southwest Kansas, through mixed-grass portions of south central Kansas, northwest Oklahoma and northeast Texas Panhandle, into the shinnery oak (\textit{Quercus havardii}) grasslands of eastern New Mexico and western Texas (Figure 1).
Population trends of LEPC have been monitored using spring lek counts since the 1940s. Survey effort and methods have varied over time, but lek data were the best available long term data set to assess trend. Breeding season sex ratio, detection probability, and lek attendance rates are not well understood (Behney et al. 2012). These factors, including variation in sampling methods, require several assumptions to be made when estimating the population size from lek count information (Walsh et al. 2004, Garton et al. 2011). Thus, Hagen et al. (2004) recommended a unified approach to estimate population size and trend across the 5 states for long term assessment of populations and success of conservation actions.

Our objectives were to develop consistent, statistically robust survey and analysis methods to estimate LEPC population size and monitor trends across a study area that included the estimated occupied range (EOR). To achieve this, we had to address issues of regional variation as well as the co-occurrence of greater prairie-chicken (*Tympanuchus cupido*, GPCH) and of hybrid lesser_greater prairie-chickens (HPC) in northwestern Kansas. We estimated LEPC and lek abundances for four ecoregions: 1) Shinnery Oak Prairie Region (SOPR) located in eastern New Mexico-southwest Texas Panhandle, 2) Sand Sagebrush Prairie Region (SSPR) located in southeastern Colorado-southwestern Kansas-western Oklahoma Panhandle, 3) Mixed-Grass Prairie Region (MGPR) located in the northeast Texas Panhandle-western Oklahoma-south central Kansas, and 4) Shortgrass Prairie-Conservation Reserve Program Mosaic (SGPR) located in northwestern Kansas (Figure 1).

**STUDY AREA**
Our study area included the 2011 EOR of LEPC as defined by the Lesser Prairie-chicken Interstate Working Group and mapped in the Western Association of Fish and Wildlife Agencies’ web site [http://www.wafwa.org/documents/lpc/april2012/SGPCHAT.pdf](http://www.wafwa.org/documents/lpc/april2012/SGPCHAT.pdf). In addition,
we included habitats with relatively high probability of lek occurrence in northwest Kansas as measured by the Western Governors Association Southern Great Plains Crucial Habitat Assessment Tool http://www.ksre.ksu.edu/doc13895.ashx. The study area for both 2012 and 2013 was illustrated in Figure 1 where we indicated the grid cells selected and not selected for survey in 2013. The buffered areas surrounding the sub-areas delineated an approximate 77.7 km (30 mi) buffer into which the survey may be expanded in the future.

**METHODS**

**Probabilistic Samples**

We ranked 15- × 15-km grid cells in the study area from 1 to 536 by an equal probability sampling procedure known as Generalized Random Tessellation Stratified (GRTS) sampling (Stevens and Olsen 2004). Cells selected by the GRTS procedure maintain a spatially balanced sample for aerial resources such that any contiguous subset, if taken in order, was an equal probability sample of the target population. Cells can be dynamically removed from the ranked list and the next cells sequentially on the list added to the sample as non-target or inaccessible cells (e.g., military lands) are discovered, if any existed.

The first 180 cells in the GRTS list were selected for survey in 2012. Funds became available for survey of additional cells in two regions. Forty additional cells were selected in Kansas and 36 additional cells were selected in New Mexico and western Texas from their respective top ranked cells in the GRTS list for a total sample size of 256 probabilistically selected cells for aerial survey in 2012. Effectively, this resulted in 3 strata with different sampling intensities. In addition, four ecoregions were defined and superimposed on the study area during analysis of the results, effectively re-stratifying and resulting in 6 strata with different sampling intensities. Ecoregions SOPR and SGPR in 2012 were individual strata with
equal probability sampling in each: 75 of 123 cells surveyed in SOPR and 80 of 165 cells surveyed in SGPR. Ecoregion SSPR had two strata in the conditional design: one with 13 of 37 cells surveyed and one with 16 of 34 cell surveyed. Ecoregion MGPR also had two strata in the conditional design: one with 35 of 100 cells surveyed and one with 37 of 75 cells surveyed. Data from 2012 were analyzed and summarized by ecoregion using the Overton and Stehman (1996) rigorous probability estimator for the re-stratified conditional design.

Prior to the 2013 survey, we pre-stratified the study area using the 4 ecoregions and selected GRTS equal probability samples from each using the same GRTS list from 2012. This process resulted in resurvey of 245 grid cells from 2012 and 38 new cells for a total sample size of 283 grid cells in 2013. We flew the same transect lines as were flown in 2012 on the 245 cells which were resurveyed.

**Aerial Survey Methods**

The survey platform used for the surveys was the Raven II (R-44) (Robinson Helicopter Company, Torrance, CA) helicopter accommodating two observers in the left and right rear seats, and a third observer in the front left seat. Three helicopters and survey crews operated simultaneously within the study area each year. Transects were flown north to south or south to north at nominal values of 60 km per hour and 25 m above ground. Surveys were conducted from sunrise until approximately 2.5 hours after sunrise between March 31 and May 3 in 2012 and between March 20 and April 21 in 2013.

Two 15-km north-south transects, separated by 7.5 km, were selected in each of the survey cells. The starting point of the first transect was randomly located in the interval (200 m, 7,300 m) on the base of the cell and the second transect was located 7,500 m to the right of the first transect.
Double observer (mark-recapture) sampling trials (Seber 1982, Manly et al. 1996, Buckland et al. 2004), were conducted on the left side of the aircraft to help estimate the probability of detection of prairie-chicken clusters. To help ensure independence of observers, we installed a cardboard wall that served as a visual barrier between front left and back left observers. Observers recorded the approximate perpendicular distance to the center of a cluster of prairie-chickens from the transect line, counted any observed prairie-chickens, and remained quiet until confident that the other observer either saw or missed the cluster. The detection was then announced by one or both of the observers and the helicopter returned to the original observed location of prairie-chickens so the global positioning system (GPS) coordinates of the center could be recorded for more accurate computation of the perpendicular distance from the transect line. All GPS coordinates, including the actual flight path, were recorded in a laptop computer using Garmin’s nRoute software (Garmin International, Inc., 1200 E. 151st St., Olathe, KS 66062).

Communication of all observations during the surveys ensured that observers did not confuse two different prairie-chicken clusters for the same observation. In addition to the number of individuals counted, other covariates recorded for each observation included date of the observation, activity (flushed or not flushed), whether leks were man-made or natural, and habitat type: crop land, short-grass grassland, tall-grass grassland including CRP grassland (with little or no shrubs), sand-sage prairie, shinnery oak (including other shrub dominated land), and bare ground.

Surveys were conducted at nominal 25 m above ground level (AGL), except when necessary to avoid obstacles. At 25 m AGL there was an area beneath the aircraft 6.9 m to the left or right side of the transect line that was not visible to the rear seat observers. The front left
seat observer focused on detection of prairie-chickens on and close to the transect line and also made observations of prairie-chickens detected in the field of view of the back left seat observer. The observer in the front left seat was also responsible for helping to guide the pilot to survey transects and recording flight paths and observations into a laptop computer. Observers alternated seats between flights in order to rotate observer positions throughout the survey. This allowed for estimation of an “average probability of detection by the average observer” for each position in the helicopter.

Detections of five or more prairie-chickens in a cluster were classified as leks. This criterion was verified during helicopter aerial and ground surveys conducted in Texas 2010 and 2011 (Timmer 2012). If fewer than 5 individuals were observed, ground surveys were conducted to determine if the location would be classified as a lek with lekking birds. If lekking birds were not found during ground surveys at the specified location of the cluster of less than 5 birds, the observation was classified as a “non-lek.” All leks in ecoregion SGPR, where LEPC, GPCH, and HPC were found, were visited on the ground to determine if the observed clusters of prairie-chickens were all LEPC, all GPCH, or a mixture of lesser and greater prairie-chickens.

All observers and pilots participated in a training session prior to the surveys. The goals of the training were threefold: 1) to standardize survey methodology, 2) to improve and standardize observers’ abilities to identify prairie-chickens from the air, and 3) to provide each observer with safety training. More detailed descriptions of the aerial and ground survey methods were contained in the Appendix of Standard Operating Procedures (McDonald et al. 2011).
STATISTICAL METHODS

Probability of Detection

A basic assumption of distance sampling was perfect detection at or near the transect line. To compensate for potential violation of this assumption, we formulated a mark recapture distance sampling detection function \( p(y, z) \) as a scaled version of a distance sampling detection function (Buckland et al. 2004):

\[
p(y, z) = p(6.9, z)g(y, z),
\]

where \( z \) was a vector of covariates, \( p(6.9, z) \) was the estimated probability that at least one of the two observers made the detection at 6.9 m, \( g(y, z) \) was the estimated detection function, and \( y \) was perpendicular distance from the transect line. In addition to distance, \( y \), the explanatory covariate vector \( z \) allowed incorporation of heterogeneity of detection probability from the following sources: cluster size (\( S \)), habitat (\( H \)), and flushed or not flushed (\( F \)).

We estimated \( p(6.9, z) \), probability of detection of prairie-chicken clusters near the transect line by analyzing the double observer observations of prairie-chicken clusters on the left side of the helicopter. Analysis of the double observer observations involved estimating the probability of detection by the front left seat observer, \( p_{FL}(6.9) \), and the probability of detection by the back left seat observer, \( p_{BL}(6.9) \), using logistic regression (McCullagh and Nelder 1989) with covariates to account for heterogeneity of detection probability. Candidate models for each of the logistic regressions used all subsets of the covariate set \( S, H \) and \( F \) as defined above. For each position, FL and BL, we selected the models within 5 AICc units of the model with minimum AICc and used model averaging to estimate probabilities of detection \( \hat{p}_{FL}(6.9) \) and
\( \hat{p}_{BL}(6.9) \) of a specific cluster (Burnham and Anderson 2002). Model specific probabilities of detection were estimated for each observed covariate combination. Assuming independence between the \( FL \) and \( BL \) observers, the probability of detection by at least one observer was estimated as

\[
\hat{p}(6.9, z) = \hat{p}_{FL}(6.9, z) + \hat{p}_{BL}(6.9, z) - \hat{p}_{FL}(6.9, z)\hat{p}_{BL}(6.9, z).
\]

The R package Mark-Recapture Distance Sampling (mrds) in the R language and environment (v2.13.0; R Development Core Team 2011) was used to fit multiple covariate distance sampling detection models and conventional distance sampling detection models for \( g(y, z) \). Custom R code was developed for estimating the exponential model because the model was not provided in mrds.

Key functions for the multiple covariate distance sampling detection models were the half-normal and hazard rate. Multiple covariate models considered all subsets of the three covariates: cluster size \( (S) \), habitat \( (H) \) and flushed or not flushed \( (F) \) with no adjustment terms. Conventional distance sampling detection models were estimated using three adjustment series: cosine (none, 2, 4, 6), Hermite polynomials (none, 2, 4, 6) and simple polynomial (none, 2, 4, 6, 8). We selected models within 5 AIC units of the minimum and used model averaging to estimate probability of detection of a specific cluster (Burnham and Anderson 2002). Model specific probabilities of detection were estimated for each observed covariate combination (Buckland et al. 2004, Thomas et al. 2010). Each model averaged detection probability \( \hat{g}(y, z) \) was then scaled by multiplying by \( \hat{p}(6.9, z) \), the probability of detection near the transect line to
obtain the covariate specific, scaled, model averaged probability of detection \( \hat{p}(y, z) \). Finally, the counts of individuals or leks were adjusted, dividing by their specific probability of detection.

### Estimation of Population Parameters in SGPR

We estimated the proportions of LEPC and HPC in leks and non-leks observed in the Kansas portion of SGPR where the species overlap. Estimates of the proportions of lesser, greater and hybrid prairie-chickens in the Kansas portion of SGPR were obtained from ground surveys conducted by the Kansas Department of Wildlife, Parks and Tourism. The resulting data set included 874 counts on 741 leks (553 GPCH, 152 LEPC and 46 mixed) across Kansas from 2007-2011. Kriging (Cressie 2012) was used to interpolate the species proportions across all sampled survey cells (Figures 2 and 3; Pitman 2012). The estimate of LEPC in ecoregion SGPR required calculating the products: (count of individuals in non-lek clusters) \( \times \) (cell specific estimated proportion of LEPC) and (count of individuals in mixed lek detections) \( \times \) (cell specific estimated proportion of LEPC). These two products are then added to the cell specific count of LEPC to obtain the estimated count of LEPC in a cell surveyed in SGPR. The number of HPC in a cell surveyed in SGPR was estimated in a similar manner.

### Adjustment of Counts for Probability of Detection

A Horvitz-Thompson type adjustment was made on the count of individuals in each detected cluster of individuals, dividing the count by its respective covariate specific, scaled, model averaged, probability of detection (Horvitz and Thompson 1952, Buckland et al. 2004). Similarly, in estimation of the abundance of leks, the terms in the sums were divided by their respective covariate specific, scaled, model averaged, probability of detection.

In the 2013 survey, surveyed cells within ecoregions had equal weights for estimation of population parameters. Ecoregion SOPR had equal weighted survey cells in 2012 in the
conditional design, as did ecoregion SGPR. However, surveyed cells within ecoregions SSPR and MGPR had unequal weights based on the conditional design realized in 2012. The Overton and Stehman (1996) rigorous probability estimator was used to estimate population parameters in 2012 for each ecoregion. Estimation of the total study area population parameters was achieved by adding ecoregion specific estimated population parameters.

**Estimation of Precision of Estimated Population Parameters**

Bootstrapping (Manly 2006) was used to estimate 90% confidence intervals (CIs) for densities and population totals of LEPC, HPC, LEPC leks, and mixed leks within each ecoregion. This process involved taking 1,000 simple random samples with replacement from the 256 cells surveyed in 2012 and 1,000 simple random samples with replacement from the 283 cells surveyed in 2013. The re-sampled datasets were then used to mimic the original 2012 and 2013 data. The same subsets of detection models selected by the AICc and AIC criterion for analysis of the original data were used in each bootstrap iteration. The entire analysis was repeated with this fixed set of models on each bootstrapped sample including: re-computation of model averaged probabilities of detection \( \hat{p}(y, z) \), number of LEPC leks, mixed leks and non-leks, and average proportions of LEPC and HPC in SGPR of Kansas. We sampled from a binomial model based on observed proportions and number of observations to incorporate uncertainty due to estimates of proportions of LEPC and HPC in SGPR. Each bootstrapped sample produced new estimates of densities and population totals. We calculated confidence intervals based on the central 90% of the bootstrap distribution (the percentile method) for each estimated parameter.
RESULTS

The location of one observation of LEPC in SOPR in 2012 was not accessible for ground confirmation and was included in further analysis as a non-lek. One of the cells in the original sample of 256 in 2012 was on the Cannon Air Force Base, New Mexico, in SOPR and not accessible for aerial survey. The cell was replaced by the nearest accessible cell not originally selected for survey, because it was not logistically feasible to replace it by the next cell on the GRTS sampling list.

The numbers of mark-recapture observations of LEPC, GPCH, and HPC for modeling the components $\hat{p}_{FL}(6.9)$ and $\hat{p}_{BL}(6.9)$ for the probability of detection by at least one observer were judged to be too small to accurately estimate the parameters within each year. We elected to pool detections of leks and non-leks of LEPC, GPCH and HPC for survey years 2012 and 2013, because the aerial survey methods were identical. Pooling these data gave rise to sample sizes of 89 for estimating $\hat{p}_{BL}(6.9)$ and 94 for estimating $\hat{p}_{FL}(6.9)$. We gave the detections equal weight for modeling the components of the covariate specific, scaled, model averaged probability of detection, $\hat{p}(y, z)$.

We detected 155 leks and non-lekking clusters of LEPC, GPCH, and HPC in 2012 (83 in 2013) of which 63.2% were in short-grass grassland in 2012 and 66.3% in 2013 (Table 1). The 2012 and 2013 pooled data set for estimation of the distance sampling detection models $\hat{g}(y, z)$ consisted of 238 detections with equal weight.

Buckland et al. (2001) recommended dropping up to 5% of observations with the largest distances to the transect line to remove the influence of outliers prior to modeling probability of detection. We dropped four observations greater than 300 m from the transect line. Data were
grouped into 14 intervals for fitting models for probability of detection with the first interval spanning 0 to 40 m and all subsequent intervals encompassing 20 m. The first interval was defined at 0 – 40 m in order to compensate for potential errors in assigning distances near the transect line thus avoiding artificial “spiking” on and close to the transect line.

Covariates used in modeling probability of detection were cluster size (S), and categorical variables: habitat type (H) and flushed or not flushed (F). Due to the similarity of detection probability of prairie-chicken clusters in crop-land, short-grassland and bare ground, we combined those habitat types into one habitat category which we denoted by “SG”. The four levels considered for (H) were short-grass/cropland/bare-ground (SG), shinnery oak (SO), sand-sage prairie (SP) and tall-grass grassland (TGR).

Twelve models for $\hat{p}_{BL}(6.9)$ were within 5 AICc units of the model with minimum AICc for the BL observer position and 10 models for $\hat{p}_{FL}(6.9)$ were within 5 AICc units of the model with minimum AICc for the FL observer (Table 2). Five models for the probability of detection $\hat{g}(y, z)$ were within 5 AIC units of the minimum (Table 3). Weighted average estimates of $\hat{p}_{BL}(6.9), \hat{p}_{FL}(6.9)$, and $\hat{g}(y, z)$ were obtained for combinations of covariates associated with detections of leks and non-leks. Finally, the scaled estimates of probability of detection $\hat{p}(y, z) = \hat{p}(6.9, z) \hat{g}(y, z)$ were computed for each combination of covariates.

**Estimated Densities and Abundances of LEPC and LEPC Leks**

We adjusted counts of LEPC and detections of leks by covariate specific, scaled, model averaged probabilities of detection $\hat{p}(y, z)$ to estimate population sizes and abundance of leks in 4 ecoregions and the total study area (Tables 4, 5, 6, 7, and Figure 4). We estimated a total population size of 34,440 LEPC in 2012 (90% CI from 21,718 to 52,076) and 17,616 in 2013.
(90% CI from 8,442 to 20,978), an estimated decrease of approximately 50% in 2013 relative to 2012 (Tables 4 and 5). The confidence intervals do not overlap indicating a statistically significant decrease in the population size in 2013 relative to 2012 at the approximate 81% confidence level (p-value ≈ 0.2). In 2012 the estimated densities of LEPC varied from 10.65 (7.11 in 2013) per 100 km² (38.6 mi²) in SOPR to 54.65 (27.52 in 2013) per 100 km² (38.6 mi²) in SGPR (Tables 4 and 5). We estimated a total of 350 HPC in ecoregion SGPR in 2012 and 342 in 2013 (Table 8).

We estimated total abundance of LEPC leks to be 2,930 in 2012 (90% CI from 1677 to 4571) and 2,036 in 2013 (90% CI from 967 to 2508), an estimated decrease of approximately 30% in 2013 relative to 2012 (Tables 6 and 7). The confidence intervals overlap substantially for total leks indicating no statistically significant decrease in leks in 2013 relative to 2012 at the approximate 81% confidence level. In 2012 the estimated densities of LEPC leks varied from 1.32 (0.43 in 2013) per 100 km² (38.6 mi²) in SOPR to 3.86 (3.32 in 2013) per 100 km² (38.6 mi²) in SGPR (Tables 6 and 7). We estimated a total of 453 mixed LEPC-GRCH leks in ecoregion SGPR in 2012 and 356 in 2013 (Table 9).

**DISCUSSION**

Our study provides the first estimates of range wide LEPC population size based on a statistically rigorous sampling design and analytic procedures. Our estimate of 34,440 prairie-chickens in 2012 (Table 4) was within the range of less rigorous techniques that indicated a population size of 40,000 in 2007. Our estimated population size of 17,616 in 2013 was approximately 50% of the estimate of 34,440 in 2012. The estimated abundance of 2,036 LEPC leks in 2013 was approximately 70% of the estimate of 2,930 in 2012. It is well documented that there was an excessive drought throughout the southern great plains in 2012 (e.g., National
Climatic Data Center 2012). The drought was a likely contributing cause for the estimated decrease in population size in 2013.

The overall sample size on number of cells surveyed was increased in 2013 giving rise to estimates of total population size and total LEPC leks whose precisions were in a useful range; coefficients of variation were 0.28 and 0.26 respectively in 2013. A statistically significant decrease in the population size was observed from 2012 to 2013 at the approximate 81% confidence level, however this observed decrease would not be considered statistically significant at the nominal 90% confidence level (p-value = 0.10).

We are encouraged by the precision of our estimates based on our sampling design and methodology and recommend such an approach to be used for other lekking grouse species. In particular, implementation of such a methodology could provide unified range-wide population estimates for species of concern: greater or Gunnison sage-grouse (*Centrocercus urophasianus* and *C. minimus*, respectively) as well as Columbian sharp-tailed grouse (*Tymanuchus phasianellus columbianus*).

We recommend continued use of the R-44 helicopter, or equivalent seating arrangement for observers, in future surveys. Our results indicated that double observers on the left side of the platform provide valuable information to scale the probability of detection close to the transect line and adjust for apparently less than 100% probability of detection on and close to the transect lines. For safety reasons, we recommend that the pilots do not have responsibility for detection of prairie-chicken clusters. In two years of survey, the pilots observed only 2 clusters of prairie-chickens that were missed by the observers.
Adjustments to the sampling design either for future surveys of LEPCs or other lekking grouse species should consider imminent and future questions to be answered. We emphasized early detection of trends in LEPC population size and abundance of leks. We believe this was accomplished by spreading the survey effort over the entire study area (i.e. survey in 283 of 536 cells, with relatively low sampling effort in a cell; 2 line transects with maximum width 300 m covering 8% of the cell). Consequently this design had limited ability to provide early detection of changes in range and distribution of the species, but good ability to track trends in population size and abundance of leks if the same cell and transects are surveyed.

Assuming it is critical to obtain information on population trends as quickly as possible for the study area and for each of the four ecoregions, then maintaining the same study design, cells, transects, and methods as in 2013 has long been recognized as the preferred design (e.g., Overton and Stehman 1996). The other advantage of the 2013 LEPC design is the simplicity of a stratified design with direct comparison of birds and lek counts in the same units and more freedom to shift sampling effort from ecoregion to ecoregion without complicating the analysis excessively. We recommend that the 2013 survey design and methods be used for future monitoring of the size of LEPC population and abundance of leks.

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National Fish and Wildlife Foundation, and various oil and gas companies and associations. The recommended study design and methods were developed with the assistance of the following members of the Lesser Prairie-chicken Interstate Working Group: Bill Van Pelt, WAFWA Grassland Coordinator, Arizona Game and Fish Department; Jim Pitman, Kansas Department of Wildlife, Parks and Tourism; Sean Kyle, Texas Parks and Wildlife Department, David Klute, Colorado Division of Parks and Wildlife; Grant Beauprez, New Mexico Department of Game and Fish; and Doug Schoeling, Oklahoma Department of Wildlife Conservation. Valuable assistance was received from Michael Houts, GIS/Remote Sensing Specialist, Kansas Biological Survey. We also wish to acknowledge the assistance of the aerial survey crew members and pilots.

**LITERATURE CITED**


Table 1. Numbers and percent of detections of leks and non-lekking clusters of LEPC, GPCH, and HPC by habitat type in the data sets for 2012 and 2013. Habitat types were: CR = crop land, SGR = short-grass grassland, SO = shinnery oak (including other shrub dominated land), SP = sand-sage prairie, TGR = tall-grass grassland including CRP grassland (with little or no shrubs).

<table>
<thead>
<tr>
<th>Habitat Type</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR</td>
<td>30 (19.4%)</td>
<td>15 (18.1%)</td>
</tr>
<tr>
<td>SGR</td>
<td>98 (63.2%)</td>
<td>55 (66.3%)</td>
</tr>
<tr>
<td>SO</td>
<td>6 (3.9%)</td>
<td>3 (3.6%)</td>
</tr>
<tr>
<td>SP</td>
<td>5 (3.2%)</td>
<td>9 (10.8%)</td>
</tr>
<tr>
<td>TGR</td>
<td>15 (9.7%)</td>
<td>1 (1.2%)</td>
</tr>
<tr>
<td>BG</td>
<td>1 (0.6%)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Total</td>
<td>155</td>
<td>83</td>
</tr>
</tbody>
</table>

Table 2. Logistic regression models within 5 AICc units of the minimum for estimation of $\hat{p}_{BL}(6.9)$, sample size = 89, and $\hat{p}_{FL}(6.9)$, sample size = 94. Perpendicular distance from the transect line = y, S = cluster size, F = flushed/not flushed, and H = habitat type. BL = back left observer and FL = front left observer.

<table>
<thead>
<tr>
<th>BL Model Covariates</th>
<th>AICc</th>
<th>Model Weights</th>
<th>FL Model Covariates</th>
<th>AICc</th>
<th>Model Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>123.5</td>
<td>0.211</td>
<td>None</td>
<td>133.2</td>
<td>0.268</td>
</tr>
<tr>
<td>S + F</td>
<td>123.8</td>
<td>0.186</td>
<td>S</td>
<td>134.1</td>
<td>0.172</td>
</tr>
<tr>
<td>S</td>
<td>124.5</td>
<td>0.127</td>
<td>y</td>
<td>134.7</td>
<td>0.131</td>
</tr>
<tr>
<td>F</td>
<td>124.7</td>
<td>0.115</td>
<td>y + S</td>
<td>135.3</td>
<td>0.094</td>
</tr>
<tr>
<td>y</td>
<td>125.3</td>
<td>0.086</td>
<td>S + F</td>
<td>135.9</td>
<td>0.071</td>
</tr>
<tr>
<td>S + y + F</td>
<td>125.8</td>
<td>0.068</td>
<td>F</td>
<td>135.9</td>
<td>0.069</td>
</tr>
<tr>
<td>y + S</td>
<td>126.3</td>
<td>0.052</td>
<td>S + y + F</td>
<td>136.7</td>
<td>0.048</td>
</tr>
<tr>
<td>H</td>
<td>126.8</td>
<td>0.041</td>
<td>H</td>
<td>136.8</td>
<td>0.044</td>
</tr>
<tr>
<td>y + F</td>
<td>126.8</td>
<td>0.041</td>
<td>y + F</td>
<td>137.2</td>
<td>0.037</td>
</tr>
<tr>
<td>S + H</td>
<td>128.4</td>
<td>0.019</td>
<td>S + H</td>
<td>137.7</td>
<td>0.029</td>
</tr>
<tr>
<td>y + H</td>
<td>128.4</td>
<td>0.019</td>
<td>y + H</td>
<td>138.6</td>
<td>0.018</td>
</tr>
<tr>
<td>H + F</td>
<td>128.4</td>
<td>0.018</td>
<td>S + H + y</td>
<td>139.3</td>
<td>0.013</td>
</tr>
<tr>
<td>S + H + F</td>
<td>128.6</td>
<td>0.017</td>
<td>H + F</td>
<td>140.1</td>
<td>0.008</td>
</tr>
</tbody>
</table>
Table 3. Five models within 5 AIC units of the minimum for estimation of \( \hat{g}(y, z) \), the distance sampling model for probability of detection. \( S \) = cluster size, \( F \) = flushed/not flushed, and \( H \) = habitat type. Perpendicular distance from the transect line, \( y \), was included in each model.

<table>
<thead>
<tr>
<th>Model Covariates</th>
<th>Key Function</th>
<th>AIC</th>
<th>Model Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Adj Terms</td>
<td>Neg. Exponential</td>
<td>1020.82</td>
<td>0.42</td>
</tr>
<tr>
<td>S + H</td>
<td>Half-Normal</td>
<td>1021.87</td>
<td>0.25</td>
</tr>
<tr>
<td>H</td>
<td>Half-Normal</td>
<td>1022.19</td>
<td>0.21</td>
</tr>
<tr>
<td>S + H + F</td>
<td>Half-Normal</td>
<td>1023.92</td>
<td>0.09</td>
</tr>
<tr>
<td>H + F</td>
<td>Half-Normal</td>
<td>1025.53</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Table 4. Population estimates in 2012 for density of LEPC per 100 km\(^2\) (38.6 mi\(^2\)) and total population sizes (\( \hat{N} \)) with 90% confidence intervals and estimated coefficient of variation (standard error/estimate).

<table>
<thead>
<tr>
<th>Eco. Surveyed Area</th>
<th>LEPC Detected</th>
<th>Unadj. Density</th>
<th>( \hat{N} ) Low</th>
<th>( \hat{N} ) High</th>
<th>90% CI Low</th>
<th>90% CI High</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOPR 75 Cells 27,675</td>
<td>51</td>
<td>3.78</td>
<td>10.65</td>
<td>10.65</td>
<td>2.946</td>
<td>1.325</td>
<td>7.973 0.68</td>
</tr>
<tr>
<td>SSPR 29 Cells 15,975</td>
<td>28</td>
<td>5.56</td>
<td>18.81</td>
<td>18.81</td>
<td>3.005</td>
<td>134*</td>
<td>7.194 0.77</td>
</tr>
<tr>
<td>MGPR 72 Cells 39,600</td>
<td>86</td>
<td>6.79</td>
<td>20.39</td>
<td>20.39</td>
<td>8.076</td>
<td>3.022</td>
<td>14.640 0.44</td>
</tr>
<tr>
<td>SGPR 80 Cells 37,350</td>
<td>244</td>
<td>18.9</td>
<td>54.65</td>
<td>54.65</td>
<td>2.0413</td>
<td>10,669 31,564</td>
<td>0.32</td>
</tr>
<tr>
<td>Total 256 Cells 120,600</td>
<td>409</td>
<td>9.69</td>
<td>28.56</td>
<td>28.56</td>
<td>34,440</td>
<td>21,718 52,076</td>
<td>0.31</td>
</tr>
</tbody>
</table>

*The lower limit of the bootstrapped confidence interval was 0.00, an impossible value, because 134 LEPC were detected in SSPR.

Table 5. Population estimates in 2013 for density of LEPC per 100 km\(^2\) (38.6 mi\(^2\)) and total population sizes (\( \hat{N} \)) with 90% confidence intervals and estimated coefficient of variation (standard error/estimate).

<table>
<thead>
<tr>
<th>Eco. Surveyed Area</th>
<th>LEPC Detected</th>
<th>Unadj. Density</th>
<th>( \hat{N} ) Low</th>
<th>( \hat{N} ) High</th>
<th>90% CI Low</th>
<th>90% CI High</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOPR 77 Cells 27,675</td>
<td>36</td>
<td>2.6</td>
<td>7.11</td>
<td>7.11</td>
<td>1,967</td>
<td>844</td>
<td>3,754 0.53</td>
</tr>
<tr>
<td>SSPR 55 Cells 15,975</td>
<td>40</td>
<td>4.04</td>
<td>11.28</td>
<td>11.28</td>
<td>1,802</td>
<td>552</td>
<td>3,538 0.55</td>
</tr>
<tr>
<td>MGPR 78 Cells 39,600</td>
<td>39</td>
<td>2.78</td>
<td>9.01</td>
<td>9.01</td>
<td>3,567</td>
<td>968</td>
<td>6,761 0.5</td>
</tr>
<tr>
<td>SGPR 73 Cells 37,350</td>
<td>100</td>
<td>8.92</td>
<td>27.52</td>
<td>27.52</td>
<td>10,279</td>
<td>2,349</td>
<td>11,646 0.29</td>
</tr>
<tr>
<td>Total 283 Cells 120,600</td>
<td>269</td>
<td>4.81</td>
<td>14.61</td>
<td>14.61</td>
<td>17,616</td>
<td>8,442</td>
<td>20,978 0.28</td>
</tr>
</tbody>
</table>
Table 6. Estimated density per 100 km\(^2\) (38.6 mi\(^2\)) and abundance of LEPC leks in 2012 with 90% confidence intervals and estimated coefficient of variation (standard error/estimate).

<table>
<thead>
<tr>
<th>Eco. Region</th>
<th>Surveyed Cells</th>
<th>Surveyed Area km(^2)</th>
<th>LEPC Leks Detected</th>
<th>Unadj. Density</th>
<th>Est. LEPC Leks Density</th>
<th>90% CI Low</th>
<th>90% CI High</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOPR</td>
<td>75</td>
<td>27,675</td>
<td>6</td>
<td>0.44</td>
<td>1.32</td>
<td>366</td>
<td>117</td>
<td>987</td>
</tr>
<tr>
<td>SSPR</td>
<td>29</td>
<td>15,975</td>
<td>3</td>
<td>0.61</td>
<td>2.04</td>
<td>327</td>
<td>3</td>
<td>834</td>
</tr>
<tr>
<td>MGPR</td>
<td>72</td>
<td>39,600</td>
<td>9</td>
<td>0.66</td>
<td>2</td>
<td>794</td>
<td>310</td>
<td>1,420</td>
</tr>
<tr>
<td>SGPR</td>
<td>80</td>
<td>37,350</td>
<td>18</td>
<td>1.25</td>
<td>3.86</td>
<td>1,443</td>
<td>496</td>
<td>2,458</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>256</strong></td>
<td><strong>120,600</strong></td>
<td></td>
<td><strong>0.79</strong></td>
<td><strong>2.43</strong></td>
<td><strong>2,930</strong></td>
<td><strong>1,677</strong></td>
<td><strong>4,571</strong></td>
</tr>
</tbody>
</table>

*The lower limit of the bootstrapped confidence interval was 0.00, an impossible value, because 3 leks were detected in SSPR.

Table 7. Estimated density per 100 km\(^2\) (38.6 mi\(^2\)) and abundance of LEPC leks in 2013 with 90% confidence intervals and estimated coefficient of variation (standard error/estimate).

<table>
<thead>
<tr>
<th>Eco. Region</th>
<th>Surveyed Cells</th>
<th>Surveyed Area km(^2)</th>
<th>LEPC Leks Detected</th>
<th>Unadj. Density</th>
<th>Est. LEPC Leks Density</th>
<th>90% CI Low</th>
<th>90% CI High</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOPR</td>
<td>77</td>
<td>27,675</td>
<td>2</td>
<td>0.14</td>
<td>0.43</td>
<td>118</td>
<td>2</td>
<td>355</td>
</tr>
<tr>
<td>SSPR</td>
<td>55</td>
<td>15,975</td>
<td>7</td>
<td>0.71</td>
<td>2.02</td>
<td>323</td>
<td>116</td>
<td>587</td>
</tr>
<tr>
<td>MGPR</td>
<td>78</td>
<td>39,600</td>
<td>4</td>
<td>0.28</td>
<td>0.9</td>
<td>356</td>
<td>80</td>
<td>695</td>
</tr>
<tr>
<td>SGPR</td>
<td>73</td>
<td>37,350</td>
<td>14</td>
<td>1.07</td>
<td>3.32</td>
<td>1,240</td>
<td>293</td>
<td>1,499</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>283</strong></td>
<td><strong>120,600</strong></td>
<td></td>
<td><strong>0.55</strong></td>
<td><strong>1.69</strong></td>
<td><strong>2,036</strong></td>
<td><strong>967</strong></td>
<td><strong>2,508</strong></td>
</tr>
</tbody>
</table>

* The lower limit of the bootstrapped confidence interval was 0.00, an impossible value, because 2 leks were detected in SOPR.

Table 8. Population estimates in 2012 and 2013 for density of HPC per 100 km\(^2\) (38.6 mi\(^2\)) and total population sizes (\(\hat{N}\)) in SGPR ecoregion with 90% confidence intervals and estimated coefficient of variation (standard error/estimate).

<table>
<thead>
<tr>
<th>Year</th>
<th>Uadj. Density</th>
<th>Adj. Density</th>
<th>(\hat{N}) HPC</th>
<th>90% CI Low</th>
<th>90% CI High</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>0.30</td>
<td>0.94</td>
<td>350</td>
<td>179</td>
<td>561</td>
<td>0.35</td>
</tr>
<tr>
<td>2013</td>
<td>0.29</td>
<td>0.92</td>
<td>342</td>
<td>179</td>
<td>542</td>
<td>0.37</td>
</tr>
</tbody>
</table>
Table 9. Estimated abundance and density per 100 km$^2$ (38.6 mi$^2$) of mixed LEPC-GPCH leks in 2012 and 2013 with 90% confidence intervals and estimated coefficient of variation (standard error/estimate).

<table>
<thead>
<tr>
<th>Year</th>
<th>Adj. Density</th>
<th>Est. N</th>
<th>90% CI Low</th>
<th>90% CI High</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>0.42</td>
<td>453</td>
<td>69</td>
<td>871</td>
<td>0.55</td>
</tr>
<tr>
<td>2013</td>
<td>0.3</td>
<td>356</td>
<td>81</td>
<td>686</td>
<td>0.52</td>
</tr>
</tbody>
</table>
Figure 1. Study area for 2012 and 2013 lesser prairie-chicken surveys illustrated with grid cells selected for survey in 2013. The colored areas surrounding the study sub-areas indicated an approximate 77.7 km (30 mi) buffer into which the survey may be expanded in the future.
Figure 2. Estimated percentages of lesser prairie-chickens in (15 x 15 km) cells in ecoregion SGPR located in northwestern Kansas.
Figure 3. Estimated percentages of hybrid lesser-greater prairie-chickens in (15 x 15 km) cells in ecoregion SGPR located in northwestern Kansas.
Figure 4. Estimated population sizes of LEPC with 90% confidence limits in 2012 and 2013 for 4 ecoregions and total study area.