RANGE-WIDE POPULATION SIZE OF THE LESSER PRAIRIE-CHICKEN: 2012 TO 2018

Photos: Colorado Parks and Wildlife

Prepared for:

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EXECUTIVE SUMMARY

- We estimated lesser prairie-chicken population sizes annually from 2012 through 2018 in the 2011 expected occupied range of the lesser prairie-chicken in Kansas, Colorado, New Mexico, Oklahoma, and Texas.
- We estimated lesser prairie-chicken population sizes and abundances of leks in four sub-regions of the expected occupied range. We also estimated population sizes and abundances of leks of greater prairie-chicken and hybrid prairie-chicken in the Short Grass Prairie Conservation Reserve Program (CRP) Region of northwest Kansas (Appendix A).
- There were 536 total grid cells in the study area from 2012 to 2017 and 514 total grid cells in the study area in 2018. The study area was reduced in 2018 by dropping grid cells in the Mixed-Grass Prairie Region of central Kansas where no lesser prairie-chickens or leks were observed from 2012 to 2017.
- Sample cells were selected by an equal probability procedure. Two-hundred-fifty-six (256) grid cells were surveyed in 2012 and 283 grid cells were surveyed from 2013 through 2016. A total of 303 cells were surveyed in 2017 and 2018. A rotating panel design was implemented in 2017 and 2018 by selecting new grid cells for approximately 20% of the sampled area in each of the prairie regions. The same field survey methods were used from 2012 to 2018; two transects were surveyed in each grid cell and the two transects covered 8% of the grid cell.
- Eighty and/or ninety percent confidence intervals (CI) were computed on estimated parameters to account for variation in the estimates due to un-sampled grid cells, detection probability, and surveying two transect in each sampled grid cell.
- A total of 912 prairie-chicken clusters were detected from 2012 to 2018; 59.1% of the observations were in short-grass grassland, 20.9% were in cropland, 11.5% were in tall-grass grassland including CRP grassland (with little or no shrubs), 5.0% were in sand-sage prairie, 2.7% were in shinnery oak (including other shrub dominated land), and 0.75% were on bare ground.
- We estimated probability of detection on transects using the pooled data set of 912 prairie-chicken clusters. We improved the models and method for estimation of probability of detection of clusters of prairie-chickens as a function of distance from transect. Computer software became available to estimate the effect of the size of a cluster of prairie-chickens on probability of detection in all of the models as well as the effect of habitat type.
- Probability of detection increased as the size of a prairie-chicken cluster increased. In addition, habitat had an effect on probability of detection with observations in cropland, on bare ground, and in short-grass grassland having the highest probability of detection.

- In general, use of improved models for probability of detection resulted in an increase in the estimated probability of detection of larger clusters. Estimates of lesser prairie-chicken population sizes from 2012 to 2017 decreased slightly relative to estimates reported previously.
- We estimated the probability of detection of clusters of prairie-chickens using model-averaged distance sampling models scaled by the estimated probability of detection on the inside edge of the field of view of the rear seat observers. We adjusted counts of lesser prairie-chicken, greater prairie-chicken, and hybrid prairie-chicken by covariate-specific, scaled, model-averaged probabilities of detection to estimate population sizes in ecoregions and the total study area.
- For the study of trends, we estimated the total population sizes of lesser prairie-chicken to be:
    - 33,000 (90% CI: 17333, 43583) birds in 2012;
    - 17,457 (90% CI: 8384, 22834) in 2013;
    - 20,617 (90% CI: 10244, 27084) in 2014;
    - 25,779 (90% CI: 13072, 32416) in 2015;
    - 22,246 (90% CI: 12287, 27695) in 2016;
    - 29,934 (90% CI: 16002, 39103) in 2017; and
    - 38,637 (90% CI: 20233, 49698) in 2018.
- There was a statistically significant annual rate of increase in the total lesser prairie-chicken population size from 2013 to 2018 (p-value = 0.01). The average rate of increase was 3,723 lesser prairie-chicken per year in the population (standard error = 831).
- We estimated a total population increase of 8,702 lesser prairie-chicken from 2017 to 2018 (29% increase); however the increase was not statistically significant at the 80% confidence level. The 80% CI on the increase ranged from negative (-2,077) to positive (17,911).
- The estimated increase in abundance of 1,758 lesser prairie-chicken in the Sand Sagebrush Prairie Region from 2017 to 2018 was significant at the 90% CI (0, 3561).
- The estimated increase in abundance of 3,405 lesser prairie-chicken in the Shinnery Oak Prairie Region from 2017 to 2018 was significant at the 80% CI (118, 6631).
- We observed a stable to increasing population of lesser prairie-chickens since 2013 in the Mixed Grass Prairie Region of northeast Panhandle of Texas, northwest Oklahoma, and south-central Kansas and in the Short Grass Conservation Reserve Program Prairie Region of northwest Kansas.
- We observed a stable to increasing population of lesser prairie-chickens since 2014 in the Sand Sage Prairie Region of southeastern Colorado, southwestern Kansas, and the northwest Oklahoma Panhandle.

- We observed a stable to increasing population of lesser prairie-chickens since 2015 in the Shinnery Oak Prairie Region of eastern New Mexico and western Panhandle of Texas.
- The abundances of lesser prairie-chicken leks in the total population were estimated to be:
    - 3,124 (90% CI: 1443, 4564) in 2012;
    - 2,010 (90% CI: 908, 2698) in 2013;
    - 2,456 (90% CI: 1181, 3414) in 2014;
    - 1,527 (90% CI: 669, 2028) in 2015;
    - 1,852 (90% CI: 719, 2750) in 2016
    - 2,897 (90% CI: 1483, 3973) in 2017; and
    - 2,871 (90% CI: 1406, 3859) in 2018.
- The estimated total abundances and trends of greater prairie-chickens in the Short Grass/CRP of northwest Kansas corroborated our results for abundances and trends of lesser prairie-chickens (Appendix B). The estimated population sizes of the greater prairie-chicken in the Short Grass/CRP Prairie Region were:
    - 29,453 (90% CI: 13802, 3905) in 2012;
    - 14,039 (90% CI: 7134, 17884) in 2013;
    - 15,383 (90% CI: 7484, 19630) in 2014;
    - 21,123 (90% CI: 10251, 26935) in 2015;
    - 25,718 (90% CI: 12912, 33067) in 2016;
    - 32,244 (90% CI: 16843, 39584) in 2017; and
    - 33,867 (90% CI: 15644, 45333) in 2018.
- There was a statistically significant annual rate of increase of abundance of greater prairie-chickens in the Short Grass/CRP Prairie Region in northwest Kansas from 2013 to 2018 (p-value < 0.01). The average rate of increase was 4,409 greater prairie-chicken per year in the Short Grass/CRP Prairie Region (standard error = 336).

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INTRODUCTION

Ascertaining estimates of wildlife population size 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 had 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 was their 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.

Our objectives were to implement consistent, statistically robust survey and analysis methods to estimate lesser prairie-chicken (*Tympanuchus pallidicinctus*; LPC) population size and lek abundance from 2012 to 2018. To achieve this, we had to address issues of regional variation as well as the co-occurrence of greater prairie-chicken (*Tympanuchus cupido*; GPC) and of hybrid prairie-chickens (HPC) in northwestern Kansas. We estimated LPC and lek abundances for four ecoregions: 1) Shinnery Oak (*Quercus havardii*) Prairie Region (SOPR), located in eastern New Mexico and the southwest Texas Panhandle; 2) Sand Sagebrush Prairie Region (SSPR), located in southeastern Colorado, southwestern Kansas, and the western Oklahoma Panhandle; 3) Mixed-Grass Prairie Region (MGPR), located in the northeastern Texas Panhandle, north-western Oklahoma, and south-central Kansas; and 4) Short Grass Conservation Reserve Program (CRP) Prairie Region (SGPR), located in northwestern Kansas (Figure 1). We also estimated GPC and lek abundances in the SGPR located in northwestern Kansas.

STUDY AREA

Our study area included the 2011 Estimated Occupied Range of LPC as defined by the Lesser Prairie-Chicken Interstate Working Group (LPCIWG) and mapped on the Western Association of Fish and Wildlife Agencies' web site (LPCIWG 2011, McDonald et al. 2012). 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 (SGP CHAT; Kansas Applied Remote Sensing [KARS] 2015, 1983). The study area for 2018 was illustrated in Figure 1, where we indicated the grid cells selected and not selected for survey. In 2018, the study area was reduced by 22 grid cells in the MGPR where LPC were not observed from 2012 to 2017. The 2018 estimates account for the reduced survey area. The buffered areas surrounding the sub-areas delineated an approximate 77.7-kilometer (km; 30-mile [mi]) buffer into which the survey may be expanded in the future.

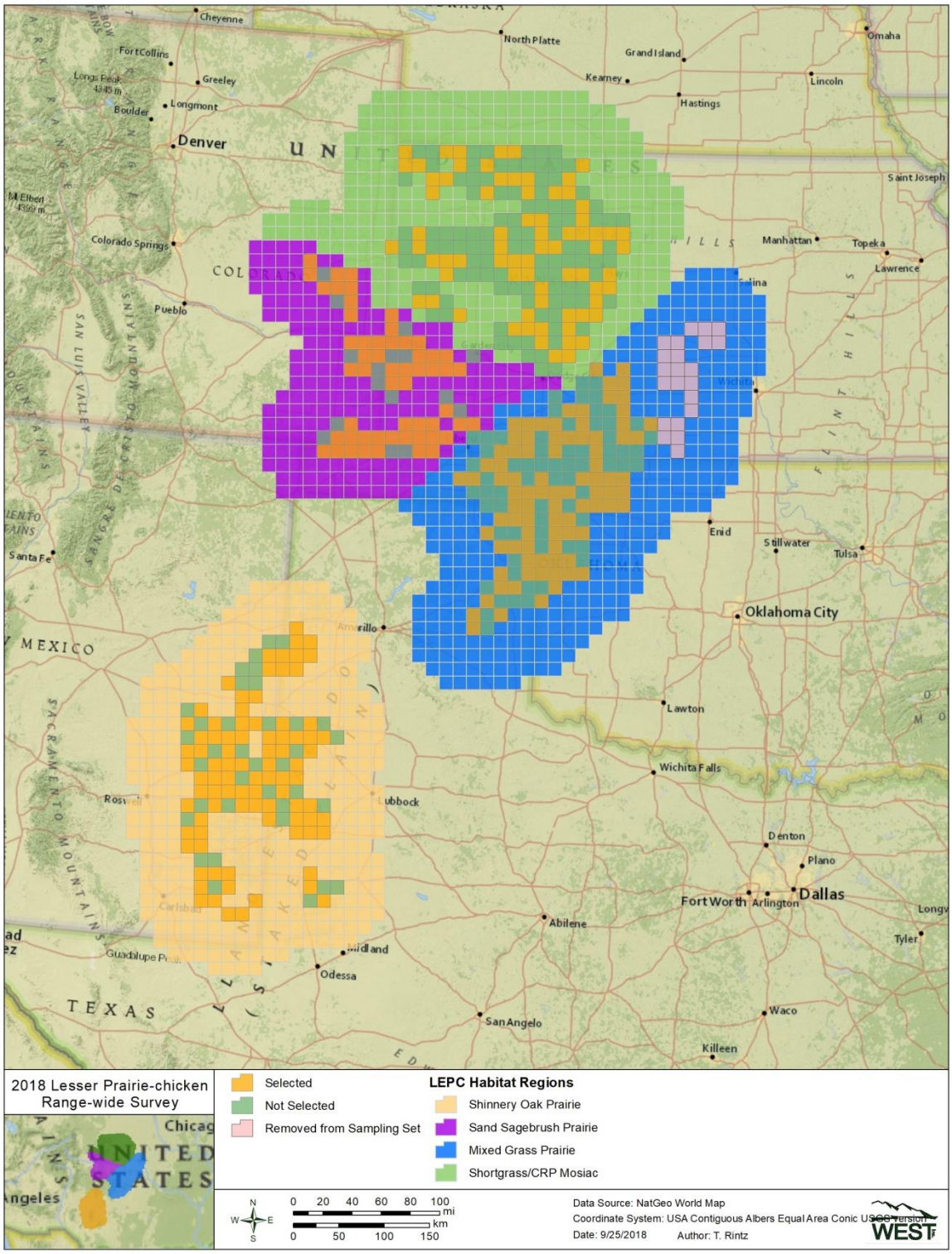

Figure 1. Study area for 2018 lesser prairie-chicken surveys illustrated with grid cells selected for survey. The colored areas surrounding the study sub-areas indicated an approximate 77.7-kilometer (30-mile) buffer into which the survey may be expanded in the future.

METHODS

Probabilistic Samples for Trend

We ranked 15- × 15-km (9.3- × 9.3-mi) grid cells in the study area from one to 536 by an equal probability sampling procedure known as the Generalized Random Tessellation Stratified (GRTS) sampling (McDonald et al. 2012, 2014; 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.

In 2012, 256 grid cells were selected for survey (Table 1). A total of 283 grid cells were surveyed from 2013 to 2016. Details on the sampling design and strata are outlined in McDonald et al. (2012 and 2014).

In 2017 and 2018, a rotating panel design was implemented in each ecoregion. A panel of approximately 20% of the top ranked grid cells on the GRTS list was dropped and a panel of equal size was added from the grid cells next on the GRTS list in each ecoregion. Funds became available for survey of additional cells in two regions in 2017 and 2018; 10 additional cells were surveyed in the SOPR and 10 additional cells were surveyed in the MGPR for a total sample size of 303 probabilistically selected grid cells.

Table 1. Total number of grid cells surveyed by year and region.

	Region				
Year	SOPR	SSPR	MGPR	SGPR	Overall
2012	75	29	72	80	256
2013	77	55	78	73	283
2014	77	55	78	73	283
2015	77	55	78	73	283
2016	77	55	78	73	283
2017	87	55	88	73	303
2018	87	55	88[1]	73	303

SOPR = Shinnery Oak Prairie Region (eastern New Mexico, western Texas), SSPR = Sand Sagebrush Prairie Region (southeastern Colorado, southwestern Kansas, Oklahoma Panhandle), MGPR = Mixed-Grass Prairie Region (northeastern Texas, northwestern Oklahoma, south-central Kansas), and SGPR = Short Grass Conservation Reserve Program Prairie Region (northwest Kansas).

[1]The total number of grid cells in the sampling frame in the MGPR was reduced from 176 grid cells 2012 - 2017 to 154 grid cells in 2018.

Aerial Survey Methods

The survey platform used for the surveys was the Raven II (R-44) (Robinson Helicopter Company, Torrance, California) helicopter accommodating two observers in the rear left and right 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 (37 mi per hour) and 25 meters (m; 82 feet

[ft]) above ground. Surveys were conducted from sunrise until approximately 2.5 hours after sunrise during the lekking period from March 15 to May 15.

Two 15-km north-south parallel transects were selected in each of the survey cells. The starting point of the first transect was randomly located in the interval (300 m, 7,200 m [984 ft, 23,622 ft]) on the base of the cell and the second transect was located 7,500 m (24,606 ft) to the right of the first transect. Survey strip width was 300 m on each side of the transect lines. The area surveyed in each grid cell was 8% of the total 225 square km.

Survey methods were the same in all seven years of the surveys and were described in detail in McDonald et al. (2012).

Statistical Methods

Probability of Detection

We improved the models and method for estimation of probability of detection of clusters of prairie-chickens in 2018. The package “Rdistance” in the R language and environment (3.5.0; R Development Core Team 2018) was used to fit all possible models with size of a cluster and habitat as covariates. Key functions considered included the negative exponential, hazard rate, and half normal distributions. The “Rdistance” package improved the estimates of probability of detection as the previous software used did not fit covariates to the negative exponential key function. Based on the pooled data set and the improved models, we estimated population sizes for 2018 and adjusted estimates of population sizes for 2012, 2013, 2014, 2015, 2016, and 2017. Estimates for 2012, 2013, 2014, 2015, 2016, and 2017 were expected to differ slightly from results reported in McDonald et al. (2012 and 2017).

The estimates of probability of detection were then scaled by the probability of detection near the transect line to obtain overall probabilities of detections. Analysis and modeling methods were reported in detail in McDonald et al. (2014).

Estimation of Population Parameters in the Short Grass Prairie Region

The proportion of LPC, GPC, and HPC in the SGPR in northwestern Kansas were estimated using ground survey data collected from 2008 through 2013. All ground survey data and initial data processing were provided by the Kansas Department of Wildlife, Parks and Tourism (KDWPT) and the Kansas Biological Survey (J. Pitman and M. Houts, pers. comm.).

Estimation of Precision of Estimated Population Parameters

We used bootstrapping techniques (Manly 2006) to estimate confidence intervals (CIs) for density and population totals of LPC, HPC, and GPC individuals and leks by year and ecoregion. From each bootstrapped sample we generated new estimates of densities, population totals, and differences. We calculated CIs based on the central 80% and/or 90% of the bootstrap distribution (the percentile method) for each estimated parameter.

Estimation of Trends in Population

To evaluate trends in LPC population over time, a generalized simple linear regression model was fit. The random error terms followed a first-order autoregressive process to account for autocorrelation in the population between years (Kutner et al. 2005).

RESULTS

We detected 141 clusters of LPC, GPC, and HPC in 2012, 73 in 2013, 92 in 2014, 133 in 2015, 129 in 2016, 172 in 2017, and 172 in 2018 while surveying on transects (i.e., within 300 m [984 ft] of the transect line) for a total of 912 detections of prairie-chickens in the combined data set (Table 2). Note that fewer cells were in the survey in 2012 (256 cells) while survey effort was increased to 283 cells from 2013 to 2016, and to 303 cells in 2017 and 2018.

Of the 912 prairie-chicken clusters detected from 2012 to 2018, 59.1% were in short-grass grassland, 20.9% were in cropland, 11.5% were in tall-grass grassland including CRP grassland (with little or no shrubs), 5.0% were in sand-sage prairie, and 2.7% were in shinnery oak (including other shrub dominated land; Table 2).

There were 368 LPC detected in 2012, 203 in 2013, 224 in 2014, 276 in 2015, 251 in 2016, 336 in 2017, and 493 in 2018 (Table 3). Note that fewer cells were in the survey in 2012 (256 cells) while survey effort was increased to 283 cells from 2013 to 2016, and to 303 cells in 2017 and 2018.

Estimates of LPC population size and density were calculated for 2018. Counts of observed LPC were adjusted for the LPC missed in the 600 m transect strips using the estimated probability that at least one of the two observers detected a cluster and the estimated probability of detection of the cluster as a function of distance from transect and covariates. Covariates for the models included cluster size and habitat. Estimates of LPC population size and density were also updated for 2012, 2013, 2014, 2015, 2016, and 2017.

Table 2. Trends in numbers and percent of detections of leks and non-lekking clusters of lesser prairie-chicken, greater prairie-chicken, and hybrid prairie-chicken by habitat type in the data sets for 2012 to 2018.

	Habitat						
Year	Bare Ground	Cropland	Short-Grass Grassland	Shinnery Oak (including other shrub dominated land)	Sand-Sage Prairie	Tall-Grass Grassland Including CRP Grassland (with little or no shrubs)	Total
2012	0 (0%)	27 (19.1%)	91 (64.5%)	6 (4.3%)	3 (2.1%)	14 (9.9%)	141
2013	0 (0%)	14 (19.2%)	49 (67.1%)	2 (2.7%)	7 (9.6%)	1 (1.4%)	73
2014	0 (0%)	11 (12.0%)	66 (71.7%)	2 (2.2%)	2 (2.2%)	11 (12.0%)	92
2015	0 (0%)	21 (15.8%)	85 (63.9%)	1 (0.8%)	10 (7.5%)	16 (12.0%)	133
2016	1 (0.8%)	32 (24.8%)	63 (48.8%)	1 (0.8%)	17 (13.2%)	15 (11.6%)	129
2017	2 (1.2%)	49 (28.5%)	92 (55.8%)	5 (2.9%)	4 (2.3%)	20 (11.6%)	172
2018	3 (1.7%)	37 (21.5%)	93 (54.1%)	8 (4.7%)	3 (1.7%)	28 (16.3%)	172
Total	**6 (0.7%)**	**191 (20.9%)**	**539 (59.1%)**	**25 (2.7%)**	**46 (5.0%)**	**105 (11.5%)**	**912**

CRP=Conservation Reserve Program

Table 3. Trends in numbers of lesser prairie-chickens detected by ecoregion (estimated number detected in SGPR) and overall from 2012 to 2018. "On transect" indicated observations were made between start and end points of transects. "Off transect" indicated observations were made while traveling to and from selected transect lines or greater than 300 m from the transect. Two-hundred-fifty-six cells were surveyed in 2012, 283 cells were surveyed in 2013, 2014, 2015, and 2016, and 303 cells were surveyed in 2017 and 2018.

	Region									
	SOPR		SSPR		MGPR		SGPR (estimated)		Total	
Year	On transect	Off transect	On transect	Off transect	On transect	Off transect	On transect	Off transect	On transect	Off transect
2012	44	7	22	6	86	0	216	16	**368**	**29**
2013	24	12	35	5	39	4	105	12	**203**	**33**
2014	17	10	8	7	70	2	129	9	**224**	**28**
2015	10	7	14	13	87	19	165	9	**276**	**48**
2016	42	12	22	0	61	0	126	0	**251**	**12**
2017	35	18	23	1	80	0	198	2	**336**	**21**
2018	90	1	57	3	95	4	251	15	**493**	**23**

SOPR = Shinnery Oak Prairie Region (eastern New Mexico, western Texas), SSPR = Sand Sagebrush Prairie Region (southeastern Colorado, southwestern Kansas, Oklahoma Panhandle), MGPR = Mixed-Grass Prairie Region (northeastern Texas, northwestern Oklahoma, south-central Kansas), and SGPR = Short Grass CRP Prairie Region (northwest Kansas).

Mark-Recapture Models

We continued to use the observations of LPC, GPC, and HPC by the front left and back left observers in "mark-recapture" models. For example, clusters of prairie-chickens seen by the front left observer were "marked" and some of those clusters were "recaptured" by the back left observer. These models were used to estimate the probability that at least one of the two observers will detect a cluster given that it was in the field of view of the back left observer (i.e., greater than the nominal value 6.8 m (22.3 ft) from the transect line). The pooled data collected from 2012 through 2018 increases the sample sizes of the datasets to 334 and 321 for the front left and back left observers, respectively (Table 4). We gave the detections equal weight for modeling the components of the covariate specific, scaled, model averaged probability of detection on the inside edge of the field of view of the back left observer.

Table 4. Sample sizes for logistic regression models to estimate the probability that at least one of the two observers will detect a cluster.

Year	Front Left	Back Left
2012	57	50
2013	24	28
2014	33	40
2015	49	46
2016	54	46
2017	64	50
2018	53	61
Total	**334**	**321**

Covariates used in the models for probability of detection were perpendicular distance to the cluster (distance), cluster size (size), and the categorical variable habitat type (habitat; Table 5). Due to the similarity of detection probability of prairie-chicken clusters in cropland and short-grassland, we combined those habitat types into one habitat category. The four levels considered for habitat type were: short-grass/cropland, shinnery oak, sand-sage prairie, and tall-grass grassland. Another categorical variable, flushed or not flushed, was not used in the models in this report because of the very small number of observed clusters of prairie-chickens that were not flushed. Weighted average estimates of probability of detection were obtained for combinations of covariates associated with detections of clusters of prairie-chickens using model averaging with the corrected Akaike Information Criterion (AICc; Akaike 1973).

Table 5. Logistic Regression models used for estimation of probabilities of detection on the inside edge of the field of view of the back left observers. Distance = perpendicular distance to detected clusters, none = no covariates, size = size of cluster, and habitat = habitat type occupied. The back left observer models estimated the probability that the back left observer detected a cluster given that the cluster was detected by the front left observer. Similarly, the front left observer models estimated the probability that the front left observer detected a cluster given that the cluster was detected by the back left observer.

Back Left Observer Model			Front Left Observer Model		
Covariates	**AICc**	**Model Weight**	**Covariates**	**AICc**	**Model Weight**
distance + size	425.73	0.52	distance + size + habitat	431.42	0.70
distance + size + habitat	427.65	0.20	distance + size	433.19	0.29
size	427.88	0.18	size + habitat	439.54	0.01
size + habitat	429.36	0.08	size	442.52	<0.01
distance	432.99	0.01	distance + habitat	446.47	<0.01
None	434.57	0.01	distance	450.46	<0.01
distance + habitat	435.42	<0.01	habitat	452.71	<0.01
habitat	436.65	<0.01	None	457.52	<0.01

AICc= Akaike Information Criterion

Probability of Detection

We dropped 17 observations from 2012 through 2018 that were greater than 300 m from the transect line as they were outside the viewshed specified in the survey protocol. 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. Data were grouped into 15 intervals for fitting models for probability of detection with the all intervals encompassing 20 m (Figures 2a and 2b). The midpoint of each interval was used in the modeling in order to compensate for potential errors in assigning the perpendicular distance from the transect line.

Data collected from surveys in 2012 (256 grid cells), 2013 to 2016 (283 grid cells), and 2017 to 2018 (303 grid cells) were used to estimate the trends in population sizes. Probability of detection was estimated as a function of distance from the transect (Figures 2a and 2b). In addition, cluster size and habitat were considered as covariates in the models. Cluster size of prairie-chickens detected varied by year and ecoregion (Table 6). The average cluster size of LPC detected increased from 3.3 to 4.2 LPC per cluster in 2017 to 2018 (Table 6). An increase in average cluster size was observed in all ecoregions from 2017 to 2018. In addition, habitat prairie-chickens were detected in varied slightly between years and was considered as a covariate in modeling probability of detection (Table 2).

Table 6. Average trends in cluster sizes of lesser prairie-chicken detected by ecoregion and overall in 2012 to 2018.

	Region				
Year	SOPR	SSPR	MGPR	SGPR	Overall
2012	3.4	7.3	6.6	4.3	**4.6**
2013	2.4	5.8	5.6	4.9	**4.7**
2014	2.4	4.0	4.4	3.9	**3.9**
2015	1.4	1.8	3.0	3.8	**3.3**
2016	2.5	2.8	3.8	3.6	**3.4**
2017	2.7	3.3	3.5	3.3	**3.3**
2018	3.5	3.8	3.8	4.6	**4.2**

SOPR = Shinnery Oak Prairie Region (eastern New Mexico, western Texas), SSPR = Sand Sagebrush Prairie Region (southeastern Colorado, southwestern Kansas, Oklahoma Panhandle), MGPR = Mixed-Grass Prairie Region (northeastern Texas, northwestern Oklahoma, south-central Kansas), and SGPR = Short Grass CRP Prairie Region (northwest Kansas).

We pooled data collected from 2012 to 2018 to estimate the probabilities of detection of clusters of prairie-chickens because the survey methods remained unchanged between years and the models accommodated changes in cluster size and habitat by year. The probability of detection for all clusters of prairie-chickens was estimated as a function of distance from transect, cluster size, and habitat (Figures 2a, 2b, 3, and 4). In general, probability of detection was highest for large clusters in cropland, bare ground, and short grass. Estimated probabilities of detection decreased as distance from transect increased (Figure 3). In addition, probability of detection increased as cluster size increased (Figure 4). Annual variation of the estimated probability of detection of clusters of prairie-chickens was illustrated in Appendix A (Figures A-1 and A-2).

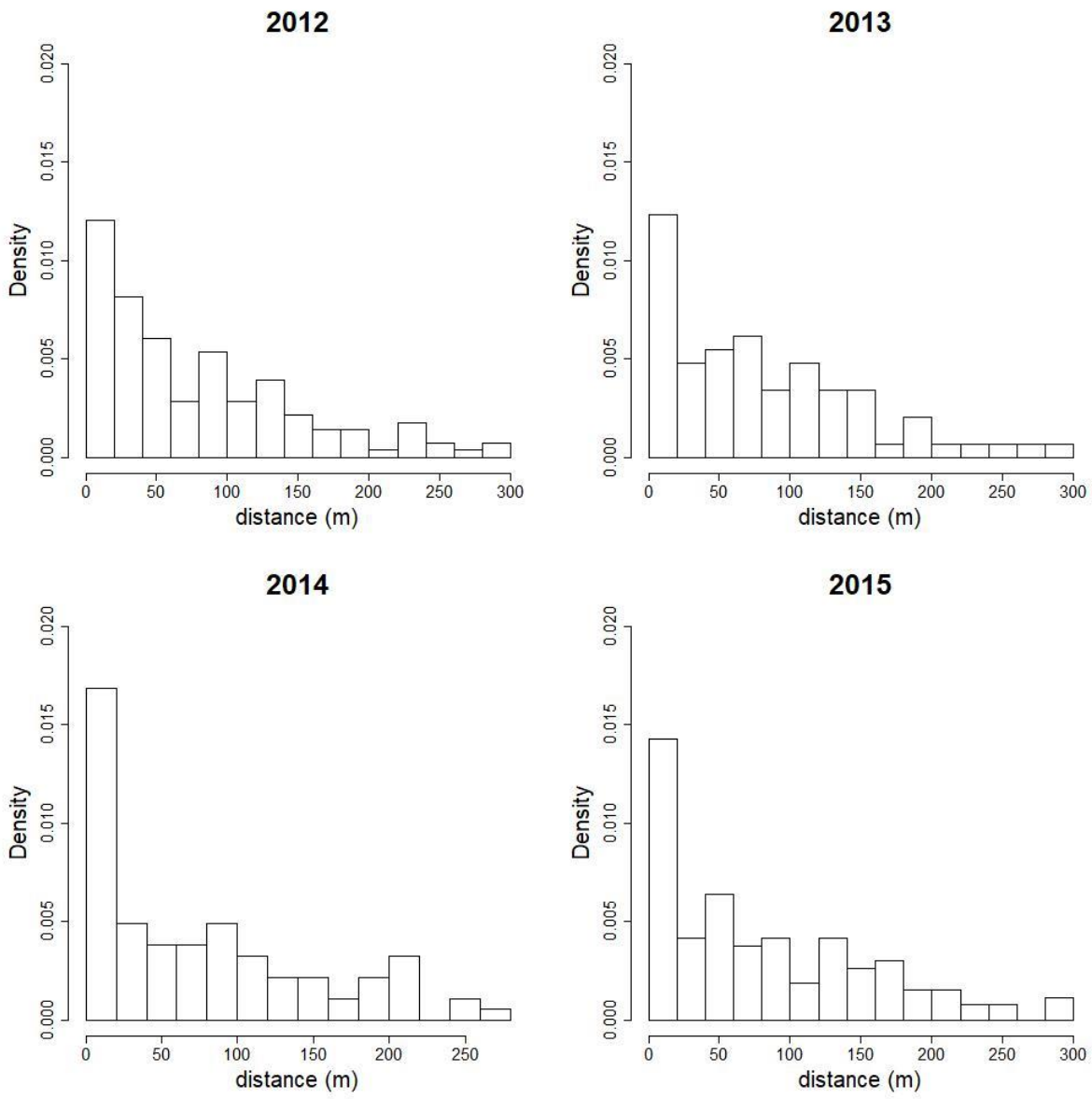

Figure 2a. Histograms of the proportions of observed distances of detected clusters of prairie-chickens from the transect line to the center of the clusters (density of detections in 20 meter [m] bins): 2012, 2013, 2014, and 2015.

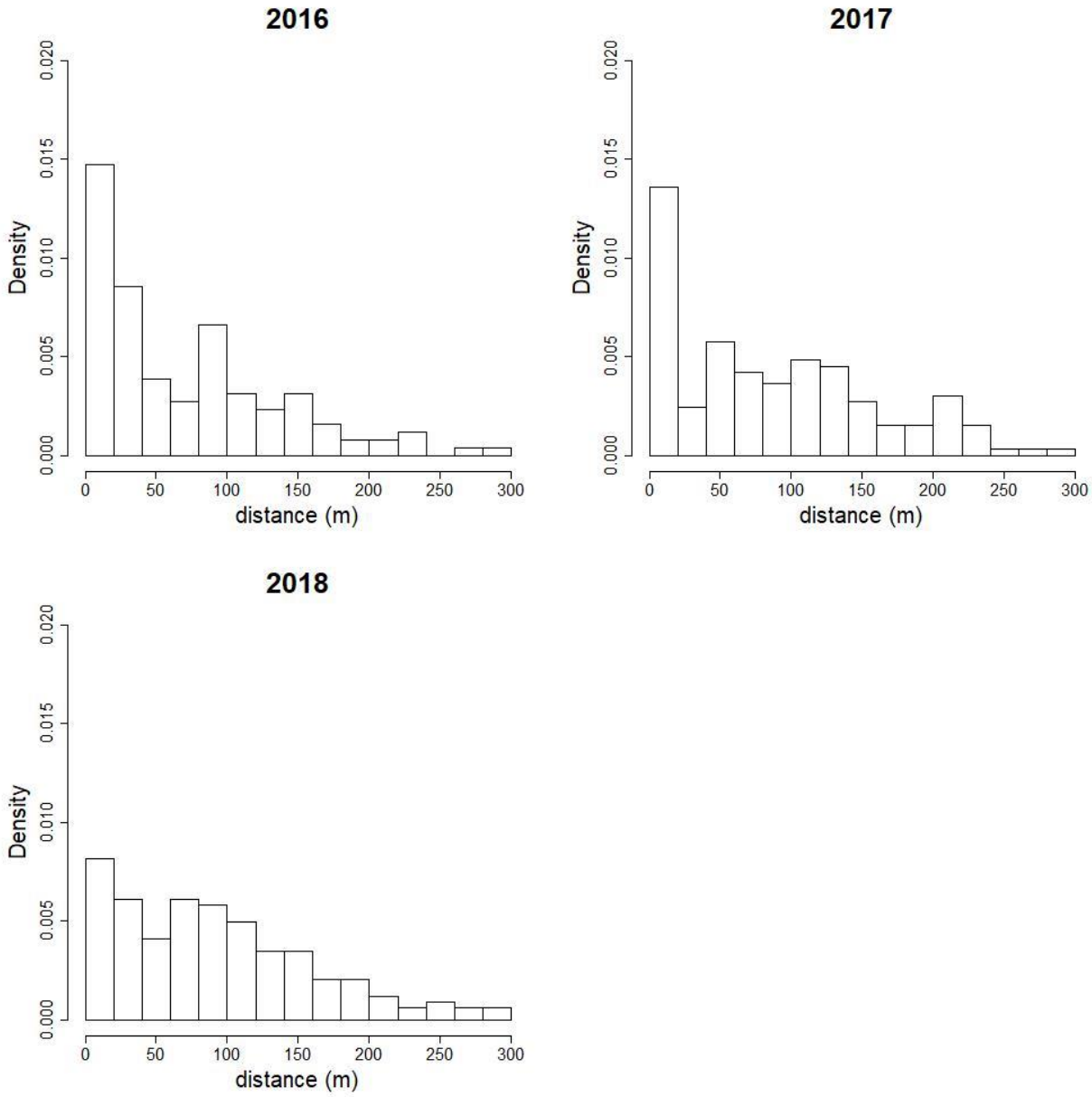

Figure 2b. Histograms of the proportions of observed distances of detected clusters of prairie-chickens from the transect line to the center of the clusters (density of detections in 20 meter [m] bins): 2016, 2017, and 2018.

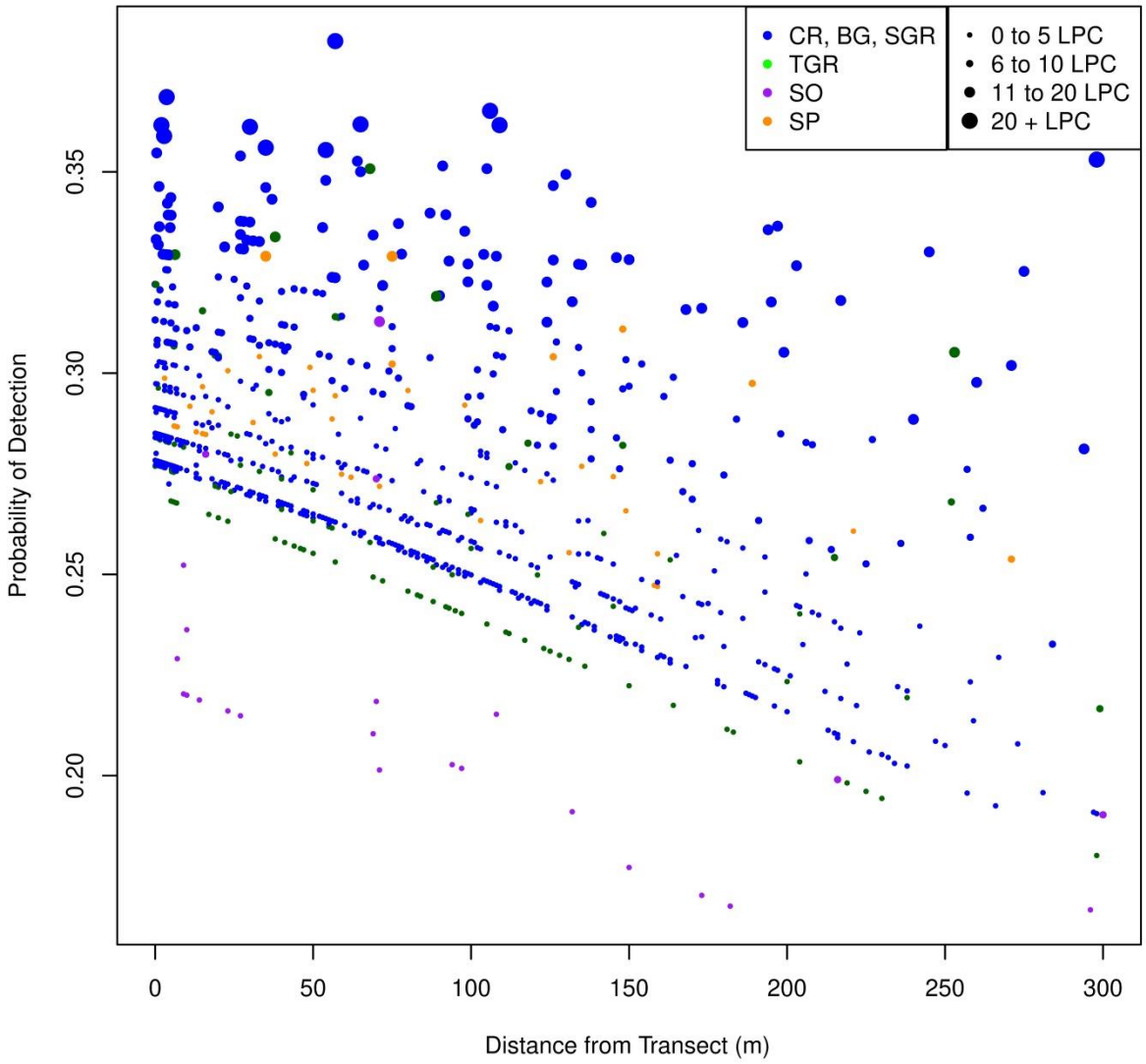

Figure 3. Estimated probability of detection of clusters of prairie-chickens plotted as a function of distance from transects with the effect of cluster size illustrated by the size of the point, and effect of habitat by color. Habitat classes were: CR = cropland, BG = bare ground, SGR = short-grass grassland, TGR = tall-grass grassland, SO = shinnery oak, and SP = sand-sage prairie.

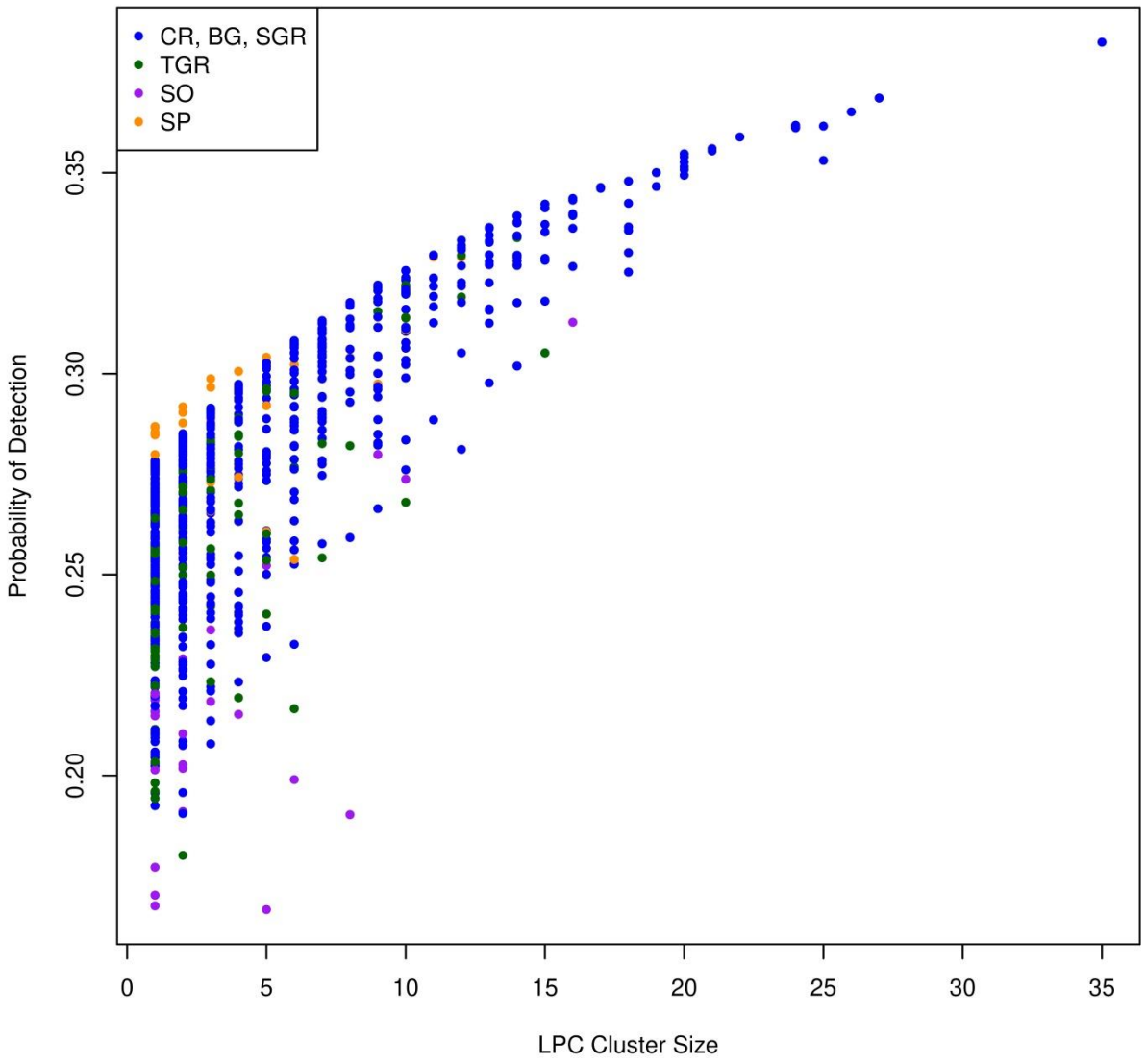

Figure 4. Estimated probability of detection plotted as a function of prairie-chicken cluster size with the effect of habitat type illustrated by the color of points. Habitat classes were: CR = cropland, BG = bare ground, SGR = short-grass grassland, TGR = tall-grass grassland, SO = shinnery oak, and SP = sand-sage prairie.

Table 7. Distance sampling models used to estimate probability of detection as a function of distance from the transect line and other covariates. Distance to detected clusters was in all models. Size = size of cluster, and habitat = habitat occupied by detected clusters. Pooled data from 2012 to 2018 were used to fit the distance sampling models. Key Functions were ne = negative exponential model, hr = hazard rate, and hn = half normal.

Model Covariates	Key Function	AICc	Model Weight
No Adj. Terms	hr	9797.77	0.398
size	ne	9798.83	0.234
No Adj. Terms	ne	9799.48	0.169
size	hr	9799.57	0.161
size + habitat	ne	9804.44	0.014
habitat	ne	9805.30	0.011
habitat	hr	9805.95	0.007
size	hn	9807.53	0.003
size + habitat	hr	9807.81	0.002
size + habitat	hn	9810.22	< 0.001
No Adj. Terms	hn	9812.05	< 0.001
habitat	hn	9814.50	< 0.001

AICc= Akaike Information Criterion

Estimated Trends in Densities and Abundances of LPC

We adjusted counts of LPC by covariate specific, scaled, model averaged probabilities of detection to estimate population sizes in four ecoregions and the original study area (Tables 8 and 9, and Figures 5, 6a, and 6b). Use of these improved models resulted in an increase in the estimated probability of detection of larger clusters. Estimates of LPC population sizes from 2012 to 2017 decreased slightly relative to estimates reported previously. We estimated the total population size of LPC to be:

- 33,000 (90% CI: 17333, 43583) LPC in 2012;
- 17,457 (90% CI: 8384, 22834) in 2013;
- 20,617 (90% CI: 10244, 27084) in 2014;
- 25,779 (90% CI: 13072, 32416) in 2015;
- 22,246 (90% CI: 12287, 27695) in 2016;
- 29,934 (90% CI: 16002, 39103) in 2017; and
- 38,637 (90% CI: 20233, 49698) in 2018.

To evaluate trends in the LPC population over time, a generalized simple linear regression model with random error terms following a first-order autoregressive process was fit to LPC population estimates from 2013 to 2018. The estimated average rate of increase of 3,723 LPC in total LPC by year was statistically significant (p-value = 0.01).

An estimated total population increase of 8,702 LCP was observed from 2017 to 2018 (29% increase); however, this increase was not statistically significant at the 80% confidence level (80% CI: -2077, 17911; Table 10a). An estimated increase in LPC in the SGPR from 2017 to 2018 of 1,758 was significant at the 90% confidence level (90% CI: 0, 3561). In addition, the estimated increase in LPC in the SOPR from 2017 to 2018 of 3,405 was significant at the 80% confidence level (80% CI: 118, 6631).

Table 8. Trends in estimated densities of lesser prairie-chickens per 100 kilometer^2 (km^2; 39 mile^2) by ecoregion and overall from 2012 to 2018. Bootstrapped 90% confidence intervals were reported on the densities of lesser prairie-chicken per 100 km^2.

	Region				
Year	SOPR	SSPR	MGPR	SGPR	Overall
2012	13.82 (5.33, 37.62)	14.06 (5.30, 19.37)	22 (9.33, 32.21)	48.78 (21.51, 65.19)	27.40 (14.37, 36.14)
2013	7.32 (3.40, 11.18)	11.64 (5.54, 15.60)	9.35 (4.54, 11.77)	26.42 (7.23, 39.23)	14.47(6.95, 18.93)
2014	4.91 (1.92, 8.06)	2.80 (1.82, 3.30)	16.47 (6.16, 23.27)	32.9 (12.61, 46.98)	17.09 (8.49, 22.46)
2015	2.96 (1.25, 4.28)	4.98 (1.97, 8.05)	22.15 (13.38, 27.17)	41.21 (15.32, 57.71)	21.37 (10.84, 26.88)
2016	10.32 (4.88, 15.81)	8.01 (2.45, 11.65)	15.14 (7.70, 19.62)	32.43 (13.26, 44.12)	18.44 (10.19, 22.96)
2017	8.70 (3.03, 17.89)	8.29 (2.74, 12.40)	17.61 (8.27, 23.13)	51.48 (20.61, 71.61)	24.82 (13.27, 32.42)
2018	21.00 (6.11, 41.22)	19.30 (7.42, 29.69)	20.28 (9.56, 27.03)	60.81 (25.06, 83.22)	33.41(17.50, 42.97)

SOPR = Shinnery Oak Prairie Region (eastern New Mexico, western Texas), SSPR = Sand Sagebrush Prairie Region (southeastern Colorado, southwestern Kansas, Oklahoma Panhandle), MGPR = Mixed-Grass Prairie Region (northeastern Texas, northwestern Oklahoma, south-central Kansas), and SGPR = Short Grass CRP Prairie Region (northwest Kansas).

Table 9. Trends in estimated population sizes of lesser prairie-chickens by ecoregion and overall from 2012 to 2018. Bootstrapped 90% confidence intervals were reported on the population sizes of lesser prairie-chicken.

	Region				
Year	SOPR	SSPR	MGPR	SGPR	Overall
2012	3823 (1475, 10411)	2246 (847, 3095)	8711 (3696, 12756)	18220 (8034, 24347)	33000 (17333, 43583)
2013	2026 (940, 3094)	1860 (884, 2493)	3701 (1797, 4661)	9870 (2701, 14651)	17457 (8384, 22834)
2014	1360 (531, 2231)	448 (290, 528)	6522 (2439, 9216)	12287 (4711, 17548)	20617 (10244, 27084)
2015	818 (346, 1183)	796 (314, 1287)	8773 (5300, 10760)	15392 (5721, 21555)	25779 (13072, 32416)
2016	2856 (1350, 4376)	1279 (392, 1861)	5997 (3040, 7771)	12113 (4951, 16478)	22246 (12287, 27695)
2017	2408 (839, 4952)	1325 (438, 1981)	6973 (3273, 9159)	19229 (7697, 26745)	29934 (16002, 39103)
2018	5812 (1691, 11408)	3083 (1184, 4742)	7028 (3314, 9367)	22714 (9362, 31082)	38637 (20233, 49698)

SOPR = Shinnery Oak Prairie Region (eastern New Mexico, western Texas), SSPR = Sand Sagebrush Prairie Region (southeastern Colorado, southwestern Kansas, Oklahoma Panhandle), MGPR = Mixed-Grass Prairie Region (northeastern Texas, northwestern Oklahoma, south-central Kansas), and SGPR = Short Grass CRP Prairie Region (northwest Kansas).

Table 10a. Estimated differences in population estimates for lesser prairie-chickens between years with bootstrapped 80% confidence intervals on the differences.

Δ Year	Region				Total
	SOPR	SSPR	MGPR	SGPR	
2013 minus 2012	-1798 (-5066, -277)	-386 (-1119, 518)	-5010 (-7954, -1267)	-8350 (-13655, 0)	**-15544 (-23732, -5411)**
2014 minus 2013	-666 (-1535, 178)	-1412 (-1853, -712)	2821 (0, 5023)	2418 (-2690, 7558)	**3161 (-2638, 8832)**
2015 minus 2014	-542 (-1210, 0)	348 (-14, 722)	2251 (-180, 5062)	3105 (-2964, 7916)	**5162 (-1150, 10779)**
2016 minus 2015	2038 (909, 3120)	483 (-194, 1000)	-2776 (-4747, -411)	-3279 (-8695, 2616)	**-3534 (-9183, 2713)**
2017 minus 2016	-449 (-1778, 1160)	46 (-603, 717)	976 (-1184, 3113)	7115 (0, 13139)	**7689 (-106, 15209)**
2018 minus 2017	3405 (118, 6631)	1758 (187, 2981)	54 (-2505, 2658)	3485 (-5565, 11499)	**8702 (-2077, 17911)**

SOPR = Shinnery Oak Prairie Region (eastern New Mexico, western Texas), SSPR = Sand Sagebrush Prairie Region (southeastern Colorado, southwestern Kansas, Oklahoma Panhandle), MGPR = Mixed-Grass Prairie Region (northeastern Texas, northwestern Oklahoma, south-central Kansas), and SGPR = Short Grass CRP Prairie Region (northwest Kansas).

Table 10b. Estimated differences in population estimates for lesser prairie-chickens between years with bootstrapped 90% confidence intervals on the differences.

Δ Year	Region				Total
	SOPR	SSPR	MGPR	SGPR	
2013 minus 2012	-1798 (-7665, 0)	-386 (-1374, 739)	-5010 (-9327, -426)	-8350 (-15906, 1267)	**-15544 (-27814, -1476)**
2014 minus 2013	-666 (-1902, 408)	-1412 (-2035, -509)	2821 (-308, 5699)	2418 (-4140, 9675)	**3161 (-4108, 10843)**
2015 minus 2014	-542 (-1468, 121)	348 (-40, 844)	2251 (-1026, 5908)	3105 (-4447, 9794)	**5162 (-3199, 12767)**
2016 minus 2015	2038 (637, 3559)	483 (-413, 1202)	-2776 (-5405, 0)	-3279 (-10809, 4076)	**-3534 (-11031, 4452)**
2017 minus 2016	-449 (-2328, 2193)	46 (-790, 921)	976 (-1798, 3691)	7115 (-1981, 15461)	**7689 (-2120, 17743)**
2018 minus 2017	3405 (-61, 8436)	1758 (0, 3561)	54 (-3266, 3362)	3485 (-8332, 15315)	**8702 (-4156, 22359)**

SOPR = Shinnery Oak Prairie Region (eastern New Mexico, western Texas), SSPR = Sand Sagebrush Prairie Region (southeastern Colorado, southwestern Kansas, Oklahoma Panhandle), MGPR = Mixed-Grass Prairie Region (northeastern Texas, northwestern Oklahoma, south-central Kansas), and SGPR = Short Grass CRP Prairie Region (northwest Kansas).

Δ Year=change in year

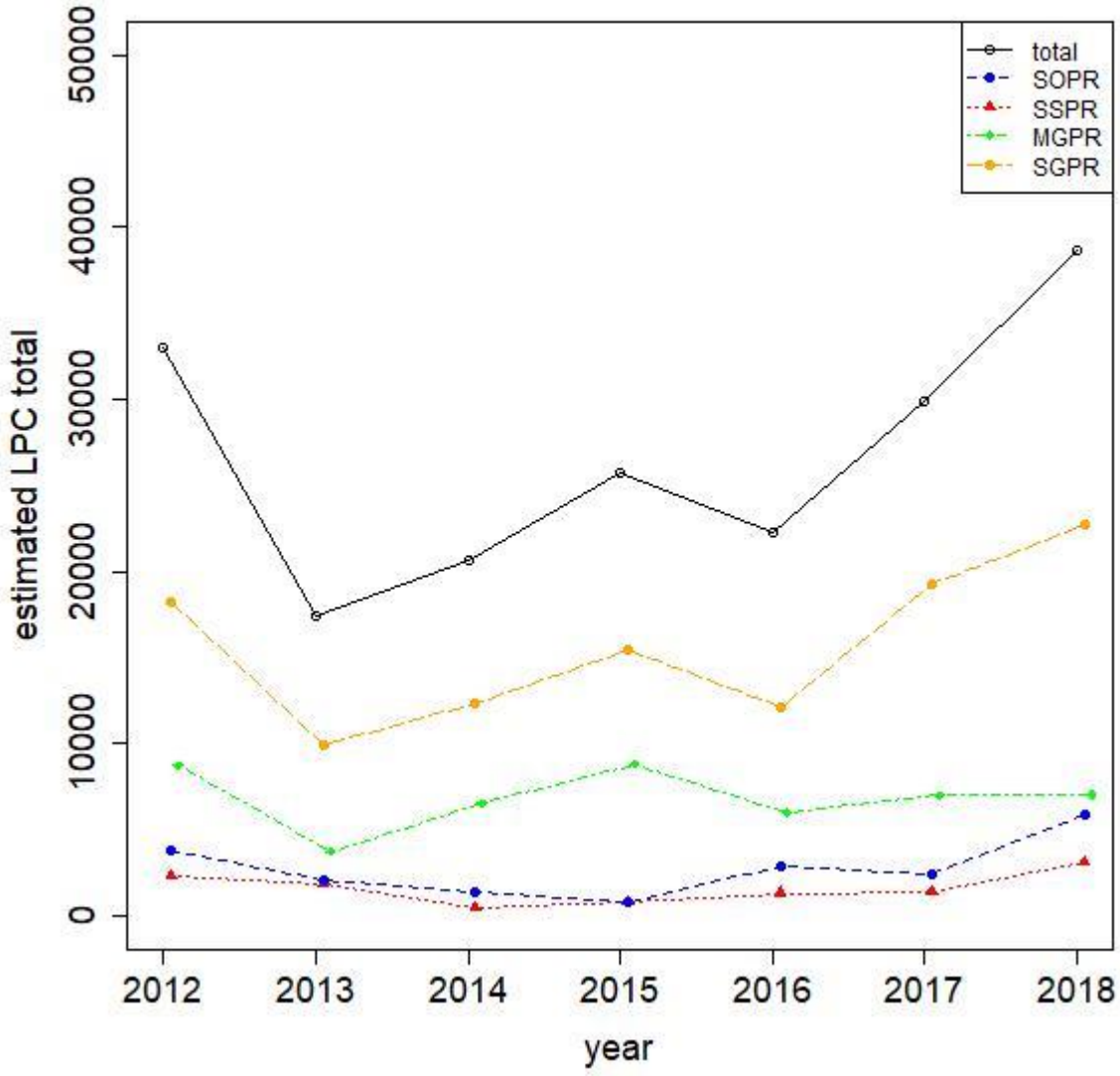

Figure 5. Trends in estimated total population sizes of lesser prairie-chicken in 2012, 2013, 2014, 2015, 2016, 2017, and 2018. SOPR = Shinnery Oak Prairie Region (eastern New Mexico, western Texas), SSPR = Sand Sagebrush Prairie Region (southeastern Colorado, southwestern Kansas, Oklahoma Panhandle), MGPR = Mixed-Grass Prairie Region (northeastern Texas, northwestern Oklahoma, south-central Kansas), and SGPR = Short Grass Conservation Reserve Program Prairie Region (northwest Kansas).

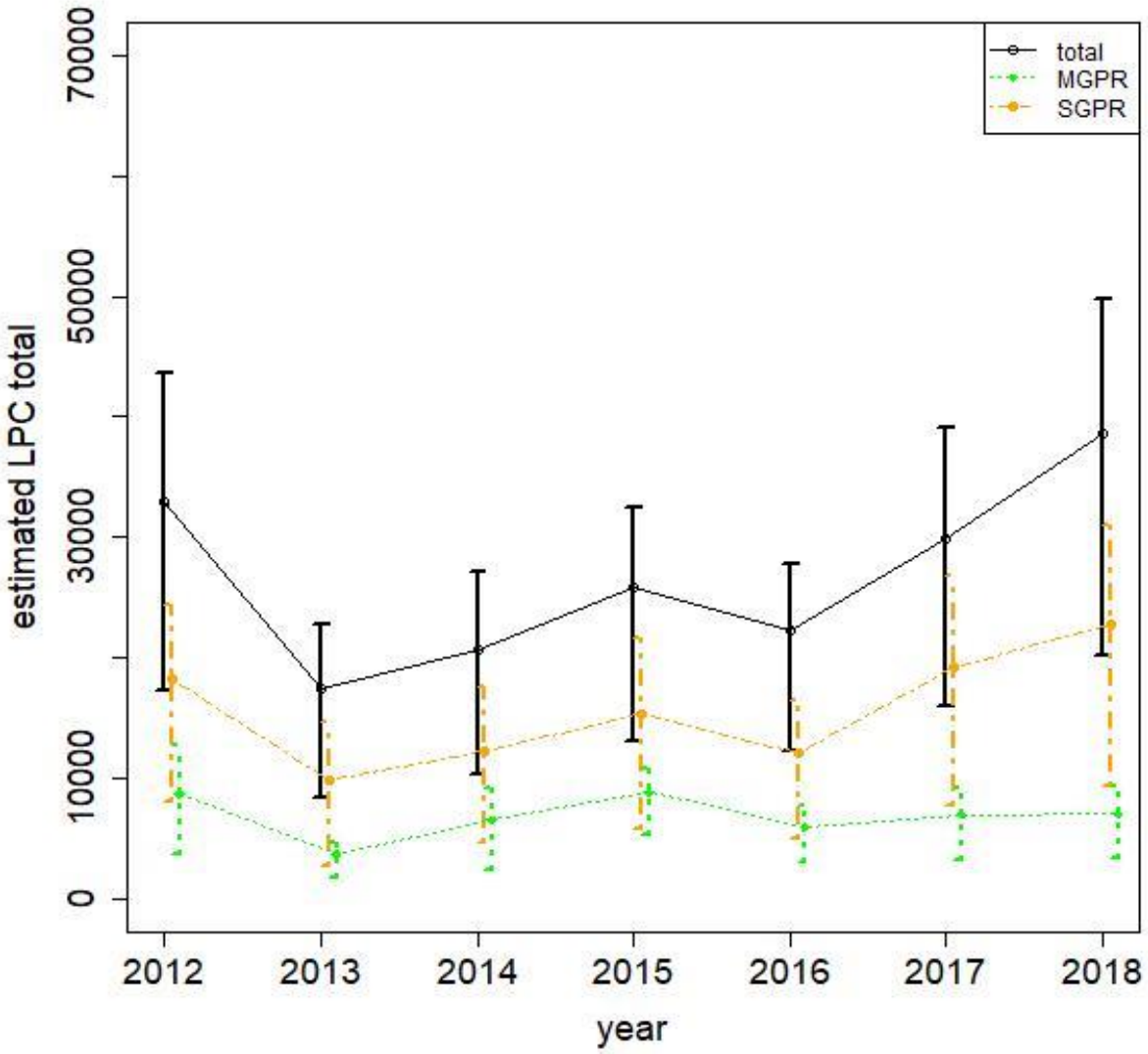

Figure 6a. Trends in estimated total population sizes of lesser prairie-chickens in 2012, 2013, 2014, 2015, 2016, 2017, and 2018 with 90% confidence intervals for the original study area, MGPR = Mixed-Grass Prairie Region (northeast Texas, northwestern Oklahoma, south-central Kansas), and SGPR = Short Grass Conservation Reserve Program Prairie Region (northwestern Kansas).

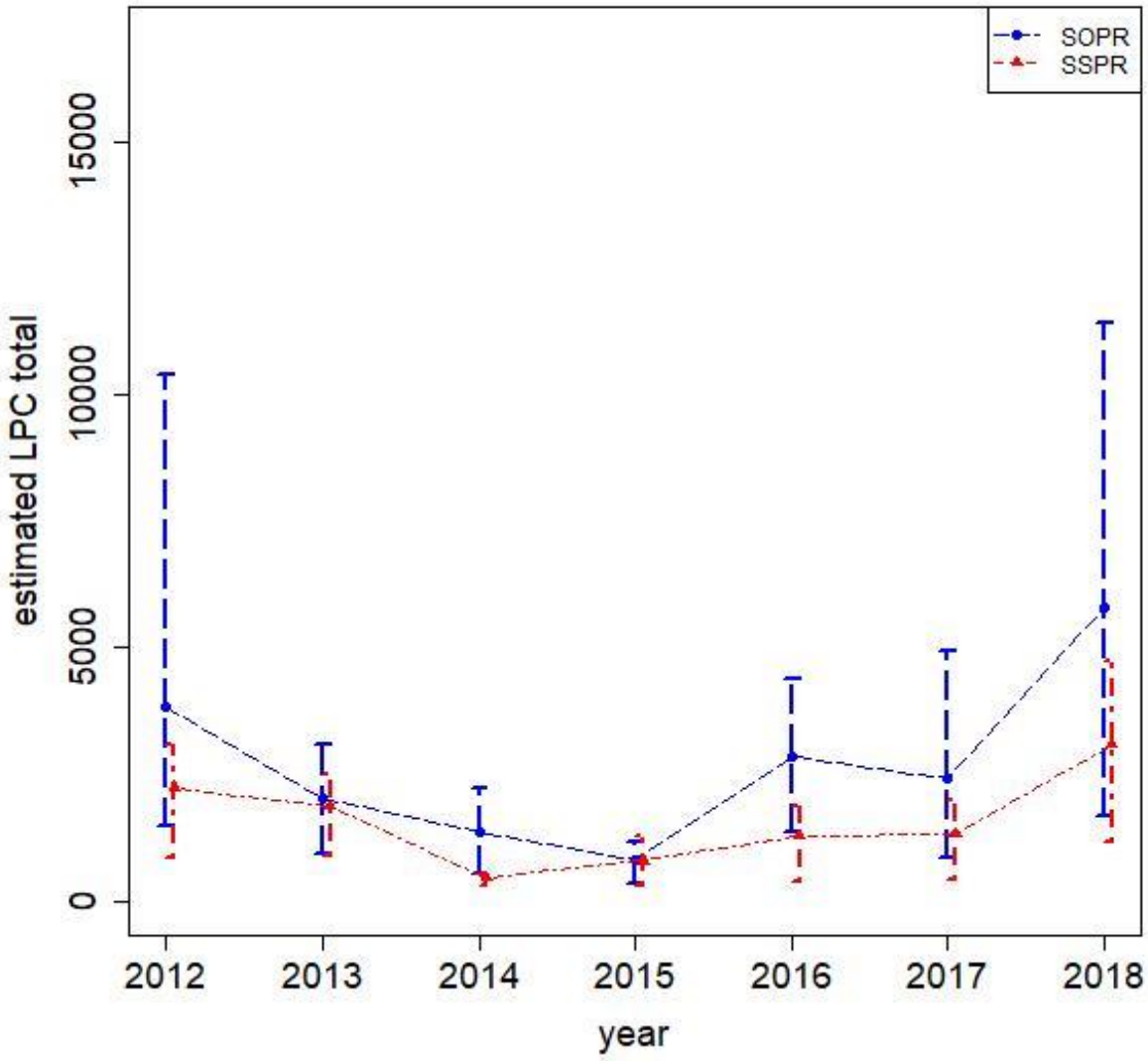

Figure 6b. Trends in estimated total population sizes of lesser prairie-chickens (LPC) in 2012, 2013, 2014, 2015, 2016, 2017, and 2018 with 90% confidence intervals in the SOPR = Shinnery Oak Prairie Region (eastern New Mexico, western Texas) and SSPR = Sand Sagebrush Prairie Region (southeastern Colorado, southwestern Kansas, Oklahoma Panhandle).

Estimated Trends in LPC Leks

We estimated a negligible decrease in the density and abundance of LPC leks in 2018 relative to 2017 (Tables 11 and 12). The abundance of LPC leks was estimated to be:

- 3,124 (90% CI: 1443, 4564) in 2012;
- 2,010 (90% CI: 908, 2698) in 2013;
- 2,456 (90% CI: 1181, 3414) in 2014;
- 1,527 (90% CI: 669, 2028) in 2015;
- 1,852 (90% CI: 719, 2750) in 2016
- 2,897 (90% CI: 1483, 3973) in 2017; and
- 2,871 (90% CI: 1406, 3859) in 2018.

Table 11. Estimated trends in densities of lesser prairie-chicken leks per 100 kilometer^2 (km^2 39 miles^2) by ecoregion and overall from 2012 to 2018. Bootstrapped 90% confidence intervals were reported on the densities of lesser prairie-chicken leks per 100 km^2.

Year	Region				Overall
	SOPR	SSPR	MGPR	SGPR	
2012	1.51 (0.40, 3.63)	1.27 (0.00, 2.00)	2.23 (0.84, 3.26)	4.34 (0.99, 6.77)	2.59 (1.2, 3.78)
2013	0.77 (0.00, 1.64)	2.11 (1.33, 2.39)	0.96 (0.27, 1.41)	2.89 (0.50, 4.57)	1.67 (0.75, 2.24)
2014	0.93 (0.08, 2.22)	0.36 (0.00, 0.76)	1.96 (0.71, 2.67)	3.65 (1.19, 5.55)	2.04 (0.98, 2.83)
2015	0.26 (0.00, 0.72)	0.33 (0.00, 0.80)	1.93 (0.68, 2.67)	1.71 (0.31, 2.73)	1.27 (0.55, 1.68)
2016	0.72 (0.00, 1.34)	0.36 (0.00, 0.86)	1.48 (0.48, 2.19)	2.71 (0.36, 5.03)	1.54 (0.6, 2.28)
2017	1.06 (0.00, 3.05)	1.05 (0.22, 1.67)	2.12 (0.96, 2.85)	4.26 (1.50, 6.38)	2.40 (1.23, 3.29)
2018	2.14 (0.53, 4.25)	0.97 (0.00, 1.99)	2.64 (1.12, 3.54)	3.24 (0.90, 4.86)	2.48 (1.22, 3.34)

SOPR = Shinnery Oak Prairie Region (eastern New Mexico, western Texas), SSPR = Sand Sagebrush Prairie Region (southeastern Colorado, southwestern Kansas, Oklahoma Panhandle), MGPR = Mixed-Grass Prairie Region (northeastern Texas, northwestern Oklahoma, south-central Kansas), and SGPR = Short Grass CRP Prairie Region (northwest Kansas)

Table 12. Estimated trends in abundances of lesser prairie-chicken leks by ecoregion and overall for 2012 to 2018. Bootstrapped 90% confidence intervals were reported on the abundances of lesser prairie-chicken leks.

Year	Region				Overall
	SOPR	SSPR	MGPR	SGPR	
2012	418 (111.99, 1005.66)	203 (0.00, 320.12)	883 (333.43, 1289.90)	1620 (369.19, 2527.64)	3124 (1443, 4564)
2013	212 (0.00, 454.12)	337 (212.04, 381.27)	381 (108.82, 560.16)	1079 (186.54, 1705.05)	2010 (908, 2698)
2014	257 (21.52, 614.74)	58 (0.00, 121.09)	778 (282.20, 1056.29)	1363 (442.71, 2074.34)	2456 (1181, 3414)
2015	72 (0.00, 198.14)	53 (0.00, 128.33)	764 (267.64, 1059.15)	638 (113.95, 1018.52)	1527 (669, 2028)
2016	198 (0.00, 369.67)	57 (0.00, 137.52)	586 (189.48, 866.90)	1011 (132.79, 1877.47)	1852 (719, 2750)
2017	294 (0.00, 844.28)	168 (34.46, 267.06)	841 (379.48, 1129.65)	1593 (561.14, 2381.90)	2897 (1483, 3973)
2018	593 (145.50, 1175.15)	155 (0.00, 317.73)	914 (388.98, 1225.65)	1209 (334.76, 1816.85)	2871 (1406, 3859)

SOPR = Shinnery Oak Prairie Region (eastern New Mexico, western Texas), SSPR = Sand Sagebrush Prairie Region (southeastern Colorado, southwestern Kansas, Oklahoma Panhandle), MGPR = Mixed-Grass Prairie Region (northeastern Texas, northwestern Oklahoma, south-central Kansas), and SGPR = Short Grass CRP Prairie Region (northwest Kansas)

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Appendix A. Estimated Probability of Detection of Lesser, Greater, and Hybrid Prairie-Chickens

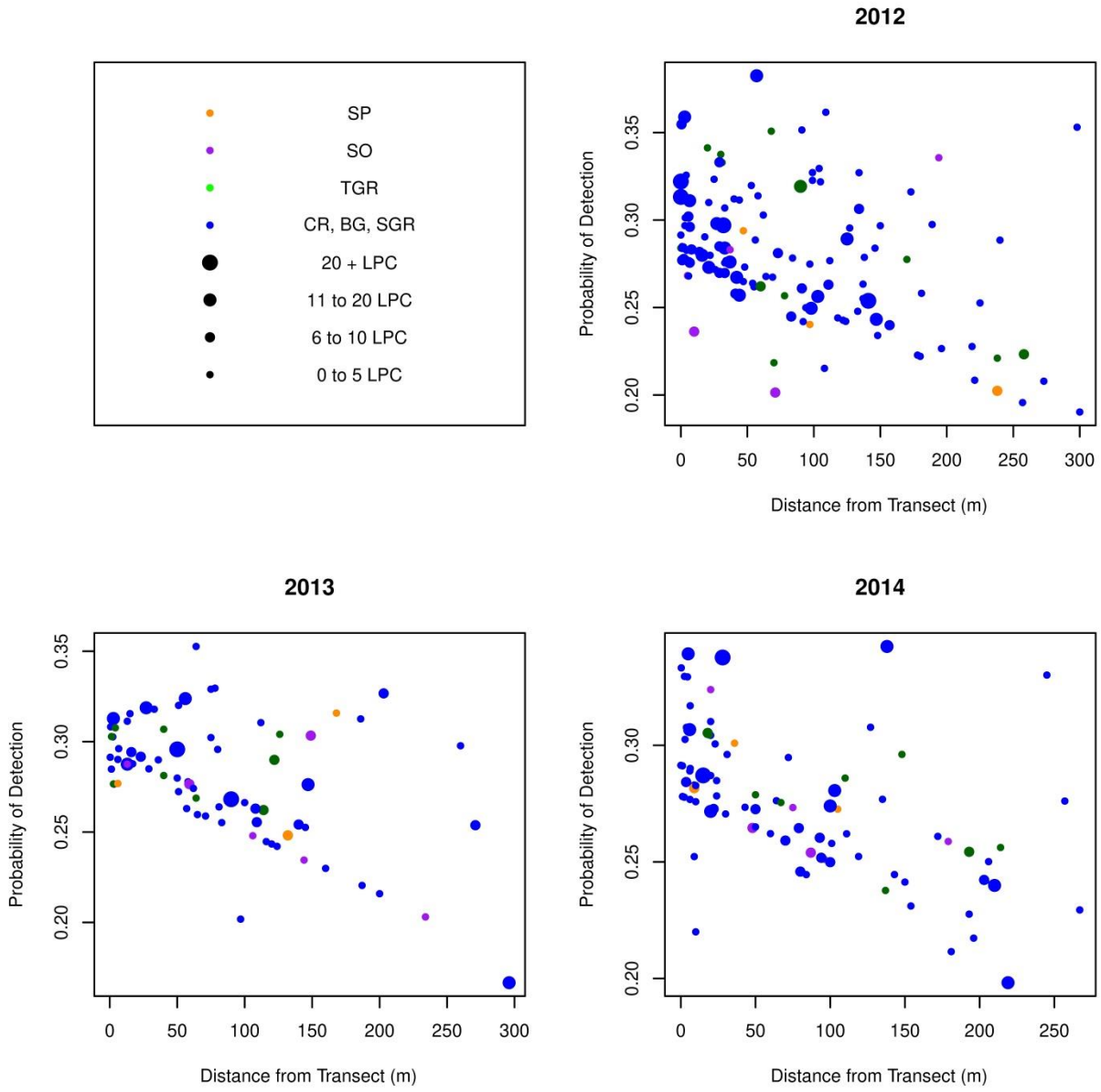

Figure A-1. Estimated probability of detection of clusters of prairie-chickens plotted as a function of distance from transects with the effect of cluster size illustrated by the size of the point and effect of habitat by color in 2012, 2013, and 2014. Habitat classes were: CR = cropland, BG = bare ground, SGR = short-grass grassland, TGR = tall-grass grassland, SO = shinnery oak, and SP = sand-sage prairie.

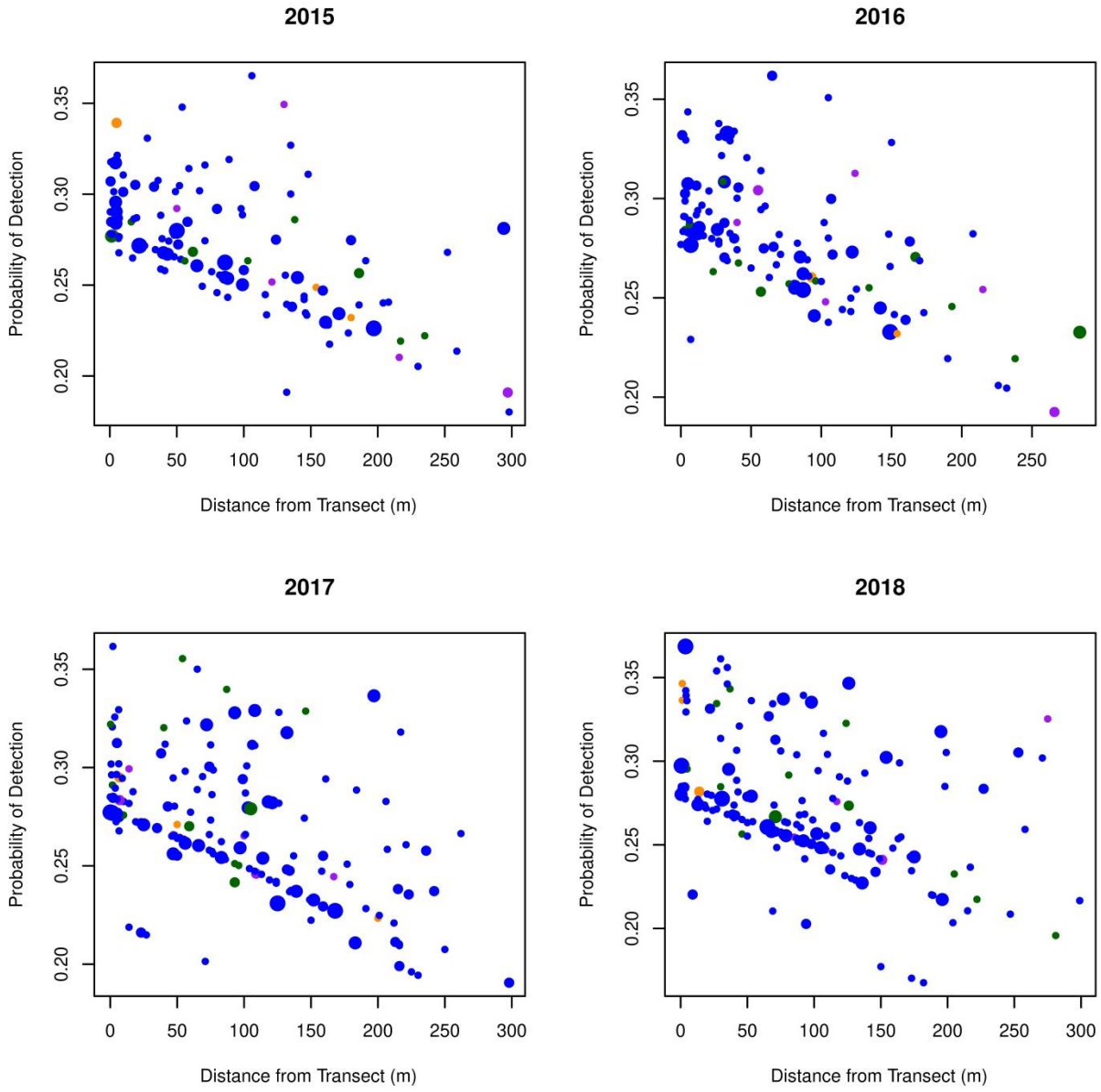

Figure A-2. Estimated probability of detection of clusters of prairie-chickens plotted as a function of distance from transects with the effect of cluster size illustrated by the size of the point and effect of habitat by color in 2015, 2016, 2017, and 2018. Habitat classes were: CR = cropland, BG = bare ground, SGR = short-grass grassland, TGR = tall-grass grassland, SO = shinnery oak, and SP = sand-sage prairie.

Appendix B. Estimated Densities and Abundances of Greater Prairie-Chicken and Hybrid Prairie-Chicken

Densities (Table B-1, Table B-2, and Figure B-1) and abundances (Table B-3) of GPC and HPC were estimated in the SGPR of northwest Kansas. The population sizes of the GPC in the SGPR were estimated to be:

- 29,453 (90% CI: 13802, 3905) in 2012;
- 14,039 (90% CI: 7134, 17884) in 2013;
- 15,383 (90% CI: 7484, 19630) in 2014;
- 21,123 (90% CI: 10251, 26935) in 2015;
- 25,718 (90% CI: 12912, 33067) in 2016;
- 32,244 (90% CI: 16843, 39584) in 2017; and
- 33,867 (90% CI: 15644, 45333) in 2018.

An increase of 1,623 GPC was observed from 2017 to 2018; however, this increase was not statistically significant (80% CI: -7930, 11229; Table B-4). There was a statistically significant annual rate of increase of abundance GPC in the SGPR in northwest Kansas from 2013 to 2018 (p-value < 0.01). The average rate of increase was 4,409 greater prairie-chickens per year in the SGPR (standard error = 336).

We estimated the number of HPC in the SGPR (Figure B-2)to be:

- 304 (90% CI: 123, 416) in 2012;
- 113 (90% CI: 36, 176) in 2013;
- 87 (90% CI: 36, 118) in 2014;
- 228 (90% CI: 90, 315) in 2015;
- 267 (90% CI: 100, 381) in 2016;
- 387 (90% CI: 161, 529) in 2017; and
- 274 (90% CI: 104, 397) in 2018.

Table B-1. Estimates of greater prairie-chicken (GPC) and hybrid prairie chicken (HPC) densities per 100 kilometer^2 (km^2; 39 miles^2) from 2012 to 2018 in the Short Grass Conservation Reserve Program Region of northwestern Kansas. Bootstrapped 90% confidence intervals were reported on the densities of GPC and HPC per 100 km^2.

Year	GPC	HPC
2012	78.86 (36.95, 104.51)	0.81 (0.33, 1.11)
2013	37.59 (19.10, 47.88)	0.30 (0.10, 0.47)
2014	41.19 (20.04, 52.56)	0.23 (0.10, 0.32)
2015	56.55 (27.45, 72.11)	0.61 (0.24, 0.84)
2016	68.86 (34.57, 88.53)	0.72 (0.27, 1.02)
2017	86.33 (45.09, 105.98)	1.04 (0.43, 1.42)
2018	90.67 (41.88, 121.37)	0.73 (0.28, 1.06)

Table B-2. Estimates of greater prairie-chicken (GPC) and hybrid prairie-chicken (HPC) population sizes from 2012 to 2018 in the Short Grass Conservation Reserve Program Region of northwestern Kansas. Bootstrapped 90% confidence intervals were reported on the population sizes of GPC and HPC.

Year	GPC	HPC
2012	29453 (13802, 3905)	304 (123, 416)
2013	14039 (7134, 17884)	113 (36, 176)
2014	15383 (7484, 19630)	87 (36, 118)
2015	21123 (10251, 26935)	228 (90, 315)
2016	25718 (12912, 33067)	267 (100, 381)
2017	32244 (16843, 39584)	387 (161, 529)
2018	33867 (15644, 45333)	274 (104, 397)

Table B-3. Estimates of greater prairie-chicken (GPC) lek densities per 100 kilometer^2 (km^2; 39 miles^2) and abundances of GPC leks from 2012 to 2018 in the Short Grass Conservation Reserve Program Prairie Region of northwestern Kansas. Bootstrapped 90% confidence intervals were reported on the population sizes of GPC and abundances of GPC leks per 100 km^2.

Year	Density	Abundance
2012	5.18 (2.37, 7.04)	1933 (884, 2629)
2013	4.00 (1.76, 5.32)	1496 (657, 1987)
2014	4.68 (2.13, 6.06)	1747 (796, 2262)
2015	3.60 (1.46, 5.13)	1344 (544, 1915)
2016	7.08 (2.90, 9.75)	2644 (1085, 3643)
2017	5.88 (2.90, 7.49)	2197 (1084, 2798)
2018	7.21 (3.00, 10.00)	2694 (1121, 3735)

Table B-4. Estimated differences in population estimates for greater prairie-chickens between years with bootstrapped 80% confidence intervals on the differences.

Δ Year	Estimate (80% Confidence Interval)
2013 minus 2012	-15414 (-22703, -5251)
2014 minus 2013	1345 (-3063, 5745)
2015 minus 2014	5740 (-313, 10776)
2016 minus 2015	4595 (-2972, 11768)
2017 minus 2016	6526 (-2125, 13514)
2018 minus 2017	1623 (-7930, 11229)

Δ Year=change in year

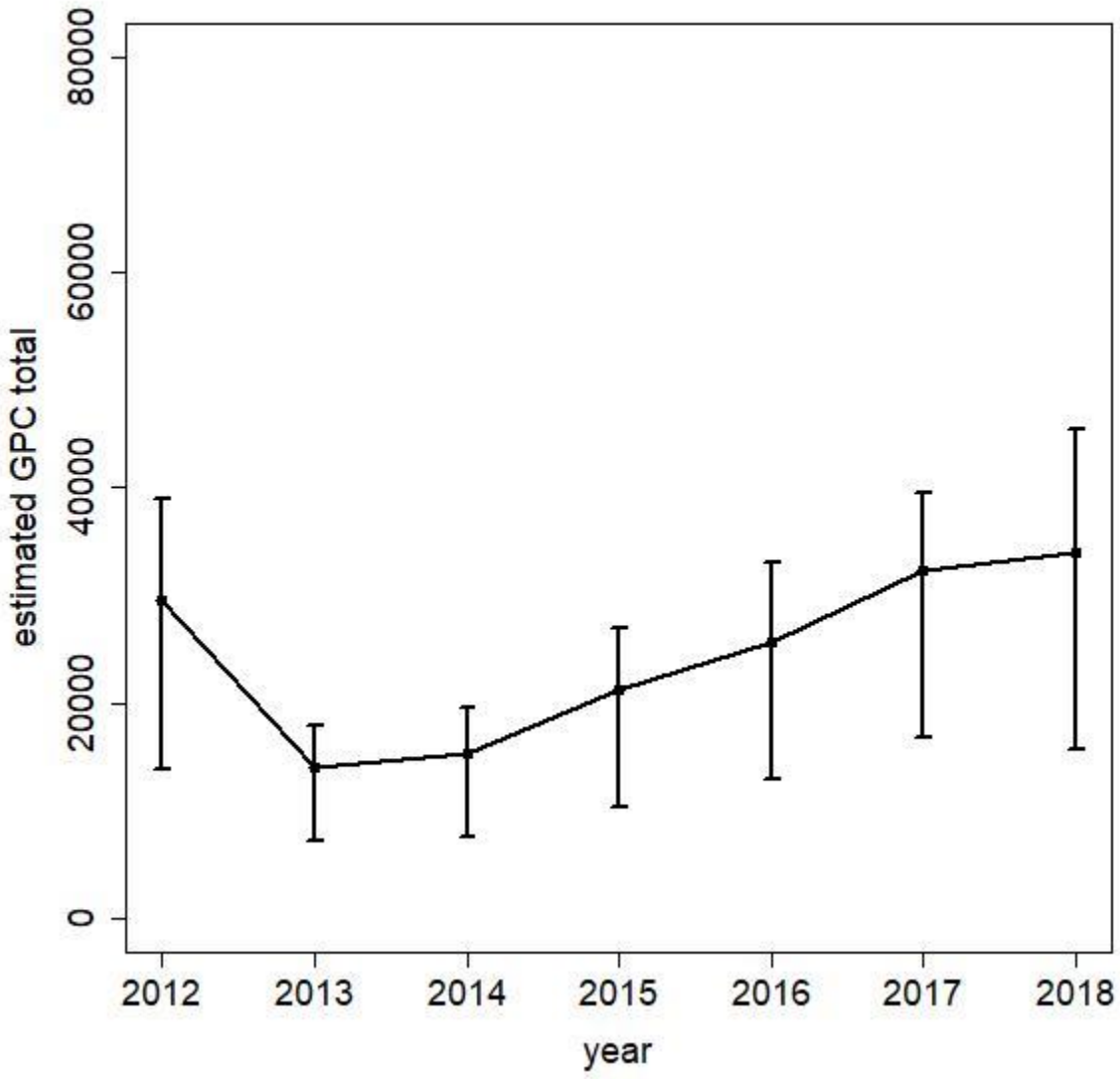

Figure B-1. Estimated population sizes of greater prairie-chickens (GPC) with 90% confidence intervals from 2012 to 2018 in the Short Grass Conservation Reserve Program Prairie Region (northwestern Kansas).

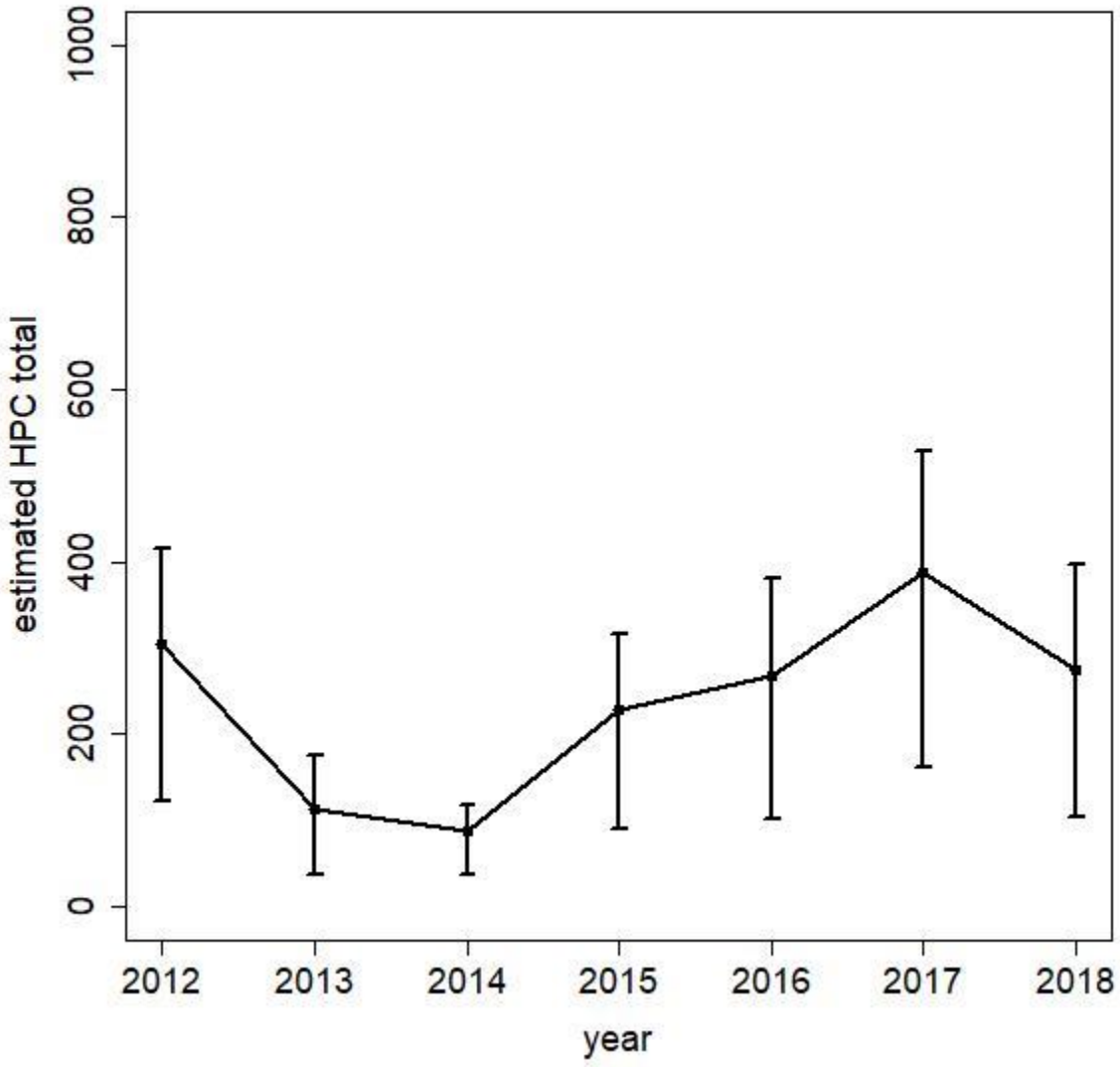

Figure B-2. Estimated population sizes of hybrid prairie-chickens (HPC) with 90% confidence intervals from 2012 to 2018 in the Short Grass Conservation Reserve Program Prairie Region (northwestern Kansas).