

Prepared in cooperation with the U.S. Fish and Wildlife Service

## A Projection of Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*) Populations Range-Wide



Open-File Report 2017–1071

U.S. Department of the Interior  
U.S. Geological Survey

**Cover:** Photograph showing male lesser prairie-chicken photographed near Canadian, Texas, 2015.  
Photograph by ©Sharon Cummings. Used with permission.

# **A Projection of Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*) Populations Range-Wide**

By Jonathan W. Cummings, Sarah J. Converse, Clinton T. Moore, David R. Smith, Clay T. Nichols,  
Nathan L. Allan, and Chris M. O'Meilia

**Prepared in cooperation with the U.S. Fish and Wildlife Service**

Open-File Report 2017–1071

**U.S. Department of the Interior  
U.S. Geological Survey**

**U.S. Department of the Interior**  
RYAN K. ZINKE, Secretary

**U.S. Geological Survey**  
William H. Werkheiser, Acting Director

U.S. Geological Survey, Reston, Virginia: 2017

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit <https://www.usgs.gov> or call 1-888-ASK-USGS (1-888-275-8747).

For an overview of USGS information products, including maps, imagery, and publications, visit <https://store.usgs.gov>.

Disclaimer: The findings and conclusions in this article are those of the author(s) and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Although this information product, for the most part, is in the public domain, it also may contain copyrighted materials as noted in the text. Permission to reproduce copyrighted items must be secured from the copyright owner.

Suggested citation:

Cummings, J.W., Converse, S.J., Moore, C.T., Smith, D.R., Nichols, C.T., Allan, N.L., and O'Meilia, C.M., 2017, A projection of lesser prairie chicken (*Tympanuchus pallidicinctus*) populations range-wide: U.S. Geological Survey Open-File Report 2017-1071, 60 p., <https://doi.org/10.3133/ofr20171071>.

ISSN 2331-1258 (online)

# Contents

Abstract .....	1
Introduction .....	1
Study Species .....	2
Lesser Prairie-Chicken Life Cycle .....	4
Lesser Prairie-Chicken Demographic Rates .....	6
Weather Covariates .....	7
Modeled Demographic Rates .....	8
Literature-Based Demographic Rates .....	8
Predictive Population Model .....	9
Uncertainty .....	9
Stochasticity .....	10
Density Dependence .....	10
Additional Calculated and Reported Population Growth Rates .....	11
Range-Wide Summary .....	12
Future Scenarios .....	12
Climate Predictions .....	12
U.S. Fish and Wildlife Service (FWS) Habitat Projections .....	14
Scenarios .....	15
Sensitivity Analyses .....	16
Results .....	18
Demographic Rates .....	18
Abundances, Population Growth Rates, and Persistence Probabilities .....	20
Additional Population Growth Rates and Range-Wide Summary .....	23
Scenario Analyses .....	24
Sensitivity Analyses .....	25
Discussion .....	26
Lesser Prairie-Chicken (LEPC) Projections .....	29
Next Steps .....	30
Summary .....	31
Acknowledgments .....	31
References Cited .....	32
Appendix A. Data Sources .....	36
Appendix B. Demographic Rates from Literature .....	37
Appendix C. Weather Covariate Definitions and Weather Data Sources .....	41
Appendix D. Demographic Modeling Outputs .....	44

## Figures

<b>Figure 1.</b> Lesser prairie-chicken (LEPC) estimated occupied range (EOR) in each of four ecoregions .....	3
<b>Figure 2.</b> Model of lesser prairie-chicken (LEPC) life cycle .....	5
<b>Figure 3.</b> Annual timeline of lesser prairie-chicken (LEPC) demographic processes .....	6
<b>Figure 4.</b> Median (yellow) and 95% credible interval (gray fill between red) abundance estimates through time for each ecoregion for the stationary scenario, Scenario A (see table 5).....	21
<b>Figure 5.</b> Probability of persistence at an abundance >0 (that is, the complement of ecoregional extinction), >50 (the complement of a quasi-extinction threshold of 50 individuals), and >500 (the complement of a quasi-extinction threshold of 50 individuals) over time for each ecoregion for the stationary scenario, Scenario A (see table 5).....	22
<b>Figure 6.</b> Trace plot of abundance trajectory from each simulation for the stationary scenario, Scenario A (see table 5), with carrying capacity abundance, median abundance, and 95% credible interval for abundance .....	23
<b>Figure 7.</b> Trace plot of abundance trajectory from each simulation for Scenario F (see table 5), with carrying capacity abundance, median abundance, and 95% credible interval for abundance .....	24
<b>Figure 8.</b> Probability of persistence at an abundance >0 (that is, the complement of ecoregional extinction), >50 (the complement of a quasi-extinction threshold of 50 individuals), and >500 (the complement of a quasi-extinction threshold of 50 individuals) over time for each ecoregion for Scenario F (see table 5).....	25

## Tables

<b>Table 1.</b> Carrying capacity densities.....	11
<b>Table 2.</b> Representative climate pathway 4.5 and 8.5 (RCP4.5 and RCP8.5) climate projection models. ...	13
<b>Table 3.</b> Climate change data grid boundaries.....	13
<b>Table 4.</b> Climate covariates used in population projections (results from appendix D, covariate definitions in appendix B).....	14
<b>Table 5.</b> Future scenarios.....	15
<b>Table 6.</b> Highest observed demographic rates (median $\pm$ standard error) for sensitivity analysis 3.....	17
<b>Table 7.</b> Projected demographic rates derived from available literature.....	18
<b>Table 8.</b> Projected demographic rates estimated by model fitting and comparison to other published demographic rate estimates. ....	19
<b>Table 9.</b> Projected population growth rates and comparisons to other estimates (median and $\pm$ standard error).....	20
<b>Table 10.</b> Demographic rates required to achieve target population growth rates in sensitivity analysis 5 ( $\lambda = 0.9$ ) and 6 ( $\lambda = 1.0$ ). ....	27

## Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
Length		
kilometer (km)	0.6214	mile (mi)
Area		
square kilometer (km <sup>2</sup> )	247.1	acre
square kilometer (km <sup>2</sup> )	0.3861	square mile (mi <sup>2</sup> )

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as °F = (1.8 × °C) + 32.

## Abbreviations

EOR	Estimated Occupied Range
ESA	Endangered Species Act of 1973
GCM	Global Circulation Model
GIS	geographic information system
LEPC	lesser prairie-chicken
MGPE	Mixed Grass Prairie Ecoregion
RCP	Representative Climate Pathway
FWS	U.S. Fish and Wildlife Service
SGPE	Short Grass Prairie Ecoregion
SSA	Species Status Assessment
SSBPE	Sand Sagebrush Prairie Ecoregion
SSOPE	Sand Shinnery Oak Prairie Ecoregion

This page left intentionally blank



# A Projection of Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*) Populations Range-Wide

By Jonathan W. Cummings<sup>1</sup>, Sarah J. Converse<sup>1</sup>, Clinton T. Moore<sup>1</sup>, David R. Smith<sup>1</sup>, Clay T. Nichols<sup>2</sup>, Nathan L. Allan<sup>2</sup>, Chris M. O’Meilia<sup>2</sup>

## Abstract

We built a population viability analysis (PVA) model to predict future population status of the lesser prairie-chicken (*Tympanuchus pallidicinctus*, LEPC) in four ecoregions across the species’ range. The model results will be used in the U.S. Fish and Wildlife Service’s (FWS) Species Status Assessment (SSA) for the LEPC. Our stochastic projection model combined demographic rate estimates from previously published literature with demographic rate estimates that integrate the influence of climate conditions. This LEPC PVA projects declining populations with estimated population growth rates well below 1 in each ecoregion regardless of habitat or climate change. These results are consistent with estimates of LEPC population growth rates derived from other demographic process models. Although the absolute magnitude of the decline is unlikely to be as low as modeling tools indicate, several different lines of evidence suggest LEPC populations are declining.

## Introduction

We built a population viability analysis (PVA) model to predict future population status of the lesser prairie-chicken (*Tympanuchus pallidicinctus*, LEPC). This model was constructed to support the Species Status Assessment (SSA) for LEPC being conducted by the U.S. Fish and Wildlife Service (FWS).

The LEPC has experienced a substantial and protracted decline, resulting in historical lows in estimated abundance in the late 1990s, followed by modest increases and subsequent declines in the 2000s in lek count-based abundance estimates (Garton and others, 2016). Recent distance sampling methods from the McDonald and others (2016) range-wide aerial survey estimate the population has been fluctuating at or near historical lows in abundance for the last 5 years. The LEPC was made a candidate for listing under the Endangered Species Act (ESA) by the FWS in 1998 and was listed as a threatened species in March 2014. This listing was subsequently vacated by a U.S. District Court decision on September 1, 2015, and the FWS removed LEPC from the List of Endangered and Threatened Wildlife (50 CFR 17.11 (h)) in July 2016. On September 8, 2016, the FWS received a petition to list the LEPC as endangered (Molvar, 2016). The FWS is now evaluating the LEPC to make another determination on whether listing under the ESA is warranted. The modeling work reported here supports the LEPC SSA, which will document the results of a comprehensive status review for the lesser prairie-chicken to inform the upcoming listing decision under the ESA.

---

<sup>1</sup> U.S. Geological Survey.

<sup>2</sup> U.S. Fish and Wildlife Service.

Unlike many species in decline, there is a relative abundance of data on LEPCs available. However, to date no model has integrated available information in a manner that meets the information needs for the FWS assessment. Assessing species condition to make an ESA classification requires assessing future changes in environmental conditions resulting from climate change, conservation, development, or other factors that influence LEPC habitat and abundance across the species' range. Fields (2004) and Hagen and others (2009) evaluated the population growth rate of LEPCs, but neither used those growth rates to project future abundance under potentially changing conditions, and each study produced estimates for only one of four ecoregions. Sullins (2017) also evaluated LEPC population growth rates in a manner similar to Fields (2004) and Hagen and others (2009) at sites from three of the ecoregions. Garton and others (2016) projected past population growth rates into the future in each ecoregion, but like Fields (2004) and Hagen and others (2009), the results do not account for future changes to climate or habitat conditions. Recent projections from Godar (2016) and Griffin (2016)—based largely on the same dataset as this model—account for climate change in each ecoregion, but differ significantly in structure, do not account for changes in habitat, and do not include the extensive sensitivity analyses reported here.

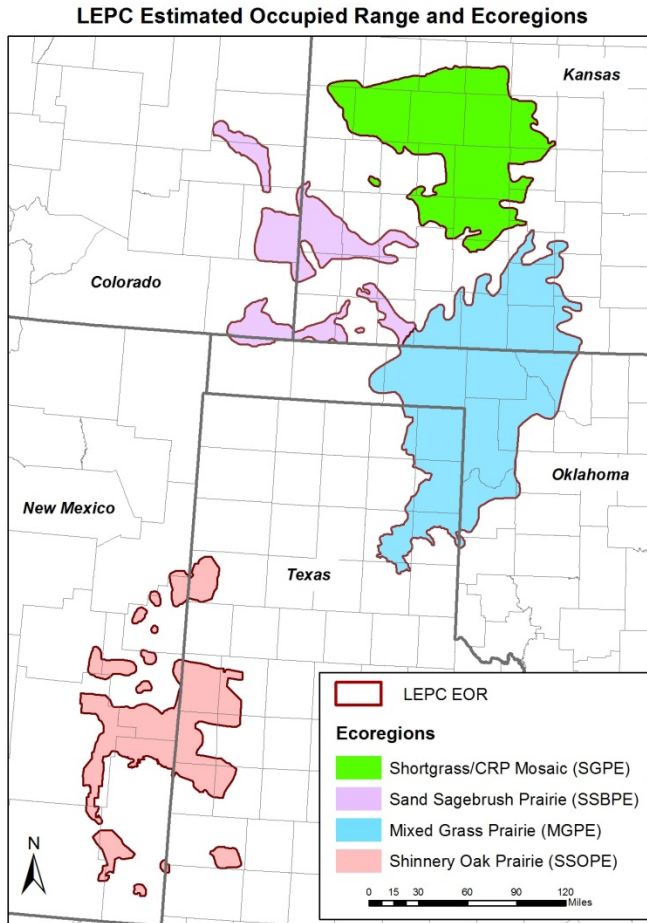
The LEPC PVA model integrates a new analysis of previously published data on relationships between demography and weather variables with previously published literature on LEPC demographic rates and population density. The model is designed to account for GIS-based information on estimated currently available habitat and projections of future available habitat by applying the results of a broad landscape-level GIS analysis (U.S. Fish and Wildlife Service unpublished habitat projections—hereinafter “FWS Habitat Projections”) conducted in a separate analysis but also in support of the LEPC SSA to derive a habitat-based carrying capacity estimate at the ecoregional scale.

The model projections incorporate uncertainty from several sources. These sources of uncertainty include demographic stochasticity, annual variation and long-term change in precipitation and temperature, variation in habitat availability due to future land use, uncertainty in demographic parameter estimates, and unexplained interannual variation. The model operates by ecoregion, and separate parameter values are used for each of four ecoregions. For each ecoregion, the model predicts persistence probability, annual population size, and population growth rates of LEPCs through the end of the century (2016–2099).

## **Study Species**

The lesser prairie-chicken (LEPC) is a medium-sized, non-migratory member of the group of North American prairie grouse species, and occupies prairies in the Southern Great Plains (Aldrich, 1963). Although the full historical abundance and extent of the LEPC range is unknown, it is estimated to have once occupied approximately 456,000 km<sup>2</sup> in parts of Kansas, Colorado, Oklahoma, Texas, and New Mexico (Van Pelt and others, 2013). There is uncertainty about this estimate, and the currently defined historical range likely includes large areas that did not provide LEPC habitat (Boal and Haukos, 2016).

The current LEPC range has been estimated to be approximately 80,000 km<sup>2</sup> (Van Pelt and others, 2013) distributed in four ecoregions (fig. 1). From north to south (based on the most northern extent of each ecoregion), they are the Short Grass Prairie Ecoregion (SGPE), the Sand Sagebrush Prairie Ecoregion (SSBPE), the Mixed Grass Prairie Ecoregion (MGPE), and the Sand Shinnery Oak Prairie Ecoregion (SSOPE). Although there is likely some limited movement between the northern three ecoregions, we treat the LEPC in each ecoregion as separate and independent populations for the purpose of our analysis, producing separate models and abundance estimates for each ecoregion, with the boundaries of each ecoregion defined as the edges of the estimated occupied range (EOR) reported in the Lesser Prairie-Chicken Range-Wide Conservation Plan (Van Pelt and others, 2013).



**Figure 1.** Lesser prairie-chicken (LEPC) estimated occupied range (EOR) in each of four ecoregions.

Boal and Haukos (2016) provide a brief introduction to lesser prairie-chicken biology, noting the lesser prairie-chicken life cycle is characterized by two phases, a breeding phase and a non-breeding phase, with the breeding phase beginning with a February to June lekking period during which males display on leks to attract female mates. Following mating, females lay a clutch (typically 10–12 eggs) sometime in mid-April through May, potentially re-nesting in June if a first attempt fails. After incubation, females will rear a brood through the remainder of the summer (Boal and Haukos, 2016). LEPC are short-lived, characterized by limited annual survival and exhibiting an *r*-selected reproductive strategy (Boal and Haukos, 2016).

A number of factors have been identified as potential sources of decline in LEPC abundance and distribution. Precipitation, or drought when presented as a source of decline, has been identified as a factor influencing LEPC adult population trends, with a potential lag effect (Giesen, 2000). Temperature also affects LEPC survival and reproduction (Grisham, 2013), indicating that future climate conditions are likely to play a role in LEPC population status (Grisham and others, 2013). Land cover conditions also influence LEPC populations, and energy development (Bartuszevige and Daniels, 2016), agricultural extent and agricultural practices (Bartuszevige and Daniels, 2016), and woody vegetation encroachment (Giesen, 1998; Lautenbach and others, 2017) have been identified as the more influential factors affecting LEPC populations.

## Lesser Prairie-Chicken Life Cycle

LEPC population abundance is forecasted using a female-only model on an annual basis as a function of three processes: recruitment, adult survival, and density dependence. Recruitment is the addition of new individuals into the adult population through reproduction and subsequent survival of offspring to adulthood (onset of the first breeding season after hatching). Thus, the model assumes a pre-breeding census in which the calculated population is the population alive just before breeding. Survival accounts for the maintenance of reproducing individuals from one year to the next. Density dependence limits the maximum size of the population in any year. Density dependence does not influence the LEPC demographic rates in our model, but acts as a cap (based on carrying capacity) to limit the maximum annual population size.

Recruitment into the adult population is modeled as a function of the following demographic rates—female nesting and re-nesting rates, nest success rate, brood success rate, brood size, sex ratio of offspring, and winter survival of juveniles (fig. 2). We model realized recruitment as the result of a series of stochastic processes based on each of these demographic rates, with expected recruitment ( $R$ ) modeled as:

$$R_{t+1} = F_t \{ P_{n1} * S_n + P_{n1} * (1 - S_n) * P_{n2} * S_n \} * S_b * B * SR * S_j. \quad (1)$$

$F_t$  is the number of adult females in year  $t$ . Nesting rate ( $P_{n1}$ ) is the probability that an adult female will attempt to nest, and re-nesting rate ( $P_{n2}$ ) is the probability that an adult female will attempt a second nest if the first fails. Nest success ( $S_n$ ) is the probability that a nest produces  $\geq 1$  hatched chick (same for first and re-nests) and brood success ( $S_b$ ) is the probability that a brood of hatched chicks produces  $\geq 1$  juvenile (defined as a bird that survives until 30 days post-hatch). Brood size ( $B$ ) is the number of juveniles per successful brood, and offspring sex ratio ( $SR$ ) is fixed at 0.5, and converts juveniles to female juveniles. Juvenile survival ( $S_j$ )—the probability that a juvenile survives from fledging to recruitment (that is, sexual maturity)—determines the number of juvenile females recruited into the adult population (fig. 2). Nest failures and brood failures resulting from mortality of the adult hen were included in the data used to estimate nest and brood success, thereby accounting for mortality of hens during their summer survival period in the calculation of recruitment.

The term in braces in equation 1 represents successful nests, including first nests:  $P_{n1} * S_n$ , and re-nests:  $P_{n1} * (1 - S_n) * P_{n2} * S_n$ . Nest success is modeled with a daily nest survival rate that is applied to the 28-day incubation period (assumed May 3–31), to arrive at the nest success rate,  $S_n$ , i.e.,  $S_n = (S_{daily\ nest\ survival})^{28}$ . Brood success is modeled with a daily brood survival rate for fledglings applied to the 30-day brood rearing period (assumed June 1–30), to produce the brood success rate,  $S_b$ , i.e.,  $S_b = (S_{daily\ brood\ survival})^{30}$ . Juvenile survival,  $S_j$ , is the survival rate for the time period from day after the end of the brood success period, July 1, to the day before the beginning of the next annual cycle, February 28.

The number of annual adult female survivors ( $AS$ ) is modeled as the product of two demographic rates representing survival over two time periods (fig. 3)—a summer season survival rate ( $S_s$ ) when nesting and brooding is occurring, from March 1 to September 12, and a winter season survival rate ( $S_w$ ), from September 13 to February 28. The number of adult females in the population at the start of the year ( $F_t$ ) is subject to this survival rate (with the number of survivors modeled as a binomial outcome). Therefore, the expected number of adults surviving to the following breeding season is:

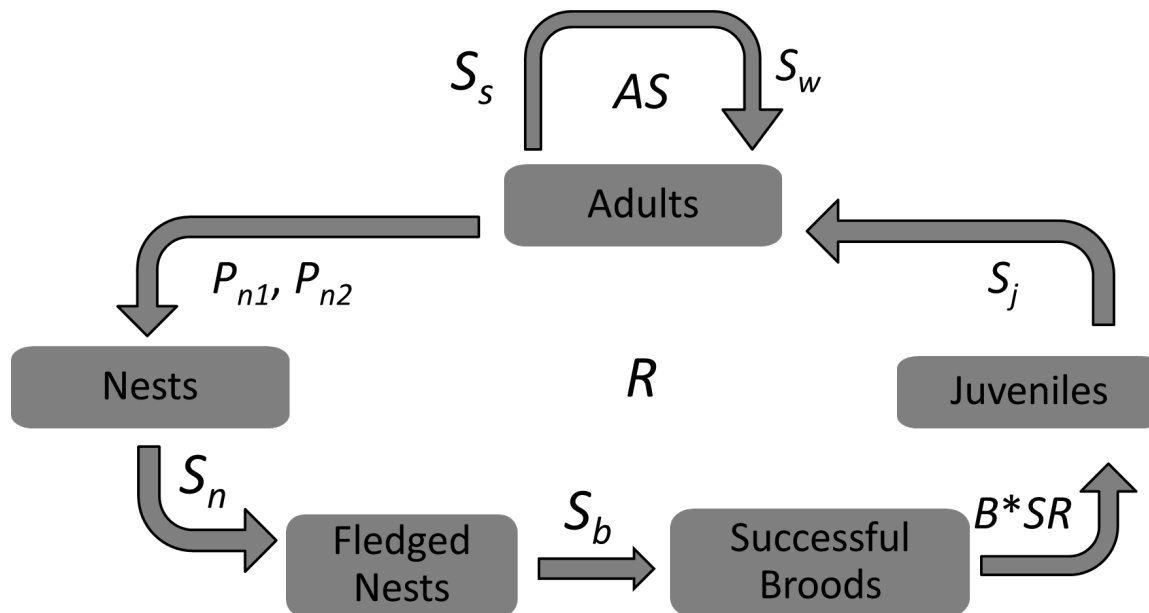
$$AS_{t+1} = F_t * S_s * S_w \quad (2)$$

The total female abundance ( $F_t$ ) is the sum of female recruits ( $R_t$ ) and number of adult females surviving from the previous year ( $AS_t$ )

$$F_{t+1} = R_{t+1} + AS_{t+1} \quad (3)$$

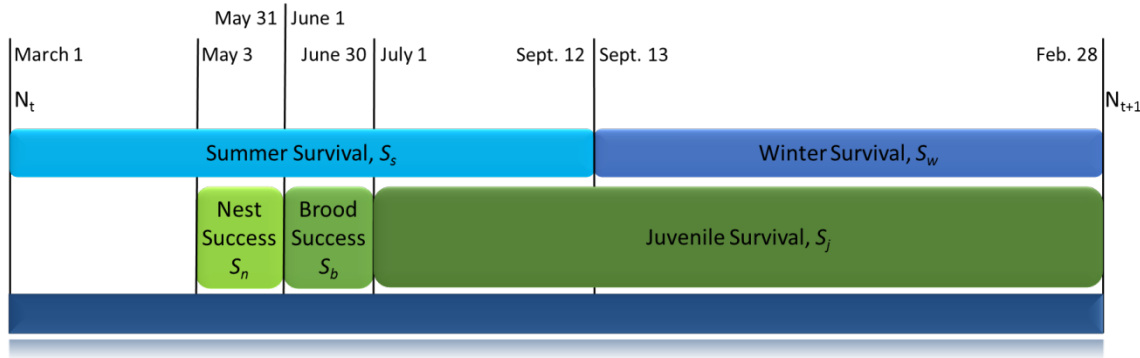
When reporting the yearly abundance in each model run, we convert the female only abundance ( $F_t$ ) to a total abundance ( $N_t$ ) by dividing by the sex ratio ( $SR$ ).

$$N_t = F_t / SR \quad (4)$$



**Figure 2.** Model of lesser prairie-chicken (LEPC) life cycle.

This assumes that the adult sex ratio is 1:1, 50% female to 50% male at the annual census, expressed as a proportion for calculations of 0.5. We also assume that the initial abundance is composed of one-half males and one-half females, which assumes that 50% of the individuals estimated in the range-wide aerial survey are female (see section, “Uncertainty”).



**Figure 3.** Annual timeline of lesser prairie-chicken (LEPC) demographic processes. Adult survival is modeled as the product of two survival rates on an annual basis: summer survival ( $S_s$ ), which occurs from March 1 to September 12, and winter survival ( $S_w$ ), which occurs from September 13 to February 28. Recruitment results from three rates: a nest success rate ( $S_n$ ) that applies from May 3 to May 31, a brood success rate ( $S_b$ ) that applies from June 1 to June 30, and a juvenile survival rate ( $S_j$ ) that applies from July 1 to February 28.

## Lesser Prairie-Chicken Demographic Rates

The demographic rates for the population viability analysis model were produced using two methods—(1) a model fitting procedure that evaluated available observation data as a function of weather conditions (see section, “Modeled Demographic Rates”), and (2) drawing estimates of demographic rates from previously published studies (see section, “Literature-Based Demographic Rates”). For the former, we were provided with information necessary to estimate nest success ( $S_n$ ), brood success ( $S_b$ ), and summer season adult survival ( $S_s$ ) from previous LEPC research efforts (sources provided in appendix A). These observations were used to fit the nest success, brood success, and summer season adult survival models as a function of weather covariates. From the same data sources, we also drew information on brood counts at fledging (30 days post-hatch) for successful broods (broods in which  $\geq 1$  individual survived). The remaining rates—nesting, re-nesting, juvenile survival, winter survival—were estimated from distributions produced from previously published studies (sources provided in appendix B) without fitting to weather covariates. Sex ratio was assumed fixed at 0.5, as in other LEPC population modeling efforts (for example, Fields, 2004; Hagen and others, 2009; Godar, 2016; Griffin, 2016).

## Weather Covariates

We identified the geographic center of each ecoregion, using the EOR boundary identified in The Lesser Prairie-Chicken Range-wide Conservation Plan (Van Pelt and others, 2013). The model runs at an ecoregional scale, requiring the application of a single climate projection to the full ecoregion. To match the projection scale, we used the ecoregion center points when selecting the historical weather data for model fitting. In addition, the demographic rate observations provided to us were not associated with study locations, only the ecoregion in which they were collected. We used this geographic center point to search the list of weather stations listed in the National Oceanic and Atmospheric Administration's (NOAA) National Climate Data Center (NCDC) archive of daily weather observations housed at the Climate Data Online (CDO) website (<https://www.ncdc.noaa.gov/cdo-web/datatools/findstation>) to determine the station nearest the geographic center of each ecoregion with data available from January 1, 1996, to December 31, 2016. We downloaded the daily summary of precipitation, snowfall, maximum temperature, and minimum temperature from each of the four ecoregion-associated weather stations (appendix C, table C1). The daily summaries of weather parameters were further summarized over longer time periods as appropriate for inclusion in demographic rate modeling, such as a year for annual weather covariates, or the 3 winter months for winter covariates (time periods covered by each covariate are provided in appendix C, table C2) to produce a set of weather covariates for each modeled demographic rate.

We produced 23 covariates based on the weather data available, the covariate set used by Godar (2016) and Griffin (2016), and input from the LEPC SSA Working Group (table C2). The covariates were sorted into four groups relative to the breeding season (specific dates are provided in table C2)—(1) pre-season precipitation covariates, (2) in-season precipitation covariates, (3) in-season hot weather covariates, and (4) in-season cold-weather covariates.

Covariates in group 1 (pre-season precipitation covariates) included total annual precipitation (APrecip), total annual snowfall (ASnow), total winter precipitation (WPrecip), and total prior summer precipitation (PSPrecip).

Covariates in group 2 (in-season precipitation attributes) included total precipitation in the nesting season (May 1–June 29, NPrecip), the brood season (June 1–July 30, BPrecip), the first 2 weeks of the brood season (June 1–14, BPrecipF2W), and overall summer season (March 1–September 12, SPrecip). The number of wet days (days with rainfall >2.5 cm) in the nesting season (NWet), the brood season (BWet), and overall summer season (SWet) also were included.

Covariates in group 3 (in-season hot weather attributes) included average maximum temperature in the nesting season (NTemp), the brood season (BTemp), the first 2 weeks of the brood season (BTempF2W), and the overall summer season (STemp). This group also included number of hot days (days with maximum temperature > 32.2 °C) in the nesting season (NHot), the brood season (BHot), the first 2 weeks of the brood season (BHotF2W), and the overall summer season (SHot).

Finally, covariates in group 4 (in-season cold weather attributes) included number of cold days (days with minimum temperature < 0 °C) in the nesting season (NCold), the brood season (BCold), first 2 weeks of the brood season (BColdF2W), and the overall summer season (Scold). In some cases, the NCold, BCold, or BColdF2W covariates were excluded because no cold days were observed across the set of years included in the demographic rate dataset (appendix D, table D1).

## Modeled Demographic Rates

Weather covariates were fit to the demographic rates and the final demographic rate models were selected in a three-step process. In the first step, we fit single covariate models and used Akaike's Information Criterion corrected for small sample sizes (AIC<sub>c</sub>, Akaike, 1974; Hurvich and Tsai, 1989; Burnham and Anderson, 2002) to select the single best weather covariate from each of the four weather covariate groups (pre-season precipitation, in-season precipitation, in-season hot weather, in-season cold weather) for a given demographic rate in a given ecoregion (table D1). In the second step, we selected amongst the set of 16 models composed of all possible combinations of the four weather covariates selected in step 1, including the constant model, using AIC<sub>c</sub> scores to determine the single top model for each demographic rate in each ecoregion (appendix D). These models were used in projecting future demographic rates in the projection model, see section, "Predictive Population Model."

We fit the nest and brood success models using the nest survival model (Dinsmore and others, 2002) and we fit summer adult female survival using the known fate model in Program MARK 6.1 (White and Burnham, 1999). We used standardized covariates and a logit link function in the nest survival model in Program MARK. The nest success and brood success models produced daily survival rate estimates given the first date of observation (*i*), last date observed alive (*j*), and the final date of observation (*k*) when fate was determined. We fit known-fate models with a logit transformation and standardized covariates for the summer survival models, based on observations of radio-marked females in each ecoregion over 2-week periods from March 1 to September 12.

In the last step, we refit equivalent formulations of the top (that is, lowest AIC<sub>c</sub>) model for each demographic rate using Markov-chain Monte Carlo (MCMC) simulation in JAGS 4.2.0 (Plummer, 2003) via the jagsUI package (Kellner, 2016) in R (Version 3.3.2, R Core Team, 2016). Three MCMC chains were run for each model fit, with convergence considered to be successful at  $\hat{R}$  values  $< 1.1$ . After discarding burn-in samples, with the length of burn-in determined based on inspection of trace plots, we ran enough iterations for each model fit to achieve convergence. In the JAGS analyses, we added random effects of year to the top model for each demographic rate, resulting in estimation of the following model parameters: an intercept (estimated demographic rate when all covariates are held at their mean values), weather covariate coefficients (effect size for each weather covariate), and  $\sigma$  (standard deviation of annual variation). Diffuse normal priors with a mean of zero and precision (1/variance) of 0.001 were used for the intercept and weather covariate coefficients, while a uniform distribution from 0.25 to 10 was used as the prior for  $\sigma$ . Including  $\sigma$  as a model parameter allows our predictive model to include annual temporal variation in demographic rates beyond that explained by the weather covariates. The MCMC samples constitute random draws from the posterior distributions for each parameter, and they were saved for use in the predictive model.

## Literature-Based Demographic Rates

The brood size predictions in each ecoregion were based on observed brood size counts collected during the observational studies described in appendix A. The observed brood sizes ranged from 1 to 11 in the 11 observations from the SGPE, 1 to 7 in the 19 observations from the SSBPE and the 12 observations from the MGPE, and 1 to 4 in the 6 observations from the SSOPE. For each successful brood (survival of  $\geq 1$  individual) in the predictive population model, we sampled a single value from the set of observed brood counts to determine the size of the brood.



The remaining demographic rates were drawn from published theses, dissertations, and peer-reviewed journal articles (appendix B). The rates drawn from the available literature are the nesting rate, re-nesting rate, and winter survival rate (used to estimate both juvenile survival and winter survival, appendix B, section, “Demographic Rates by Ecoregion”) with unique rates for each ecoregion as available.

## Predictive Population Model

We predict future population size over an 84-year period (2016–2099, the duration of available climate projection data), in each of the four ecoregions, using a separate model for each ecoregion. These four ecoregional models each use the same LEPC life cycle description (see section, “Lesser Prairie-Chicken Life Cycle”)—the equations to determine recruitment and survival (eqs. 1 and 2) are the same (see section, “Lesser Prairie-Chicken Demographic Rates”)—but the fitted and literature-based estimates of the demographic rates in those equations differ, as do the weather covariates selected for use in the population projection.

## Uncertainty

Multiple types of uncertainty are accounted for in the model. First, we include structural uncertainty, represented by multiple scenarios of future conditions, including different representative climate pathways (RCPs), and habitat conservation and habitat loss scenarios (see section, “Future Scenarios”). Second, we included parametric uncertainty, represented by sampling distributions for the demographic rates (either represented by samples from the MCMC chains from the model fitting exercise or as reported in the literature from which published rates were drawn), uncertainty in the initial abundance, uncertainty within a single RCP represented by multiple model projections within each RCP, and uncertainty within a single future habitat conservation and habitat loss scenario represented by different randomly generated outcomes of available habitat.

For a single simulation (iteration) of the projection model, nest success ( $S_n$ ), brood success ( $S_b$ ), and summer survival ( $S_s$ ) rates are predicted using a single sample from the MCMC chains produced by the program JAGS. We sample the intercept, covariate coefficients, and  $\sigma$  parameters produced by drawing single (correlated) values from these chains for each model fit. Those values are used to predict the demographic rates when combined with the relevant projected weather covariates.

The uncertainty in the nesting rate ( $P_{n1}$ ), re-nesting rate ( $P_{n2}$ ), and winter survival rates for adults ( $S_w$ ) and juveniles ( $S_j$ ) is accounted for by sampling from a distribution described by the means and standard errors reported in the available literature for each simulation (iteration, appendix B). The reported mean and standard error are converted to the logit scale; a single value of the demographic rate is drawn from a normal distribution with the logit-converted mean and standard error; and the resulting logit scale rate is transformed back to the real scale for use across years in the simulation.

Initial abundance is also sampled from a distribution using the mean abundance estimated from the 2016 range-wide aerial survey and a standard error derived from the 90% confidence interval provided in the 2016 range-wide aerial survey report (McDonald and others, 2016; appendix B). The range-wide aerial survey occurs over a larger area than the EOR, so we are assuming that all estimated LEPC occur within the EOR when we use the range-wide aerial survey abundance estimates to determine the initial abundance in the EOR. We apply a truncated normal to this sampling distribution to restrict the resulting initial abundance to be equal to or greater than the number of individuals actually observed as reported in table 5 of the 2016 range-wide aerial survey report (McDonald and

others, 2016). The population is initially distributed between 1-year-old female LEPCs and 2+-year-old female LEPCs in accordance with the stable age distribution produced by the model's demographic rates (0.49:0.51, 0.43:0.57, 0.27:0.73, and 0.08:0.92 first year to second year and older in the SGPE, SSBPE, MGPE, and SSOPE). That is, we allocate the total initial abundance into the two life stages based on an approximate stable age distribution.

## Stochasticity

In addition to uncertainty that is accounted for at the simulation level, there are two sources of stochasticity that influence year-to-year variation within a single simulation—environmental and demographic stochasticity. We account for environmental stochasticity on an annual basis for each modeled demographic rate (nest success, brood success, and summer survival) by drawing a value from a normal distribution with a mean of zero and a variance equal to the value of a single sample from the sampling distribution for  $\sigma$  produced in the fitting process (see section, “Modeled Demographic Rates”). That is, we draw three independent  $\sigma$  values for each year of a simulation, one each from the distributions produced in the fitting process for the nest success, brood success, and summer survival models.

Demographic stochasticity is accounted for by drawing the realized numbers of nesting females, successful nests, successful broods, and adults from binomial distributions, with the probability determined by the relevant demographic rate in the life cycle. Brood size is drawn, with replacement, in each year from the list of observed brood sizes as previously described; the number of draws is equal to the number of successful broods.

## Density Dependence

A carrying capacity cap determined by habitat availability is applied in all simulations. Each year of a simulation we determine the area of available habitat that can support LEPC. Available habitat is calculated through linear extrapolation between the current area (starting with 2017) and the habitat projections produced by the FWS for 2042 (see section, “FWS Habitat Projections”). The carrying capacity of each ecoregion is determined by combining the projected area each year with the carrying capacity density in the following equation:

$$CC_t = A_t * D \quad (5)$$

where  $CC_t$  is the carrying capacity abundance, and  $A_t$  is the habitat area in blocks of suitable habitat, both in year  $t$ .  $D$  is the carrying capacity density in blocks of suitable habitat. If the projected future abundance in year  $t$  exceeds the carrying capacity abundance, then year  $t$  abundance is set equal to the carrying capacity abundance in year  $t$ . The proportion of first year to second year and older birds prior to applying the carrying capacity cap is maintained when the abundance is reduced to the carrying capacity abundance. Direct estimates of LEPC carrying capacity and carrying capacity densities are unavailable. In place of carrying capacity density estimates, the carrying capacity densities were drawn from the target densities provided in the Lesser Prairie-Chicken Range-wide Conservation Plan (Van Pelt and others, 2013 p. 72) based on input from the LEPC SSA Working Group.

**Table 1.** Carrying capacity densities.

[From Van Pelt and others, 2013]

Ecoregion	Carrying capacity density ( $D$ ) per km <sup>2</sup>
SGPE	23.31
SSBPE	12.95
MGPE	18.13
SSOPE	10.34

### Additional Calculated and Reported Population Growth Rates

We also report  $\lambda$  values taken directly from other sources, or calculated from other sources. We report population growth rates from three other demographic rate studies (Fields, 2004; Hagen and others, 2009; Sullins, 2017). We report the ground based lek count population growth rates in the Garton and others (2016) study, and calculate population growth rates from the McDonald and others (2016) range-wide aerial survey. Using the population estimates from those annual surveys (McDonald and others, 2016), we calculated annualized growth rates in a manner that accounts for uncertainty, to provide a comparison for our model-based estimates of population growth rate. We began by calculating the sampling SEs for the abundance estimates using the 95% CIs for the first (2012) and most recent (2016) years of the range-wide aerial survey, from each ecoregion, as:

$$SE = \frac{\text{Upper 95\% Interval Bound} - \text{Lower 95\% Interval Bound}}{3.92} \quad (6)$$

We then generated 1,000 (paired but independent) samples of abundance based on the reported mean and the calculated SE for the 2012 and 2016 years of the range-wide aerial survey from a normal distribution. We calculated the annualized population growth rate for all pairs of samples as:

$$\left( \frac{N'_{2016}}{N'_{2012}} \right)^{0.25} \quad (7)$$

where  $N'_t$  is a sample from a normal distribution with the reported mean abundance and calculated SE for a given ecoregion in year  $t$ .

## Range-Wide Summary

Finally, we use the population growth rate estimates for each ecoregion from our analysis (using Scenario A) from Garton and others (2016), and calculated from McDonald and others (2016) to produce range-wide population growth rate estimates. We projected 1 year forward starting with the median 2016 abundance estimates from the range-wide aerial survey for each ecoregion, and using the  $\lambda$  estimate associated with each ecoregion, to determine the resulting abundance for each ecoregion the following year. The total abundance across ecoregions after projecting the population in each ecoregion for 1 year was divided by the total of the initial range-wide aerial survey abundance across ecoregions to provide a range-wide estimate of  $\lambda$ .

## Future Scenarios

We conducted an analysis of seven scenarios that combine habitat projections developed by the FWS (FWS Habitat Projections) with climate change scenarios (see section, “Scenarios”). Each model run represents an analysis of a single scenario across the four ecoregions. Within each model run we produce 10,000 simulated futures by iterating the model for that number of simulations to account for uncertainty (see section, “Uncertainty”). Each simulation is run for 84 years, where year 1 is 2016 and year 84 is 2099, with stochasticity operating on an annual basis within each simulation (see section, “Stochasticity”).

## Climate Predictions

Uncertainty in climate predictions for the LEPC range takes two forms. First, the various representative climate pathways (RCPs) express uncertainty about the status of future atmospheric conditions that drive climate and weather conditions. Representative climate pathways are greenhouse gas concentration trajectories adopted by the Intergovernmental Panel on Climate Change that represent possible climate futures. We treat this uncertainty as structural, and confine model runs to a single RCP. Second, differences between the various global circulation models (GCMs) which project the outcomes of the RCPs represent uncertainty about the relationship between atmospheric conditions and future climate and weather conditions given an RCP. We treat this uncertainty as parametric—that is, uncertainty about the exact weather conditions at any point in the future, given an RCP—by drawing predictions from a single GCM for each model simulation. Structurally, we include two RCPs (RCP4.5 and RCP8.5) in our scenarios. For both RCP4.5 and RCP8.5, we sampled from 19 available GCMs (table 2).

We obtained projections of temperature and precipitation for each GCM within each RCP on a daily basis for January 1, 2016, to December 31, 2099, from the Lawrence Livermore National Laboratory website ([http://gdo-dcp.ucllnl.org/downscaled\\_cmip\\_projections/#Projections:%20Subset%20Request](http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/#Projections:%20Subset%20Request), accessed on March 20, 2017). We downloaded projections produced from the Bias Corrected Constructed Analogs (BCCA) versions of the Coupled Model Intercomparison Project Phase 5 (CMIP5) climate projections at the 1 degree scale, selecting the projections from the 1 degree grid cell that overlaps the center of each ecoregion (table 3).

**Table 2.** Representative climate pathway 4.5 and 8.5 (RCP4.5 and RCP8.5) climate projection models.

[Model names are the shorthand used at the Lawrence Livermore Internet site from which they were downloaded]

<b>RCP4.5 models</b>	<b>RCP8.5 models</b>
access1.0.1.rcp45	access1.0.1.rcp85
bcc.csm1.1.1.rcp45	bcc.csm1.1.1.rcp85
canesm2.5.rcp45	canesm2.5.rcp85
ccsm4.2.rcp45	ccsm4.2.rcp85
cesm1.bgc.1.rcp45	cesm1.bgc.1.rcp85
cnrm.cm5.1.rcp45	cnrm.cm5.1.rcp85
csiro.mk3.6.0.10.rcp45	csiro.mk3.6.0.10.rcp85
gfdl.esm2g.1.rcp45	gfdl.cm3.1.rcp85
gfdl.esm2m.1.rcp45	gfdl.esm2g.1.rcp85
inmcm4.1.rcp45	gfdl.esm2m.1.rcp85
ipsl.cm5a.lr.4.rcp45	inmcm4.1.rcp85
ipsl.cm5a.mr.1.rcp45	ipsl.cm5a.lr.4.rcp85
miroc.esm.1.rcp45	ipsl.cm5a.mr.1.rcp85
miroc.esm.chem.1.rcp45	miroc.esm.1.rcp85
miroc5.3.rcp45	miroc.esm.chem.1.rcp85
mpi.esm.lr.3.rcp45	miroc5.3.rcp85
mpi.esm.mr.3.rcp45	mpi.esm.lr.3.rcp85
mri.cgcm3.1.rcp45	mpi.esm.mr.1.rcp85
noresm1.m.1.rcp45	mri.cgcm3.1.rcp85

**Table 3.** Climate change data grid boundaries.

[Grid cell boundaries used to select the global circulation models used in the climate projections for each ecoregion]

<b>Ecoregion</b>	<b>Latitude bounds</b>	<b>Longitude bounds</b>
SGPE	38, 39	-101, -100
SSBPE	37, 38	-102, -101
MGPE	36, 37	-100, -99
SSOPE	33, 34	-104, -103

As with the weather data in demographic model fitting, we converted the daily climate projections into summarized climate covariates for use in the projection model. We produced covariates for the same time periods and using the same summaries used to produce the weather covariates (see section, “Weather Covariates”), retaining only the covariates selected for the modeled demographic rates (table 4).

**Table 4.** Climate covariates used in population projections (results from appendix D, covariate definitions in appendix B).

Demographic rate	Ecoregion			
	SGPE	SSBPE	MGPE	SSOPE
Nest success	NTemp <sup>1</sup>	NTemp <sup>1</sup>	WPrecip <sup>2</sup>	None
Brood success	BHotF2W <sup>3</sup>	BWet <sup>4</sup>	None	None
Summer survival	APrecip <sup>5</sup>	Scold <sup>6</sup>	WPrecip <sup>2</sup> , SWet <sup>7</sup>	STemp <sup>8</sup>

<sup>1</sup>Average nesting season maximum temperature.

<sup>2</sup>Total winter precipitation.

<sup>3</sup>Average maximum temperature during the first 2 weeks of the brooding season.

<sup>4</sup>Brooding season wet days.

<sup>5</sup>Total annual precipitation.

<sup>6</sup>Summer cold days.

<sup>7</sup>Summer wet days.

<sup>8</sup>Average summer maximum temperature.

## U.S. Fish and Wildlife Service (FWS) Habitat Projections

The future condition of habitat in the LEPC range was modeled (in a separate analysis by project cooperators at the FWS, FWS Habitat Projections) as the total area of suitable land cover in each ecoregion at a density high enough to support LEPCs. The density analysis was conducted for each patch of suitable land cover; a patch was considered habitat if 40% or more of the area within 1 mile of the center of the patch was also suitable land cover. Patches are the GIS polygons that result from the FWS’s land cover analysis, which classified the landscape into suitable or unsuitable categories based on land cover type and surrounding features that impact a location’s suitability. For each scenario (and multiple stochastic simulations of future landscapes within each scenario), areas of these habitat blocks were summed to determine the total habitat area in the present year (applied to 2016 and 2017 in the model projection) and in 2042, for each ecoregion.

The land cover makeup in each ecoregion was predicted based on scenarios concerning the level of habitat conservation and habitat loss that may occur in each ecoregion over the next 25 years. Habitat conservation actions included restoration, such as removal of woody vegetation, conversion of cropland to grassland, and removal of energy infrastructure. Habitat loss included mainly habitat impacts from future energy development (oil and gas extraction and wind power) and conversion to cropland, as well as encroachment of woody vegetation. Three levels of potential habitat conservation and habitat loss were projected: a high level of conservation, a continuation of conservation efforts at current levels, and a low level of conservation. Similarly, high, moderate, and low levels of habitat loss were considered. Five combinations of habitat conservation and habitat loss were selected to represent the range of potential future habitat conditions: a high habitat conservation/low habitat loss scenario, a low habitat conservation/high habitat loss scenario, a continuation of conservation/low habitat loss scenario, a continuation of conservation/moderate habitat loss scenario, and a continuation of conservation/high habitat loss scenario (table 5).

**Table 5.** Future scenarios.

[These scenarios are used to project LPC abundance within four ecoregions and from the present to the turn of the century (2016–2099) based on a stochastic population viability model (PVA). The PVA model directly incorporated weather variables based on two representative climate pathways (RCP) to represent plausible emission scenarios. A separate projection of available habitat incorporated levels of habitat conservation and habitat loss. Available habitat was translated into maximum density or carrying capacity, which was used as a density-dependent cap on population abundance within the PVA model]

PVA scenario	Factors		
	Habitat conservation	Habitat loss	Climate
A (Stationary)	None	None	None
B	High	Low	RCP 4.5
C	Continuation	Low	RCP 4.5
D4.5	Continuation	Middle	RCP 4.5
D8.5	Continuation	Middle	RCP 8.5
E	Continuation	High	RCP 8.5
F	Low	High	RCP 8.5

## Scenarios

The first of the seven scenarios (table 5) is a stationary scenario (Scenario A), in which there is no climate effect, and the habitat area remains constant through time. In effect, this results in a continuation of current climate conditions and habitat area into the future. To remove the projected climate change effect, we supply the mean weather covariate value, while still sampling from the posterior distributions for the intercept and annual variation. Because the weather effects were modeled using standardized covariate values, setting the weather covariates at their mean values is achieved by setting the weather covariate value equal to zero. Although the annual variation parameter ( $\sigma$ ) is retained in Scenario A, setting the weather covariate to its mean each year removes the annual variation associated with variation in weather from Scenario A.

The other six scenarios were chosen to represent the uncertainty in future climate forcing that drives climate change (see section, “Climate Predictions”), and habitat status resulting from conservation measures and habitat loss (see section, “FWS Habitat Projections”). The six scenarios bracket the range of expected conditions affecting LEPCs, from Scenario B with the largest expected habitat area and lower level of climate change, to Scenario F, with the smallest expected habitat area and greatest level of climate change (table 5). The intermediate scenarios represent additional likely scenarios and enable evaluation of the population impacts resulting from individual factors.

## Sensitivity Analyses

We evaluated the effect of changes in the demographic rates on the resulting projected rates of population change through a set of six sensitivity analyses. The first set of three sensitivity analyses accounted for the impact of potential biases in the demographic parameter estimates including (1) nesting rates, (2) brood sizes, and (3) the full set of demographic rates. Sensitivity analyses 1 and 2 were motivated by particular concerns about the quality of nesting rate and brood size information, while sensitivity analysis 3 was motivated by a desire to understand the highest possible population growth rates for LEPCs given reported demographic rates. For sensitivity analysis 1, we set the initial nesting rate equal to one and evaluated the resulting population growth rate ( $\lambda$ ) estimates. For sensitivity analysis 2, we adjusted the set of observed brood sizes in each ecoregion by a brood detection rate. Dahlgren and others (2010) estimated a walking flush count detection rate of 0.72 for greater sage-grouse (*Centrocercus urophasianus*), which we apply here to calculate a new set of brood size observations for sensitivity analysis 2 using equation 8:

$$\hat{B}_i = B_i/0.72 \quad (8)$$

where  $\hat{B}_i$  is the  $i$ th element in the set of adjusted brood sizes calculated from the  $i$ th element in the set of observed brood sizes  $B_i$ . As with sensitivity analysis 1, we report the resulting population growth rate ( $\lambda$ ) estimates from this adjustment to the brood size parameter. For sensitivity analysis 3, we selected the study with highest median estimate reported in the literature for each demographic rate (table 6) and used the mean and standard error from that study in our analysis. That is, if two studies estimated the nesting rate in the SGPE, we ran our model using the estimates from the study with the higher of the two median nesting rate estimates. Annual variation, that is, the  $\sigma$  parameters estimated in the nest success, brood success, and summer survival rates, were not included in sensitivity analysis 3. Apart from the changes described above for these analyses, the models were executed as described previously. These three sensitivity analyses were conducted using Scenario A, the continuation of current climate and habitat area scenario.



**Table 6.** Highest observed demographic rates (median  $\pm$  standard error) for sensitivity analysis 3.

[These rates were obtained by taking the median value from the single study which reported the highest median demographic rate estimate across the set of studies that evaluated that demographic rate]

Demographic rate	Ecoregion			
	SGPE	SSBPE	MGPE	SSOPE
$P_{n1}$	0.97 $\pm$ 0.06	0.92 $\pm$ 0.02	0.63 $\pm$ 0.09	1.00 $\pm$ 0.00
$P_{n2}$	0.09 $\pm$ 0.05	0.31 $\pm$ 0.04	0.14 $\pm$ 0.13	0.50 $\pm$ 0.20
$S_n$	0.54 $\pm$ 0.08	0.58 $\pm$ 0.12	0.67 $\pm$ 0.10	0.71 $\pm$ 0.09
$S_b$	0.60 $\pm$ 0.14	0.60 $\pm$ 0.14	0.60 $\pm$ 0.14	0.50 $\pm$ 0.13
$S_j$	0.56 $\pm$ 0.08	0.59 $\pm$ 0.09	0.72 $\pm$ 0.06	0.90 $\pm$ 0.06
$S_w$	0.67 $\pm$ 0.06	0.69 $\pm$ 0.07	0.79 $\pm$ 0.05	0.93 $\pm$ 0.04
$S_s$	0.58 $\pm$ 0.14	0.72 $\pm$ 0.04	0.66 $\pm$ 0.07	0.62 $\pm$ 0.15

In the fourth sensitivity analysis, we evaluated the impact of climate conditions on our model predictions. We replaced the projected climate covariate value (table 4), relevant to each demographic rate and ecoregion, with the most favorable observed covariate value from 1996 to 2016 as computed from the weather data. If the coefficient for the weather effect was negative, we selected the lowest observed value of the covariate, if the effect was positive we selected the highest observed value of the covariate. For example, NTemp was negatively related to nest success in the SGPE. Therefore 26.03 was used for every simulation and year for the NTemp covariate for this sensitivity analysis as it was the lowest average maximum daily temperature that was observed during the nesting period from 1996 to 2016. This sensitivity analysis included the fully stochastic model (aside from uncertainty and annual variation in climate conditions), under Scenario A.

The last two sensitivity analyses determined the demographic rates necessary to achieve target annual population growth rates ( $\lambda$ ) of 0.9, for sensitivity analysis 5, and 1.0, for sensitivity analysis 6, by changing a single demographic rate in the model while keeping the others constant at their median values. Sensitivity analysis 6 will provide the change to each demographic rate necessary to achieve a stable population size ( $\lambda$  of 1), while sensitivity analysis 5 will provide the change to each demographic rate that would result in a rate of decline similar to the estimates from the Garton and others (2016) and range-wide aerial survey (McDonald and others, 2016) analyses. Stochasticity was removed from the demographic model to produce a deterministic model for sensitivity analyses 5 and 6.

# Results

## Demographic Rates

We report the median value for each demographic rate from Scenario A (constant and invariable climate and habitat conditions) in each ecoregion (tables 7 and 8). The Mixed Grass Prairie Ecoregion (MGPE) had the lowest median nesting probability, 0.62 (95% CI = 0.45–0.77), and the Short Grass Prairie Ecoregion (SGPE) the highest, 0.97 (0.35–1.00). The median nesting probabilities in the Sand Sagebrush Prairie Ecoregion (SSBPE) and in the Sand Shinnery Oak Prairie Ecoregion (SSOPE) were 0.92 (0.87–0.95) and 0.71 (0.54–1.00), respectively. The median re-nesting rate following a failed first nest attempt ranged from 0.31 (0.24–0.39) in the SSBPE to 0.09 (0.03–0.26) in the SGPE. The median nest success probability (probability a nest hatches  $\geq 1$  chick) across ecoregions ranged from 0.28 in the MGPE (95% CI = 0.13–0.45) and SSOPE (95% CI = 0.13–0.47) to 0.41 (0.00–0.98) in the SGPE. There was a larger range in the median brood success values across ecoregions, with values of 0.31 (0.00–0.99) in the SGPE, 0.67 (0.07–0.96) in the SSBPE, 0.53 (0.00–0.99) in the MGPE, and 0.14 (0.00–0.78) in the SSOPE. The median brood sizes in the observed brood count data were 4.5 (1.0–7.10), 3.2 (1.3–5.0), 3.8 (1.0–7.0), and 2.3 (1.0–4.0) in the SGPE, SSBPE, MGPE, and SSOPE respectively. The median values of juvenile survival rate were 0.56 (0.41–0.70), 0.59 (0.41–0.75), 0.72 (0.58–0.82) and 0.61 (0.31–0.80) in the SGPE, SSBPE, MGPE, and SSOPE respectively. In combination we found that these rates result in median realized recruitment rates of 0.40 (0.01–1.17), 0.20 (0.03–0.58), 0.10 (0.02–0.39), and 0.02 (0.00–0.16) in the SGPE, SSBPE, MGPE, and SSOPE respectively. These median values correspond to an additional 0.02, in the SSOPE, to 0.40, in the SGPE, females joining the adult population per adult female per year.

The median winter survival rates were 0.67 (95% CI = 0.53–0.78), 0.69 (0.54–0.81), 0.79 (0.68–0.87), and 0.70 (0.43–0.85) in the SGPE, SSBPE, MGPE, and SSOPE respectively (table 7). In SSBPE, MGPE, and SSOPE, the median summer survival rate values of 0.74 (0.00–1.00), 0.64 (0.22–0.89), and 0.71 (0.45–0.88) were similar to corresponding winter survival rates (table 8). In contrast, the summer survival rate for SGPE was 0.32 (0.00–0.99), less than one-half the winter survival rate. For Scenario A, median annual realized adult survival rates were 0.21 (0.00–0.67), 0.50 (0.00–0.75), 0.50 (0.17–0.71), and 0.49 (0.26–0.67) in the SGPE, SSBPE, MGPE, and SSOPE respectively.

**Table 7.** Projected demographic rates derived from available literature.

[Nesting rate ( $P_{n1}$ ), re-nesting rate ( $P_{n2}$ ), juvenile survival ( $S_j$ ), winter survival ( $S_w$ ), Projected rates (median and standard error) resulting from Scenario A. The published demographic rate estimates from which these rates were derived are listed in appendix B]

Demographic rate	Ecoregion			
	SGPE	SSBPE	MGPE	SSOPE
$P_{n1}$	0.97 $\pm$ 0.16	0.92 $\pm$ 0.02	0.62 $\pm$ 0.08	0.71 $\pm$ 0.12
$P_{n2}$	0.09 $\pm$ 0.16	0.31 $\pm$ 0.02	0.14 $\pm$ 0.08	0.10 $\pm$ 0.12
$B$	4.5 $\pm$ 1.60	3.2 $\pm$ 0.94	3.8 $\pm$ 1.53	2.3 $\pm$ 0.77
$S_j$	0.56 $\pm$ 0.08	0.59 $\pm$ 0.08	0.72 $\pm$ 0.06	0.61 $\pm$ 0.12
$S_w$	0.67 $\pm$ 0.06	0.69 $\pm$ 0.07	0.79 $\pm$ 0.05	0.70 $\pm$ 0.11

**Table 8.** Projected demographic rates estimated by model fitting and comparison to other published demographic rate estimates.

[Nest success ( $S_n$ ), brood success ( $S_b$ ), brood size ( $B$ ), realized annual recruitment rate (recruits per female,  $R/F$ ), summer survival ( $S_s$ ), and realized annual adult survival rate (adult survivors per female,  $AS/F$ ). Projected rates (median and standard error) resulting from Scenario A are bolded. Standard case rates are the median estimates from previously published estimates (followed by their source) for the associated demographic rate. Brood size ( $B$ ) was not estimated from a model, but drawn directly from the set of observed brood sizes]

Demographic rate	Ecoregion			
	SGPE	SSBPE	MGPE	SSOPE
$S_n$	<b>0.41 ±0.25</b>	<b>0.29 ±0.17</b>	<b>0.28 ±0.08</b>	<b>0.28 ±0.09</b>
	0.30 Lautenbach, 2015	0.26 Pitman and others, 2005	0.36 Holt, 2012	0.22 Haukos, 1988
	0.54 Fields, 2004	0.29 Hagen and others, 2009	0.39 Lautenbach, 2015	0.24 Boal and others, 2014
		0.58 Lautenbach, 2015	0.62 Lyons and others, 2011	0.27 Davis and others, 1979
			0.67 Jones, 2009	0.28 Wisdom, 1980
				0.32 Merchant, 1982
				0.32 Fritts and others, 2016
				0.35 Smythe and Haukos, 2009
				0.37 Lyons and others, 2011
				0.43 Grisham and others, 2014
			0.45 Grisham, 2012	
			0.57 Grisham and others, 2013	
			0.71 Davis, 2009	
$S_b$	<b>0.31 ±0.25</b>	<b>0.67 ±0.23</b>	<b>0.53 ±0.25</b>	<b>0.14 ±0.20</b>
	0.35 Fields, 2004	0.34 Jamison, 2000	0.14 Holt, 2012	0.50 Davis, 2009
	0.22–0.60 Lautenbach, 2015	0.34 Pitman and others, 2006 0.22–0.60 Lautenbach, 2015	0.22–0.60 Lautenbach, 2015	
$R/F$	<b>0.40 ±0.30</b>	<b>0.20 ±0.14</b>	<b>0.10 ±0.10</b>	<b>0.02 ±0.04</b>
	0.59 Fields, 2004	0.15 Hagen and others, 2009	0.46–0.53	
	0.19 Sullins, 2017	0.55 Sullins, 2017	Sullins, 2017	
$S_s$	<b>0.32 ±0.25</b>	<b>0.74 ±0.25</b>	<b>0.64 ±0.17</b>	<b>0.71 ±0.11</b>
	0.36 Plumb, 2015	0.47 Plumb, 2015	0.53 Plumb, 2015	0.33–0.41 Meyers, 2016
	0.58 Fields, 2004	0.54 Hagen and others, 2007	0.55 Holt, 2012	0.48 Lyons and others, 2009
		0.72 Jamison, 2000	0.59 Toole, 2005	0.59 Haukos, 1988
			0.63 Jones, 2009	0.62 Strong, 2016
			0.66 Lyons and others, 2009	
$AS/F$	<b>0.21 ±0.17</b>	<b>0.50 ±0.19</b>	<b>0.50 ±0.14</b>	<b>0.49 ±0.11</b>
	0.44 Fields, 2004	0.30 Hagen and others, 2009	0.52 Jones, 2009	0.31 Lyons and others, 2009
	0.28 Sullins, 2017	0.44 Sullins, 2017	0.52 Lyons and others, 2009	0.66 Campbell, 1972
			0.43–0.48 Sullins, 2017	

## Abundances, Population Growth Rates, and Persistence Probabilities

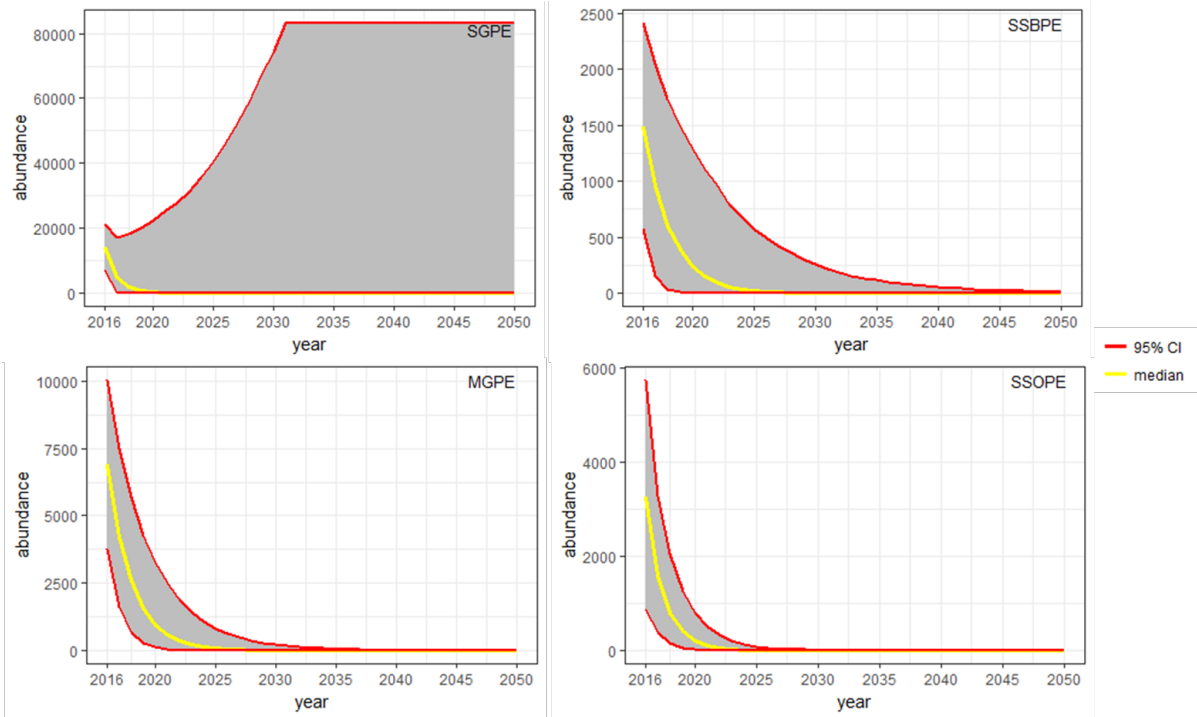
Under Scenario A, our model projected declining abundance in each ecoregion, with the SGPE declining most quickly, and the SSBPE declining least quickly (table 9). The median population growth rates from Scenario A were 0.37 (95% CI = 0.00–1.13), 0.69 (0.13–1.08), 0.63 (0.29–0.91), and 0.51 (0.27–0.72) in the SGPE, SSBPE, MGPE, and SSOPE, respectively. At these growth rates, the median abundance declined to zero by 2026, 2031, 2033, and 2028 in the SGPE, SSBPE, MGPE, and SSOPE (fig. 4). We evaluated the probability of persistence through time at three levels of abundance—> 0, (that is, the complement of ecoregional extinction), > 50 (the complement of a quasi-extinction threshold of 50 individuals) and > 500 (the complement of a quasi-extinction threshold of 500 individuals; fig. 5). By 2099 the probability of persistence in every ecoregion for all abundance levels is 0, with the exception of the SGPE where the persistence probability is 0.062. Although the SGPE has the lowest median  $\lambda$  value amongst the ecoregions, it also has the greatest uncertainty in projected abundance, likely due to the fewer years of demographic observations available in this ecoregion (appendix A, table A1) and the associated uncertainty in estimated demographic rates. At the growth rates projected here, populations in all ecoregions are expected to decline below 500 individuals in the near future, and no population has more than a 25% chance of persistence (abundance >0) by 2037.

Under these demographic conditions, the carrying capacity that results from a constant habitat area as calculated from the FWS Habitat Projections did not limit population growth in the MGPE or SSOPE in any simulations (fig. 6). In the other two ecoregions, very few simulations (3.94% and 0.04% of simulations for SGPE and SSBPE, respectively) reached the carrying capacity from the FWS analysis.

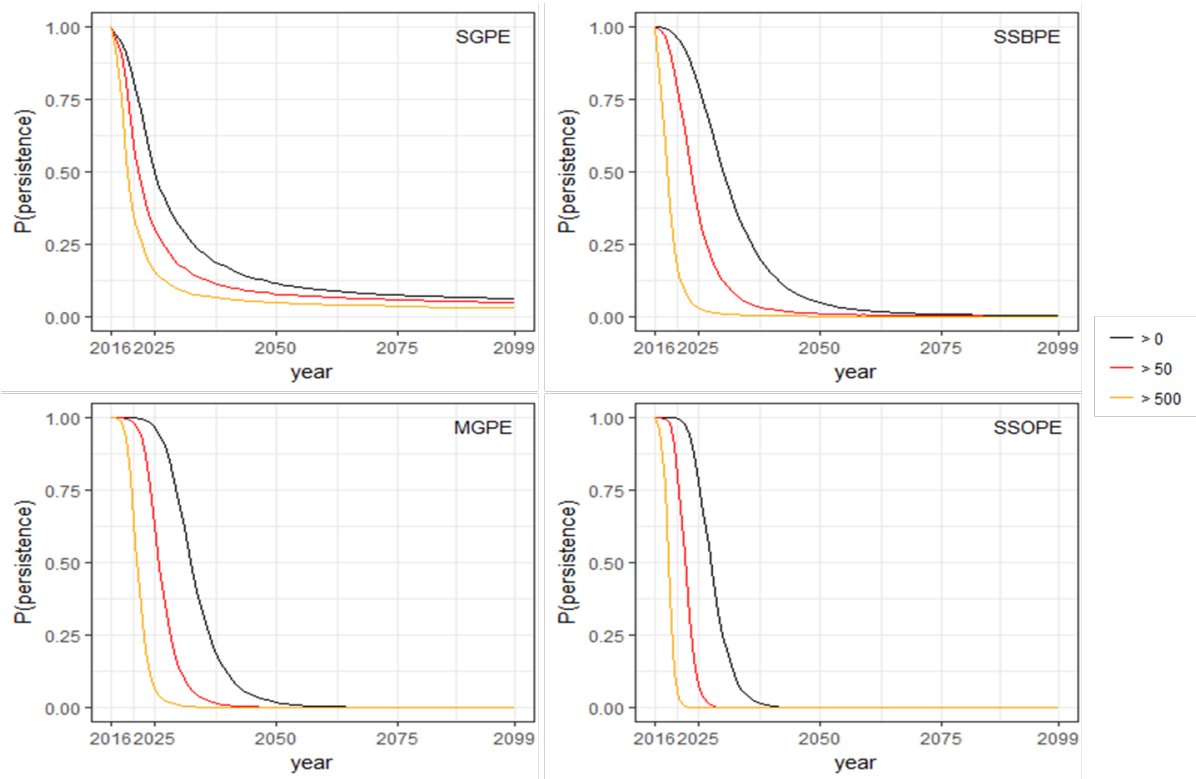
**Table 9.** Projected population growth rates and comparisons to other estimates (median and  $\pm$  standard error).

Source	Ecoregion			
	SGPE	SSBPE	MGPE	SSOPE
Scenario A	0.37 $\pm$ 0.29	0.69 $\pm$ 0.24	0.63 $\pm$ 0.16	0.51 $\pm$ 0.11
Sensitivity analysis 1	0.38 $\pm$ 0.30	0.71 $\pm$ 0.25	0.71 $\pm$ 0.25	0.52 $\pm$ 0.12
Sensitivity analysis 2	0.41 $\pm$ 0.36	0.76 $\pm$ 0.27	0.68 $\pm$ 0.18	0.53 $\pm$ 0.12
Sensitivity analysis 3	0.77 $\pm$ 0.17	0.83 $\pm$ 0.13	0.87 $\pm$ 0.12	0.99 $\pm$ 0.17
Sensitivity analysis 4	0.78 $\pm$ 0.48	0.92 $\pm$ 0.28	0.78 $\pm$ 0.25	0.67 $\pm$ 0.12
Published matrix models	0.61 Fields, 2004 0.58 $\pm$ 0.13 Sullins, 2017	0.54 $\pm$ 0.14 Hagen and others, 2009 0.74 $\pm$ 0.19 Hagen and others, 2009 0.79 $\pm$ 0.17 Sullins, 2017	0.83 $\pm$ 0.11 Sullins, 2017 0.79 $\pm$ 0.13 Sullins, 2017	NA
Lek counts (Garton and others, 2016)	1.02 $\pm$ 0.10	0.88 $\pm$ 0.10	0.83 $\pm$ 0.12	0.94 $\pm$ 0.13
Range-wide aerial survey (McDonald and others, 2016) <sup>1</sup>	0.90 $\pm$ 0.07	0.87 $\pm$ 0.09	0.91 $\pm$ 0.07	0.95 $\pm$ 0.12

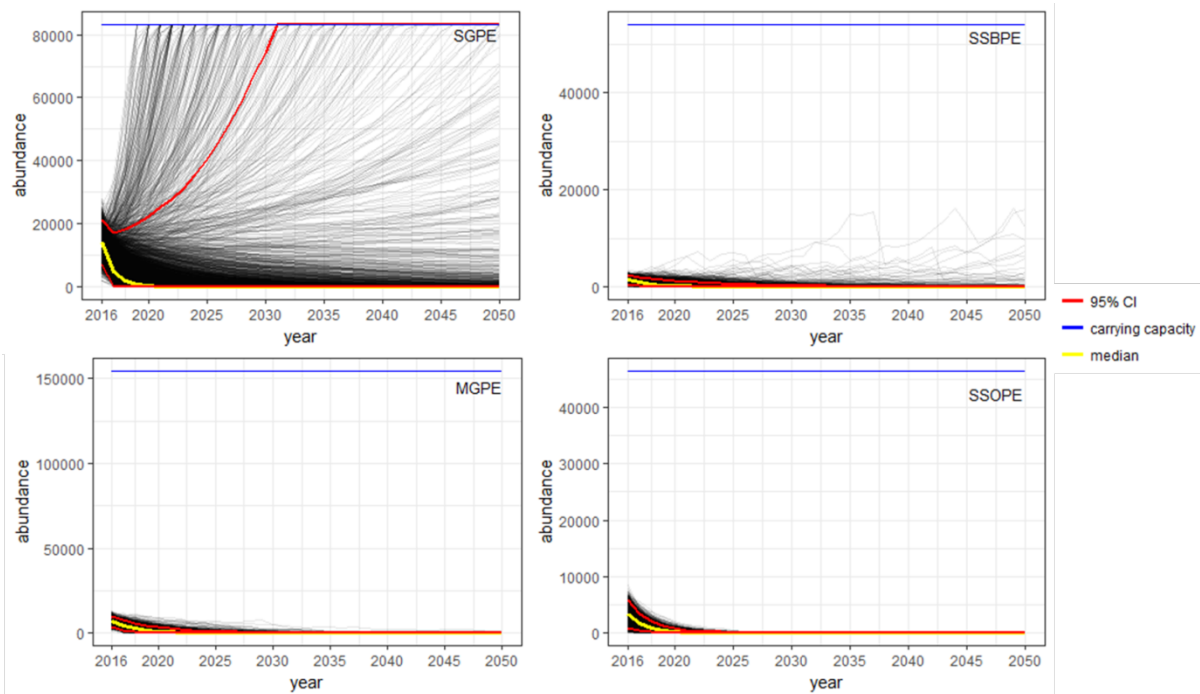
<sup>1</sup>The population growth rate was computed from the range-wide aerial survey abundance estimates as described in the range-wide aerial survey portion of the LEPC Projections section.



**Figure 4.** Median (yellow) and 95% credible interval (gray fill between red) abundance estimates through time for each ecoregion for the stationary scenario, Scenario A (see table 5). Note that the range of the y axis (abundance) differs for each ecoregion.



**Figure 5.** Probability of persistence at an abundance  $>0$  (that is, the complement of ecoregional extinction),  $>50$  (the complement of a quasi-extinction threshold of 50 individuals), and  $>500$  (the complement of a quasi-extinction threshold of 50 individuals) over time for each ecoregion for the stationary scenario, Scenario A (see table 5).



**Figure 6.** Trace plot of abundance trajectory from each simulation for the stationary scenario, Scenario A (see table 5), with carrying capacity abundance, median abundance, and 95% credible interval for abundance. Note that the range of the y axis (abundance) differs for each ecoregion.

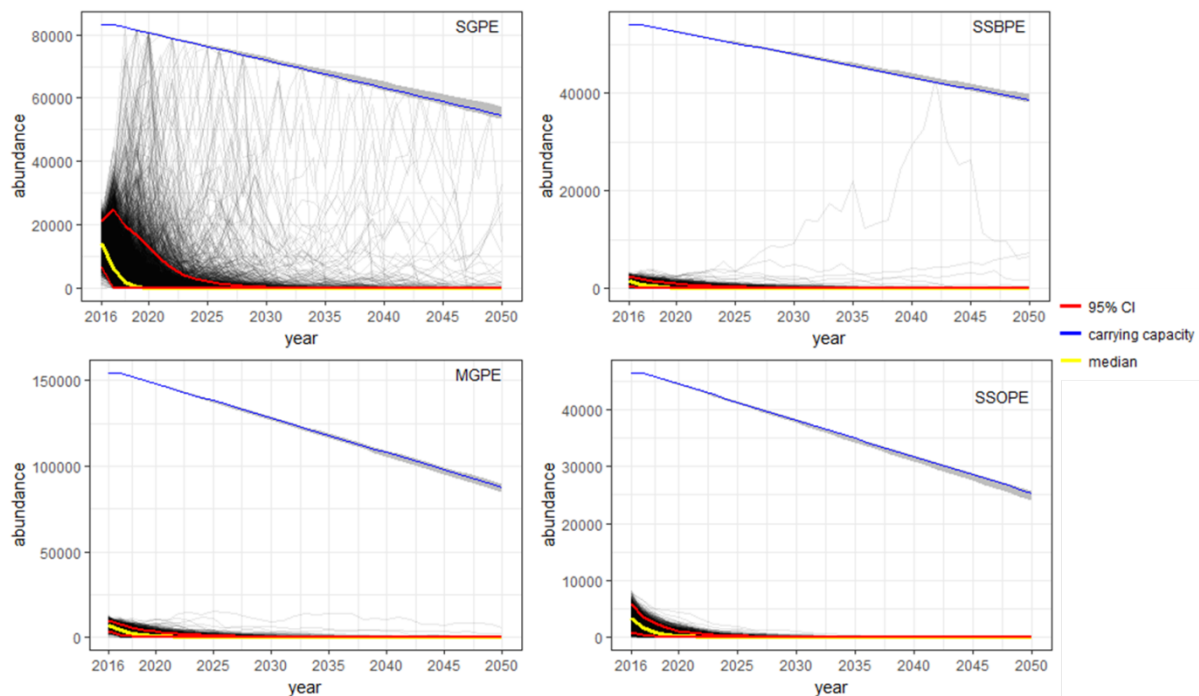
### Additional Population Growth Rates and Range-Wide Summary

Fields (2004), Hagen and others (2009), and Sullins (2017) produced matrix model estimates of LEPC population growth rates (table 9). Fields (2004) and Sullins (2017) estimated growth rates of 0.61 and 0.58 at sites in the SGPE. In the SSBPE, Hagen and others (2009) estimated growth rates of 0.54 and 0.74 at two sites, and Sullins (2017) estimated a growth rate of 0.79 across two sites. Sullins (2017) also estimated growth rates of 0.83 and 0.79 at two sites in the MGPE. Garton and others (2016) reconstructed population estimates from LEPC lek counts, producing population growth rate estimates for the 2005–2012 time period for each ecoregion (table 9). The population growth rates were 1.02, 0.88, 0.83, and 0.94 for the SGPE, SSBPE, MGPE, and SSOPE, respectively. The calculated growth rates from the range-wide aerial survey were 0.90 (95% CI = 0.76–1.05; probability of decline = 0.924), 0.87 (0.69–1.04; 0.94), 0.91 (0.78–1.07; 0.88), and 0.95 (0.73–1.19; 0.71) in the SGPE, SSBPE, MGPE, and SSOPE from 2012 to 2016 (table 9).

When the median  $\lambda$  estimates from individual ecoregions were projected forward for 1 year from the initial abundance in each ecoregion, our demographic model-based range-wide  $\lambda$  estimate under Scenario A was 0.48, while the Garton and others (2016) model produced a range-wide  $\lambda$  estimate of 0.95, and calculations of growth rate from the range-wide aerial survey produced a range-wide  $\lambda$  estimate of 0.91.

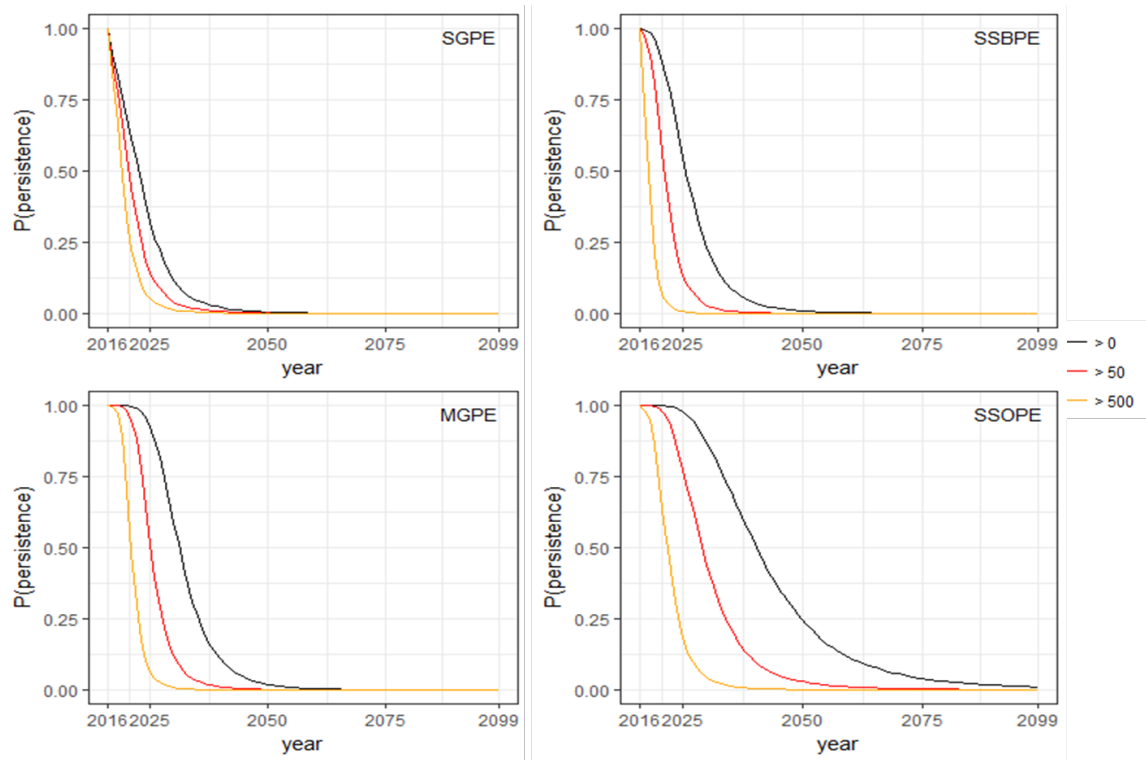
## Scenario Analyses

The result from Scenario A indicated that carrying capacity, as estimated based on the FWS Habitat Projections of land cover, plays a very limited role in projected abundances. Given the limited role carrying capacity played in Scenario A, we focus on the relative effect of climate change (Scenarios D4.5 and D8.5) and the effect of the scenario resulting in the lowest carrying capacity (Scenario F), in our reporting of scenario analyses results. The median population growth rates in Scenarios D4.5 and D8.5 were very similar, with  $\lambda$  rates of 0.45 (SE  $\pm$ 0.40, 95% CI = 0.00–1.58), 0.62 (SE  $\pm$ 0.25, 0.06–1.03), 0.61 (SE  $\pm$ 0.18, 0.23–0.92), and 0.53 (SE  $\pm$ 0.14, 0.21–0.78) for Scenario D4.5 and 0.49 (SE  $\pm$ 0.41, 0.00–1.62), 0.60 (SE  $\pm$ 0.25, 0.06–1.04), 0.61 (SE  $\pm$ 0.17, 0.23–0.92), and 0.54 (SE  $\pm$ 0.14, 0.21–0.78) for Scenario D8.5, in the SGPE, SSBPE, MGPE, and SSOPE, respectively. Scenario F, in which a low level of conservation occurs, a high level of habitat loss occurs, and climate change effects reflect the higher level of climate forcing from RCP8.5, presents the most challenging scenario to LEPC. In this scenario, abundance was less limited by carrying capacity than in Scenario A with 0 simulations for the SSBPE, 0 for the MGPE, 0 for the SSOPE ecoregions, and only 0.06% of SGPE simulations (fig. 7) reaching the carrying capacity abundance. Climate effects drove this change in SGPE abundances from Scenario A to Scenario F, as well as the changes to the persistence probabilities in the other ecoregions, nearly completely nullifying the reduction in carrying capacity from Scenario A to Scenario F. With this level of climate change, the population in the SGPE was expected to no longer persist by 2060, while the SSBPE persistence probability was also reduced (fig. 8) compared to the prediction for Scenario A. Under forecasted climate change for the weather variables selected, populations in the MGPE and SSOPE were projected to improve (fig. 8) compared to the prediction for Scenario A.



**Figure 7.** Trace plot of abundance trajectory from each simulation for Scenario F (see table 5), with carrying capacity abundance, median abundance, and 95% credible interval for abundance. Note that the range of the y axis (abundance) differs for each ecoregion.





**Figure 8.** Probability of persistence at an abundance  $>0$  (that is, the complement of ecoregional extinction),  $>50$  (the complement of a quasi-extinction threshold of 50 individuals), and  $>500$  (the complement of a quasi-extinction threshold of 500 individuals) over time for each ecoregion for Scenario F (see table 5).

## Sensitivity Analyses

Increasing the nesting rate in sensitivity analysis 1 resulted in slight increases in the estimated population growth rates, increasing them to 0.38 (2.7% increase, 95% CI = 0.00–1.17), 0.71 (2.5%, 0.15–1.11), 0.71 (13.0%, 0.33–1.07), and 0.52 (2.0%, 0.29–0.75) for the SGPE, SSBPE, MGPE, and SSOPE, respectively (table 9), compared to Scenario A. Increasing the brood size by adjusting for a detection rate of 0.72 in sensitivity analysis 2 resulted in increases in growth rates to 0.41 (10.7%, 0.00–1.40), 0.76 (9.9%, 0.17–1.24), 0.68 (7.3%, 0.32–1.03), and 0.53 (3.3%, 0.29–0.76) in the SGPE, SSBPE, MGPE, and SSOPE, respectively (table 9). Using the highest observed median demographic rates from previously published sources in sensitivity analysis 3 increased the  $\lambda$  values to 0.77 (105.2%, 0.45–1.10), 0.83 (18.9%, 0.60–1.11), 0.87 (38.0%, 0.64–1.13), and 0.99 (91.6%, 0.65–1.31). Finally, in sensitivity analysis 4, using the best observed weather conditions as predictors,  $\lambda$  values increased to 0.78 (110.0%, 0.00–1.88), 0.92 (32.0%, 0.23–1.33), 0.78 (24.2%, 0.42–1.12), and 0.67 (30.1%, 0.41–0.86) in the SGPE, SSBPE, MGPE, and SSOPE, respectively. None of these four sensitivity analyses altered the median population growth rates sufficiently to result in stable or growing populations as all estimates of  $\lambda$  were  $<1.00$ , however the best demographic rates observed in the SSOPE resulted in a nearly stable population growth rate of 0.99.

Removing stochasticity and keeping the remaining demographic rates constant while increasing a single rate failed to achieve population growth rates equal to 0.9 for sensitivity analysis 5 or 1.0 for sensitivity analysis 6 in most cases (table 10). Only the brood size ( $B$ ), recruitment rates ( $R/F$ ) or adult survival ( $AS/F$ ) rates can be sufficiently increased to result in a population growth rate of 1.0, to achieve a stable population growth rate. However, some of the brood sizes required exceed reported clutch sizes of LEPC (average of 10 to 12, Boal and Haukos, 2016), as the brood sizes necessary to achieve a population growth rate of 1.0 were 22.00, 7.37, 13.56, and 55.28 in the SGPE, SSBPE, MGPE, and SSOPE, respectively. The overall recruitment rates would need to be increased to between 2.5 to 25-fold, to values of 0.79, 0.49, 0.50, and 0.50, and the adult survival rates would need to be increased to values of 0.82, 0.80, 0.87, and 0.98 in the SGPE, SSBPE, MGPE, and SSOPE, respectively, to achieve a population growth rate 1.0.

## Discussion

We built a LEPC population viability model to integrate available data and evaluate the future trajectory of LEPC across four ecoregions. Our model has elements critical to meeting information needs of the FWS's SSA, including projection of climate impacts on LEPC demographic rates, as well as the implications of land-cover projections (produced from habitat conservation and habitat loss projections, FWS Habitat Projections) as a limit to LEPC growth. Our model also produces independent projections for each of the four LEPC ecoregions. The model is based on published data and studies, and it is structured in a similar manner to previous LPC modeling efforts (Fields, 2004; Hagen and others, 2009; Godar, 2016; Griffin, 2016; Sullins, 2017). Fields (2004) and Hagen and others (2009) also estimated the population growth rate of LEPC populations, but did not use those estimates to project future abundance. Each study also only reported estimates in one ecoregion. Garton and others (2016) projected past population growth rates into the future in each ecoregion, but as with the Fields (2004) and Hagen and others (2009) results, they do not account for changing climate or habitat conditions into the future. More recent projections from Godar (2016) and Griffin (2016) make projections from demographic rates that account for climate change in each ecoregion, but these projections did not account for the changes in habitat that are accounted for here, and used different modeling structure including the use of a Poisson distribution on brood size that sometimes resulted in unreasonably high and biologically unachievable reproductive rates.

**Table 10.** Demographic rates required to achieve target population growth rates in sensitivity analysis 5 ( $\lambda = 0.9$ ) and 6 ( $\lambda = 1.0$ ).

[When the target  $\lambda$  values are unachievable, the  $\lambda$  resulting from the maximum value for the rate is reported in the rightmost column. The median  $\lambda$  from Scenario A for each ecoregion was: 0.37, 0.69, 0.63, and 0.51]

Demographic rate	Ecoregion	Sensitivity Analysis 5 ( $\lambda = 0.9$ )	Sensitivity Analysis 6 ( $\lambda = 1.0$ )	Maximum value (and resulting $\lambda$ )
Nesting Rate ( $P_{n1}$ )	SGPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.42$ )
	SSBPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.72$ )
	MGPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.70$ )
	SSOPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.54$ )
Re-nesting Rate ( $P_{n2}$ )	SGPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.52$ )
	SSBPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.78$ )
	MGPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.69$ )
	SSOPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.54$ )
Nest Success ( $S_n$ )	SGPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.68$ )
	SSBPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.86$ )
	MGPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.90$ )
	SSOPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.59$ )
Brood Success ( $S_b$ )	SGPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.81$ )
	SSBPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.80$ )
	MGPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.74$ )
	SSOPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.69$ )
Brood Size ( $B$ )	SGPE	19.20	22.00	
	SSBPE	5.86	7.37	
	MGPE	10.86	13.56	
	SSOPE	44.29	55.28	
Juvenile Survival ( $S_j$ )	SGPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.57$ )
	SSBPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.84$ )
	MGPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.67$ )
	SSOPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.54$ )
Realized Recruitment Rate ( $R/F$ )	SGPE	0.69	0.79	
	SSBPE	0.39	0.49	
	MGPE	0.40	0.50	
	SSOPE	0.40	0.50	
Winter Survival ( $S_w$ )	SGPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.54$ )
	SSBPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.93$ )
	MGPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.75$ )
	SSOPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.74$ )
Summer Survival ( $S_s$ )	SGPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.85$ )
	SSBPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.88$ )
	MGPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.91$ )
	SSOPE	Unachievable	Unachievable	1.0 ( $\lambda = 0.73$ )
Realized Adult Survival ( $AS/F$ )	SGPE	0.72	0.82	
	SSBPE	0.70	0.80	
	MGPE	0.77	0.87	
	SSOPE	0.88	0.98	

It is important to consider the assumptions and limitations associated with any modeling effort and to view results as only one source of evidence when considering the status of a species. As an empirically based projection of LEPC abundance, one of the key assumptions is that the data available are representative. It is possible that studies of LEPC demographic rates have not occurred at random locations or at random times. As such, it is possible that the levels of habitat quality—and therefore demographic rates—at those locations do not represent the habitat quality experienced by LEPC in other locations. Sensitivity analysis 3 allows for a partial evaluation of this issue by using the highest reported demographic rates for the species. If the higher estimates of demographic rates used in sensitivity analysis 3 result from higher habitat quality, increases in habitat quality would result in improvement to LEPC growth rates. The rates from sensitivity analysis 3 did not result in stable or growing median population estimates, indicating that all possible combinations of available demographic rate estimates result in a likely decline in LEPC populations. However, stable or growing populations cannot be ruled out as the upper 95% credible intervals on the  $\lambda$  estimates in sensitivity analysis 3 exceed 1 (1.10, 1.11, 1.13, and 1.31 in the SGPE, SSBPE, MGPE, and SSOPE). It is also possible that the years during which demographic rate studies occurred are not representative of the demographic rates occurring in unobserved years. As LEPC annual abundance fluctuations have been suggested to be closely tied to weather conditions (Haukos and Zavaleta, 2016), if studies occurred following drought years or failed to capture years of population booms or busts, then the observed rates could differ from long-term averages. In addition to sensitivity analysis 3, sensitivity analysis 4 evaluates the impacts of some factors suggested to contribute to the potential effects of non-representative observation years, with sensitivity analysis 4 specifically assessing the role of weather conditions. The results of sensitivity analysis 4 indicate that annual variation influences the growth rate of LEPCs. However, based on the modeled effect of weather on demographic rates, the best weather conditions in the past 20 years were insufficient to create stable or positive growth rates (table 9), but again without ruling out stable or growing population size in all but the SSOPE (upper 95% credible intervals on the  $\lambda$  estimates 1.88, 1.33, 1.12, and 0.86 in the SGPE, SSBPE, MGPE, and SSOPE).

It is also possible that observed nesting rates and brood sizes are not representative because nesting females and broods are often difficult to observe, which could lead to underestimates of nesting rates and brood sizes due to imperfect detection. While no assessments of nest detection or brood detection in LEPCs have occurred, we evaluated the effects that underestimated nesting rates and brood sizes could have through sensitivity analysis, applying detection rate estimates from greater sage-grouse, which has a similar life history and ecological setting to LEPC. The higher nesting rate and brood sizes evaluated in sensitivity analyses 1 and 2 resulted in minor increases in the LEPC growth rates with resulting growth rates well less than 1.0 (table 9).

Sample sizes in the data available on LEPC demography varied considerably (table A1). Many observations contributed to some demographic rates: at the high end, 391 individual birds were available to estimate summer survival in the SSOPE, while very few observations contributed to others, for example, only 26 observations contributed to the estimate of brood success in the SSOPE. The number of years over which observations occurred also varied, from a high of 12 years for some SSOPE rates to a low of 3 for the SGPE rates. This range of years in available data contributed to the range of uncertainty in the estimates of demographic rates, and the relatively greater uncertainty in the SGPE.

The small sample sizes and limited durations of some of these observations resulted in a high degree of model selection uncertainty for some of the demographic rates (appendix D, AIC<sub>c</sub> tables). Across all ecoregions, no top-ranked model received >26% model weight, and the number of plausible models ( $\Delta AIC_c \leq 2$ ) ranged from 4 to 13 models across the set of modeled demographic rates, indicating multiple plausible weather covariates that correlate closely with a given demographic rate. In all cases, we made inference from the top models (for a demographic rate within an ecoregion) only.

One additional limitation specific to Scenario A was the lack of annual variation in the weather component of the demographic rate projection. We did not obtain a projection of climate conditions under current climate forcing conditions, so we were not able to project current weather patterns into the future in a manner that accounts for daily and annual variation in weather conditions. This limits our ability to directly compare Scenario A to Scenarios B to F. The exclusion of annual variability in weather covariates likely produced slightly more optimistic projections under Scenario A than would result from the inclusion of annual variability in weather covariates, because increasing stochasticity increases a population's risk of extinction.

## **Lesser Prairie-Chicken (LEPC) Projections**

The results reported here are one line of evidence among many about the possible future status of LEPC. Many analyses of individual demographic rates have occurred in the past, providing multiple lines of evidence about LEPC populations. Many of those studies were incorporated directly into our projections (appendix B) through inclusion in the literature-based demographic rates or through the use of the observations collected in those studies (appendix A). The previous studies of nest success, brood success, and summer survival rates are consistent with the rates reported here, and the rates reported here typically fall within the range of other studies (table 8).

Our overall growth rates appear likely to be unrealistically low. Given the length of time that has elapsed since the data were collected, if the growth rates were accurate, these populations would likely be extinct now. The exact reasons for the low growth rates projected by demographic process models are not clear, but reason suggests they are due to unrepresentative data. As noted in the discussion of the sensitivity analyses, one possibility is that LEPC have boom and bust years or source and sink populations, and relatively few boom years or source populations are represented. Another possibility resulting in unrepresentative data is that imperfect detection is not fully accounted for in estimates of brood sizes or clutch survival rates. While the exact growth rates we estimated are likely to be overly pessimistic, there are multiple lines of evidence indicating that the species is declining.

In addition to our results, a second line of evidence comes from other population modeling efforts. Three previous studies combined demographic rates for LEPC in a related manner, two for sites in single ecoregions and one for sites from three ecoregions. Fields (2004) estimated a population growth rate ( $\lambda$ ) of 0.61 in the SGPE, also suggesting a markedly declining population, but at a slower rate than suggested by the population growth rate of 0.37 we estimated for the SGPE. Hagen and others (2009) estimated a population growth rate at two sites in the SSBPE estimating  $\lambda$  values of 0.54 and 0.74, which when combined would indicate a slightly more rapid decline in population size than our estimate of 0.69. Sullins (2017) estimated a population growth rate of 0.58 in the SGPE, 0.79 in the SSBPE, and 0.83 and 0.79 at two sites in the MGPE.

A third line of evidence is provided by studies that estimate population growth rates not from demographic rate analyses of female productivity and survival, but from counts of individuals. Two datasets are available to produce estimates of population growth rates from LEPC counts—counts at LEPC leks, and the range-wide aerial survey. Garton and others (2016) reconstructed population estimates from LEPC lek counts, producing population growth rate estimates for the 2005 to 2012 time period for each ecoregion. The population growth rates were 1.02, 0.88, 0.83, and 0.94 for the SGPE, SSBPE, MGPE, and SSOPE, respectively. These results indicate declining populations in all but the SGPE, but at substantially slower rates than indicated by our results. These lek-based estimates, which predominantly count males, may differ from the growth rates derived from (female-based) demographic process models due to the differences in male and female survival, and, importantly, due to the information content of lek surveys. Lek attendance and detection rates may differ by year (Blomberg and others, 2013; Sadoti and others, 2016), date, or time of observation (Walsh and others, 2004; Johnson and Rowland, 2007; Monroe and others, 2016) environmental conditions (Sadoti and

others, 2016) and observer (Johnson and Rowland, 2007), which can lead to inaccuracies in lek-based analyses (Walsh and others, 2004, 2010; Blomberg and others, 2013). The lek sampling design is also not a random sample of locations on the landscape (Johnson and Rowland, 2007; Timmer and others, 2013), and regularly counted leks may constitute “core” leks where attendance will respond relatively slowly to population declines.

To avoid some of the potential sources of inaccuracy in lek counts, aerial surveys have been conducted since 2012, using distance sampling to estimate LEPC density and abundance in each ecoregion. Resulting population growth rates, calculated from reported abundance as described in Additional Calculated and Reported Population Growth Rates, were 0.90, 0.87, 0.91, and 0.95 in the SGPE, SSBPE, MGPE, and SSOPE from 2012 to 2016. The range-wide aerial survey data represent a random sample of the landscape and account for detection probabilities, but the detections may be mostly associated with leks (which are predominantly populated by males and where birds are relatively more detectable), so may still be subject to influence from variation in lek attendance rates and any differential trends in the male and female components of the population. In addition, these growth rate estimates are based on a relatively short-term dataset, and therefore, are likely sensitive to the starting and ending year abundance estimates.

All available information on population trends is reliant on past data. Changes in habitat quality or quantity in the future could change the situation for LEPC. The FWS is evaluating potential changes in future habitat conditions (FWS Habitat Projection), and we expect that will be discussed in their upcoming SSA report.

## **Next Steps**

Based on the potential limitations discussed above and the results of the sensitivity analyses, additional research and monitoring have the potential to substantially improve understanding of LEPC populations. Longer population studies, if undertaken at random locations across the landscape, would help to ensure a more representative dataset for demographic estimation. Such data might result in a change in overall estimated demographic rates or, barring that, would increase confidence that the currently available rates are robust. Longer studies would better account for fluctuations in productivity present in LEPCs. In particular demographic rate estimates for the SGPE were based on fewer years of data than in other ecoregions, resulting in substantial uncertainty in the estimated demographic rates (and resulting population growth rates). The sample sizes for brood counts in each ecoregion also are quite small. Increasing the sample sizes may provide enough data to model the effect of weather conditions on brood size (or per-bird brood survival).

An integrated population model (IPM) could better integrate multiple lines of evidence into one framework, including both demographic rate observations and counts, and allow for an integrated estimation and projection tool (for example, Besbeas and others, 2002; Schaub and Abadi, 2011). It would further be possible to use a spatially explicit IPM that could account for variation in habitat conditions and habitat quality in population projections.

We only evaluated logit-linear effects of weather conditions on demographic rates. It is possible that non-linear models would better account for the influence of weather conditions on demographic rates (for example, quadratic models). Furthermore, future demographic studies could focus on additional factors hypothesized to influence demography, such as habitat quality or management actions, but this is likely to require observation over relatively large spatial or temporal scales.

## Summary

The results reported here, as well as other estimates of LEPC population growth rates, indicate that LEPC are in decline (table 9). Our results found that the SGPE had relative similar demographic rates to the other ecoregions with the exception of brood success, and in particular summer survival, which was one-half of the next lowest summer survival rates in the other ecoregions, leading to an annual adult survival of less than one-half that of the next highest ecoregion. This led to the lower population growth rate estimate in this ecoregion, which also drives the low range-wide estimate of population growth rate due to the larger initial abundance in this ecoregion. Although the SGPE has the lowest estimated median population growth rate from our analysis, this rate is the least certain among the four ecoregions ( $\lambda = 0.37$ , 95% CI = 0.00–1.13 for Scenario A), due to the high degree of uncertainty in the summer survival rate and other demographic rates in this ecoregion. Matrix model studies with estimates of population growth rates in the SGPE have also produced rates indicating substantial decline ( $\lambda = 0.61$  from Fields, 2004;  $\lambda = 0.58$  from Sullins, 2017). The range-wide aerial survey (McDonald and others, 2016) also indicated a decline, although a lesser one ( $\lambda = 0.90$ ), while the Garton (2016) estimate indicated a very slight increase ( $\lambda = 1.02$ ).

Other ecoregions also have population growth rates indicating decline, with relatively less uncertainty than in the SGPE, but in many instances results indicate some likelihood the ecoregions may be stable or increasing. In our analysis the 95% CI for  $\lambda$  extended above 1 ( $\lambda = 0.69$ , 95% CI = 0.13–1.08) for the SSBPE under Scenario A, but not for the MGPE ( $\lambda = 0.63$ , 95% CI = 0.29–0.91) and SSOPE ( $\lambda = 0.51$ , 95% CI = 0.27–0.72). The 95% CI on  $\lambda$  extended beyond 1 for all sensitivity analyses in the SGPE, SSBPE, and MGPE, but only in sensitivity analysis 3 for the SSOPE. Matrix model studies (Hagen and others, 2009; Sullins, 2017) for the SSBPE and MGPE have also produced rates indicating decline ranging from slightly more to slightly less rapid than our results (table 9). The range-wide aerial survey (McDonald and others, 2016) and Garton (2016) estimates also indicate declines in the SSBPE, MGPE, and SSOPE of less substantial magnitude than our results indicated.

Across all ecoregions, our demographic projection model estimated  $\lambda$  at 0.48, while the study by Garton and others (2016) indicated a  $\lambda$  value of 0.95, and calculations of growth rate from the range-wide aerial survey produced a  $\lambda$  estimate of 0.91. Therefore, although there is substantial uncertainty about the magnitude of population decline, and whether the demographic rate studies are overestimating declines, all lines of evidence indicate some degree of range-wide decline.

## Acknowledgments

The work described in this report would not be possible without the extraordinary efforts of the numerous field biologists, data managers, and analysts who have studied lesser prairie-chickens over the years. In particular, we acknowledge Alixandra Godar, Cody Griffin, Blake Grisham, Sarah Fritts, and Daniel Greene at Texas Tech University for their input on LEPC biology and for providing the data necessary for this work. They either directly collected this data or passed on data graciously provided to them and thereby to us by Christian Hagen, Jim Pitman, Dave Haukos and his students Joseph Lautenback, Reid Plumb, and Samantha Robinson, and the Sutton Avian Research Center. This work has also benefitted from conversations with the LEPC SSA Working Group (G. Beauprez, C. Boal, K. Fricke, S Fuhlendorf, C. Hagen, D. Haukos, A. Janus, M. Patten, J. Pitman, L. Rossi, and B. Simpson). We are grateful to Beth Ross and Dan Walsh, who carefully reviewed this report and offered suggestions that have improved it substantially. We also thank the FWS's LEPC team members, Jim Dick, Mike Dick, Caitlin Snyder, Jennifer Davis, Kevin Burgess, and Patricia Echo-Hawk for their contributions to the LEPC Species Status Assessment.

## References Cited

- Akaike, H., 1974, A new look at the statistical model identification: *IEEE Transactions on Automatic Control*, v. 19, no. 6, p. 716–723.
- Aldrich, J.W., 1963, Geographic orientation of American tetraonidae: *Journal of Wildlife Management*, v. 27, p. 529–545.
- Bartuszevige, A.M., and Daniels, A., 2016, Impacts of energy development, anthropogenic structures, and land use change on lesser prairie-chickens, *in* Haukos, D.A., and Boal, C.W., eds., *Ecology and conservation of lesser prairie-chickens*: Boca Raton, Florida, CRC Press, Studies in Avian Biology series, no. 48, p. 205–220.
- Besbeas, P., Freeman, S.N., Morgan, B.J.T., and Catchpole, E.A., 2002, Integrating mark–recapture–recovery and census data to estimate animal abundance and demographic parameters: *Biometrics*, v. 58, p. 540–547.
- Blomberg, E.J., Sedinger, J.S., Nonne, D.V., and Atamian, M.T., 2013, Annual male lek attendance influences count-based population indices of greater sage-grouse: *Journal of Wildlife Management*, v. 77, p. 1,583–1,592.
- Boal, C.W., Borsdorf, P.K., and Gicklhorn, T., 2014, Assessment of lesser prairie-chicken use of wildlife water guzzlers: *Bulletin of the Texas Ornithological Society*, v. 46, p. 10–18.
- Boal, C.W., and Haukos, D.A., 2016, The lesser prairie-chicken—A brief introduction to the grouse of the southern Great Plains, *in* Haukos, D.A., and Boal, C.W., eds., *Ecology and conservation of lesser prairie-chickens*: Boca Raton, Florida, CRC Press, Studies in Avian Biology series, no. 48, p. 1–11.
- Burnham, K.P., and Anderson, D.R., 2002, *Model selection and multimodel inference a practical information-theoretic approach* (2d ed.): New York, Springer-Verlag.
- Campbell, H., 1972, A population study of lesser prairie chickens in New Mexico: *Journal of Wildlife Management*, v. 45, p. 776–778.
- Dahlgren, D.K., Messmer, T.A., Thacker, E.T., and Guttery, M.R., 2010, Evaluation of brood detection techniques—Recommendations for estimating greater sage-grouse productivity: *Western North American Naturalist*, v. 70, no. 2, p. 233–237.
- Davis, C.A., Riley, T.Z., Suminski, H.R., and Wisdom, M.J., 1979, Habitat evaluation of lesser prairie chickens in eastern Chaves County, New Mexico: Final Report to Bureau of Land Management, Roswell, New Mexico, Contract YA-512-CT6-61, prepared by Department of Fishery and Wildlife Sciences, New Mexico State University, Las Cruces.
- Davis, D.M., 2009, Nesting ecology and reproductive success of lesser prairie-chickens in sand shinnery oak-dominated rangelands: *Wilson Journal of Ornithology*, v. 121, p. 322–327.
- Dinsmore, S.J., White, G.C., and Knopf, F.L., 2002, Advanced techniques for modeling avian nest survival: *Ecology*, v. 83, no. 12, p. 3,476–3,488.
- Fields, T.L., 2004, Breeding season habitat use of conservation reserve program (CRP) land by lesser prairie-chickens in west central Kansas: Fort Collins, Colorado State University, M.S. thesis.
- Fritts, S.R., Grisham, B.A., Haukos, D.A., Boal, C.W., Patten, M.A., Wolfe, D.H., Dixon, C.E., Cox, R.D., and Heck, W.R., 2016: Long-term lesser prairie-chicken nest ecology in response to grassland management: *Journal of Wildlife Management*, v. 80, no. 3, p. 527–539.
- Garton, E.O., Hagen, C.A., Beauprez, G.M., Kyle, S.C., Pitman, J.C., Schoeling, D.D., and Van Pelt, W.E., 2016, Population dynamics of the lesser prairie-chicken, *in* Haukos, D.A., and Boal, C.W., eds., *Ecology and conservation of lesser prairie-chickens*: Boca Raton, Florida, CRC Press, Studies in Avian Biology series, no. 48, p. 49–76.
- Giesen, K.M., 1998, Lesser prairie-chicken (*Tympanuchus Pallidicinctus*)—The birds of North America: Philadelphia, Academy of Natural Sciences, no. 364, 20 p.



- Giesen, K.M., 2000, Population status and management of lesser prairie-chicken in Colorado: The Prairie Naturalist, v. 32, no. 3, 137–148.
- Godar, A.J., 2016, Influence of climate change and land use on lesser prairie-chicken (*Tympanuchus pallidicinctus*) population persistence in the sand sagebush and short-grass prairies: Lubbock, Texas Tech University, M.S. thesis.
- Griffin, C., 2016, The influence of environmental and landscape variables on lesser prairie-chickens in the Sand Shinnery Oak Prairie Ecoregion of Texas and New Mexico and the Mixed-Grass Prairie Ecoregion of Oklahoma and Kansas: Lubbock, Texas Tech University, M.S. thesis.
- Grisham, B.A., 2012. The ecology of lesser prairie-chickens in shinnery oak-grassland communities in New Mexico and Texas with implications toward habitat management and future climate change: Lubbock, Texas Tech University, Ph.D. dissertation.
- Grisham, B.A., Boal, C.W., Haukos, D.A., Davis, D.M., Boydston, K.K., Dixon, C., and Heck, W.R., 2013, The predicted influence of climate change on lesser prairie-chicken reproductive parameters: PloS ONE, v. 8, no. 7, 10 p.
- Grisham, B.A., Borsdorf, P.K., Boal, C.W., and Boydston, K.K., 2014, Nesting ecology and nest survival of lesser prairie-chickens on the southern high plains of Texas: Journal of Wildlife Management, v. 78, p. 857–866.
- Hagen, C.A., 2003, A demographic analysis of lesser prairie-chicken populations in southwestern Kansas—Survival, population viability, and habitat use: Manhattan, Kansas, Kansas State University, Ph.D. dissertation.
- Hagen, C.A., Pitman, J.C., Loughin, T.M., Sandercock, B.K., Robel, R.J., and Applegate, R.D., 2011, Impacts of anthropogenic features on habitat use by lesser prairie-chickens, *in* Sandercock, B.K., Martin, K., and Segelbacher, G., eds., Ecology, conservation, and management of grouse: Berkeley, University of California Press, p. 63–75.
- Hagen, C.A., Pitman, J.C., Sandercock, B.K., Robel, R.J., and Applegate, R.D., 2007, Age-specific survival and probable causes of mortality in female lesser prairie-chickens: Journal of Wildlife Management, v. 71, p. 518–525.
- Hagen, C.A., Sandercock, B.K., Pitman, J.C., Robel, R.J., and Applegate, R.D., 2009, Spatial variation in lesser prairie-chicken demography: A sensitivity analysis of population dynamics and management alternatives: Journal of Wildlife Management, v. 73, p. 1,325–1,332.
- Haukos, D.A., 1988, Reproductive ecology of lesser prairie-chickens in west Texas. Lubbock, Texas Tech University, M.S. thesis.
- Haukos, D.A., and Zavaleta, J.C., 2016, Habitat, *in* Haukos, D.A., and Boal, C.W., eds., Ecology and conservation of lesser prairie-chickens: Boca Raton, Florida, CRC Press, Studies in Avian Biology series, no. 48, p. 99–132.
- Holt, R.D., 2012, Breeding season demographics of a Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*): Lubbock, Texas Tech University, Ph.D. dissertation.
- Hurvich, C.M., and Tsai, C., 1989, Regression and time series model selection in small samples: Biometrika, v. 76, no. 2, p. 297–307.
- Jamison, B.E., 2000, Lesser prairie-chicken chick survival, adult survival, and habitat selection and movement of males in fragmented rangelands of southwestern Kansas: Manhattan, Kansas, Kansas State University, M.S. thesis.
- Johnson, D.H., and Rowland, M.M., 2007, The utility of lek counts for monitoring greater sage-grouse: *in* Reese K.P., and Bowyer, R.T., eds., Monitoring populations of sage-grouse: Proceedings of a symposium at Idaho State University hosted by University of Idaho and Idaho State University, p. 15–23
- Jones, R.S., 2009, Seasonal survival, reproduction, and use of wildlife areas by lesser prairie chickens in the northeastern Texas panhandle: College Station, Texas A&M University, M.S. thesis.

- Kellner, K., 2016, jagsUI: A wrapper around 'rjags' to streamline 'JAGS' analyses: R package version 1.4.4., <https://CRAN.R-project.org/package=jagsUI>.
- Lautenbach, J.M., 2015, Lesser prairie-chicken reproductive success, habitat selection, and response to trees: Manhattan, Kansas, Kansas State University, M.S. thesis.
- Lautenbach, J.M., Plumb, R.T., Robinson, S.G., Hagen, C.A., Haukos, D.A., and Pitman, J.C., 2017, Lesser prairie-chicken avoidance of trees in a grassland landscape: *Rangeland Ecology & Management*, v. 70, no. 1, p. 78–86.
- Lusk, D.J., 2016, Non-breeding season ecology of lesser prairie-chickens (*Tympanuchus pallidicinctus*) assessing survival and resource selection with southeastern New Mexico: Las Cruces, New Mexico State University, M.S. thesis.
- Lyons, E.K., Collier, B.A., Silvy, N.J., Lopez, R.R., Toole, B.E., Jones, R.S., and DeMaso, S.J., 2009, Breeding and non-breeding survival of lesser prairie-chickens *Tympanuchus pallidicinctus* in Texas, USA: *Wildlife Biology*, v. 15, no. 1, p. 89–96.
- Lyons, E.K., Jones, R.S., Leonard, J.P., Toole, B.E., McCleery, R.A., Lopez, R.R., Peterson, M.J., DeMaso, S.J., and Silvy, N.J., 2011, Regional variation in nesting success of lesser prairie-chickens, in Sandercock, B.K., Martin, K., and Segelbacher, G., eds., *Ecology, conservation, and management of grouse*: Berkeley, University of California Press, Studies in Avian Biology series, no. 39, p. 223–231.
- Merchant, S.S., 1982, Habitat-use, reproductive success, and survival of female lesser prairie-chickens in two years of contrasting weather: Las Cruces, New Mexico State University, M.S. thesis.
- McDonald, L., Nasman, K., Rintz, T., Hornsby, F., and Gardner, G., 2016, Range-wide population size of the lesser prairie-chicken—2012, 2013, 2014, 2015, and 2016: Prepared for the Western Association of Fish and Wildlife Agencies, [http://www.wafwa.org/initiatives/grasslands/lesser\\_prairie\\_chicken/annual\\_range-wide\\_aerial\\_surveys/](http://www.wafwa.org/initiatives/grasslands/lesser_prairie_chicken/annual_range-wide_aerial_surveys/).
- Meyers, A., 2016, Survival, resources selection, and seasonal space use of conservation reserve program and shinner oak habitat by lesser prairie-chickens in eastern New Mexico: Las Cruces, New Mexico State University, M.S. thesis.
- Molvar, E., 2016, Petition to list the lesser prairie chicken (*Tympanuchus pallidicinctus*) and three distinct population segments under the U.S. Endangered Species Act and emergency listing petition for the Shinnery Oak Prairie and Sand Sage Prairie distinct population segments: Wild Earth Guardians Web site, [http://www.wildearthguardians.org/site/DocServer/LPC\\_petition\\_2016\\_final\\_opt\\_2.pdf](http://www.wildearthguardians.org/site/DocServer/LPC_petition_2016_final_opt_2.pdf).
- Monroe, A.P., Edmunds, D.R., and Aldridge, C.L., 2016, Effects of lek count protocols on greater sage-grouse population trend estimates: *Journal of Wildlife Management*, v. 80, p. 667–678.
- Patten, M.A., Wolfe, D.H., and Sherrod, S.K., 2006, The effects of shrub control and grazing on habitat quality and reproductive success of lesser prairie-chickens: Final Report to New Mexico Department Game and Fish, prepared by University of Oklahoma, Sutton Avian Research Center, Bartlesville, Oklahoma.
- Pirius, N.E., Boal, C., Haukos, D.A., and Wallace, M.C., 2013, Winter habitat use and survival of lesser prairie-chickens in west Texas: *Wildlife Society Bulletin*, v. 37, p. 759–765.
- Pitman, J.C., Hagen, C.A., Jamison, B.E., Robel, R.J., Loughin, T.M., and Applegate, R.D., 2006, Nesting ecology of lesser prairie-chickens in sand sagebrush prairie of southwestern Kansas: *Wilson Journal of Ornithology*, v. 118, p. 23–35.
- Pitman, J.C., Hagen, C.A., Robel, R.J., Loughin, T.M., and Applegate, R.D., 2005, Location and success of lesser prairie-chicken nests in relation to vegetation and human disturbance: *Journal of Wildlife Management*, v. 69, p. 1,259–1,269.

- Plumb, R.T., 2015, Lesser prairie-chicken movement, space use, survival, and response to anthropogenic structures in Kansas and Colorado: Kansas State University, Manhattan, M.S. thesis.
- Plummer, M., 2003, JAGS—A program for analysis of Bayesian graphical models using Gibbs sampling: Proceedings of the 3rd International Workshop on Distributed Statistical Computing (DSC 2003), March 20–22, Vienna, Austria.
- R Core Team, 2016, R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.
- Robinson, S.G., 2015, Landscape ecology, survival and space use of lesser prairie-chickens: Kansas State University, Manhattan, M.S. thesis.
- Sadoti, G., Johnson, K., and Albright T.P., 2016, Modelling environmental and survey influences on lek attendance using long-term survey data: *IBIS*, v. 158, p. 821–833.
- Schaub, M., and Abadi, F., 2011, Integrated population models—A novel analysis framework for deeper insights into population dynamics: *Journal of Ornithology*, v. 152 (Supplement 1), p. 227–237.
- Smythe, L.A., and Haukos, D.A., 2009, Nesting success of grassland birds in shinnery oak communities treated with tebuthiuron and grazing in eastern New Mexico: *Southwestern Naturalist*, v. 54, p. 136–145.
- Strong, C.R., 2016, Investigating lesser prairie-chicken (*Tympanuchus pallidicinctus*) breeding season survival, habitat use, and space use to understand patterns of declining lek attendance: New Mexico State University, Las Cruces, M.S. thesis.
- Sullins, D.S., 2017, Regional variation in demography, distribution, foraging, and strategic conservation of lesser prairie-chickens in Kansas and Colorado: Manhattan, Kansas, Kansas State University, Ph.D. dissertation.
- Timmer, J.M., Butler, M.J., Ballard, W.B., Boal, C.W., and Whitlaw, H.A., 2013, Abundance and density of lesser prairie-chickens and leks in Texas: *Wildlife Society Bulletin*, v. 37 p. 741–749.
- Toole, B.E., 2005, Survival, seasonal movements, and cover use by lesser prairie chickens in the Texas panhandle: College Station, Texas A&M University, M.S. thesis.
- Van Pelt, W.E., Kyle, S., Pitman, J., Klute, D., Beauprez, G., Schoeling, D., Janus, A., and Haufler, J., 2013, The lesser prairie-chicken range-wide conservation plan: Cheyenne, Wyoming, Western Association of Fish and Wildlife Agencies, 302 p.
- Walsh, D.P., Stiver, J.R., White, G.C., Remington, T.E., and Apa, A.D., 2010, Population estimation techniques for lekking species: *Journal of Wildlife Management*, v. 74, no. 7, p. 1,607–1,613.
- Walsh, D.P., White, G.C., Remington, T.E., and Bowden, D.C., 2004, Evaluation of the lek count index for greater sage-grouse: *Wildlife Society Bulletin*, v. 32, no. 1, p. 56–68.
- White, G.C., and Burnham, K.P., 1999, Program MARK—Survival estimation from populations of marked animals: *Bird Study*, v. 46 (Supplement), p. 120–138.
- Wisdom, M.J., 1980, Nesting habitat of lesser prairie chicken in eastern New Mexico: Las Cruces, University of New Mexico, M.S. thesis.

## Appendix A. Data Sources

Numerous collaborators collected and contributed data from the four ecoregions based on very-high-frequency (VHF) radio transmitter or GPS (Global Positioning System) Platform Terminal Transmitter (PTT)-marked encounter and fate data for lesser prairie-chicken females, nests, and broods (table A1). These data were used in the model fitting procedure to evaluate demographic rates as a function of weather conditions (see section, “Modeled Demographic Rates”). These data were collected near Garden City, Kansas, from 1997 to 2002 (Hagen 2003, Pitman and others, 2005, 2006; Hagen and others, 2009, 2011), which were used in the Sand Sagebrush Prairie Ecoregion. David Haukos (U.S. Geological Survey, Kansas Cooperative Fish and Wildlife Research Unit) provided summer survival, nest, and brood survival data for the Short-Grass Prairie Ecoregion from 2013 to 2015. These data were collected by students in the U.S. Geological Survey Kansas Cooperative Fish and Wildlife Research Unit (Lautenbach, 2015, Plumb, 2015; Robinson, 2015). Texas Tech University and the Sutton Avian Research Center provided data from the Sand Shinnery Oak Prairie Ecoregion from 1996 to 2006 and from 2007 to 2012, respectively. Data from the Mixed-Grass Prairie Ecoregion were provided by the Sutton Avian Research Center (1999–2013) and Kansas State University (2013–2015). Note that no spatial information was associated with these data beyond the ecoregion in which the observation was made. The data were compiled into a single dataset by Blake Grisham, Alix Godar, and Cody Griffin at Texas Tech University.

**Table A1.** Years of demographic rate observations by ecoregion.

Ecoregion	Rate	Years	Number of observations
Short Grass Prairie Ecoregion	Nest Success	2013–2015	98
	Brood Success	2013–2015	30
	Summer Survival	2013–2015	97
Sand Sagebrush Prairie Ecoregion	Nest Success	1998–2002	159
	Brood Success	1997–2002	37
	Summer Survival	1997–2002	236
Mixed–Grass Prairie Ecoregion	Nest Success	1999–2006, 2008, 2009, 2013, 2014	163
	Brood Success	2013–2015	30
	Summer Survival	1999–2010, 2013, 2014	256
Sand Shinnery Oak Prairie Ecoregion	Nest Success	1996–2012	209
	Brood Success	2006–2010	26
	Summer Survival	1996–2012	391

## Appendix B. Demographic Rates from Literature

Only one study of the sex ratio of juvenile lesser prairie chicken has been conducted. Campbell (1972) studied the sex ratio of first year LEPC observed in fall harvests from 1958 to 1968, reporting a sex ratio of 50.3% male to 49.7% female, which corresponds closely to the standard practice in LEPC models of using a 1:1 sex ratio (Hagen, 2009; Godar, 2016; Griffin, 2016; Sullins, 2017). We follow this standard practice, using a fixed 1:1 sex ratio in our predictive modeling.

### Demographic Rates by Ecoregion

We extracted the estimated mean and standard error of nesting, re-nesting, and winter survival rates for use in the predictive model from the studies described below. The values reported in the tables below are the raw demographic rate estimates from each study, which we then convert to the appropriate values for the time period over which a demographic rate applies in our model, such as September 13 to February 28 for winter survival ( $S_w$ ) or July 1 to February 28 for juvenile survival ( $S_j$ ). In many cases, multiple studies of a demographic rate occurred in an ecoregion, in which case we sampled from all relevant studies, weighting samples by the studies' sample sizes. We also used abundance estimates from the range-wide aerial survey (McDonald and others, 2016) to initialize abundance in the projection model.

#### Short Grass Prairie Ecoregion

Research on demographic rates in the Short Grass Prairie Ecoregion was conducted by Fields (2004) and Samantha Robinson (Kansas State University, written commun., 2017; table B1). Fields (2004) conducted studies of nesting and re-nesting rates in west central Kansas from 2002 to 2003, collecting 33 observations. Samantha Robinson (Kansas State University, written commun., 2017) studied winter survival rates in Gove and Logan Counties in Kansas in 2013–2015, collecting 58 observations. The reported winter survival rates are not separated by ecoregion, so we apply them to both the SGPE and MGPE.

**Table B1.** Literature-based demographic rates and abundance estimates from the Short Grass Prairie Ecoregion.

Source	Parameter	Mean	Precision
Fields (2004)	Nesting rate	0.97	SE $\pm$ 0.06
Fields (2004)	Re-nesting rate	0.094	SE $\pm$ 0.052
S. Robinson (Kansas State University, written commun., 2017)	Winter survival <sup>1</sup>	0.66	SE $\pm$ 0.0658
McDonald and others (2016)	Abundance	14,025	90% CI (8,354–20,055)

<sup>1</sup>Winter survival was estimated from September 16 to March 8.

## Sand Sagebrush Prairie Ecoregion

Research on demographic rates in the Sand Sagebrush Prairie Ecoregion was conducted by Pitman and others (2006) and Hagen and others (2007) (table B2). Pitman and others (2006) conducted studies of nesting and re-nesting rates collecting 227 observations from 1997 to 2002 in Finney County, Kansas. Hagen and others (2007) studied winter survival rates, collecting 220 observations in Finney County, Kansas, from 1997 to 2002.

**Table B2.** Literature-based demographic rates from the Sand Sagebrush Prairie Ecoregion.

Source	Parameter	Mean	Precision
Pitman and others (2006)	Nesting rate	0.92	SE $\pm$ 0.02
Pitman and others (2006)	Re-nesting rate	0.31	SE $\pm$ 0.04
Hagen and others (2007)	Winter survival <sup>1</sup>	0.77	SE $\pm$ 0.056
McDonald and others (2016)	Abundance	1,479	90% CI (762–2,310)

<sup>1</sup>Winter survival was estimated from November 1 to February 28.

## Mixed Grass Prairie Ecoregion

Research on demographic rates in the Mixed Grass Prairie ecoregion was conducted by Lyons and others (2009), Lyons and others (2011), and Samantha Robinson ((Kansas State University, written commun., 2017) (table B3). Lyons and others (2011) conducted research on nesting and re-nesting rates in the northeastern Texas panhandle from 2001 to 2003 collecting 32 nesting and 7 re-nesting observations. Lyons and others (2009) studied winter survival rates collecting 115 observations in the northeastern Texas panhandle from 2001 to 2003, while Samantha Robinson ((Kansas State University, written commun., 2017) collected 77 observations in Kiowa, Clark, and Comanche Counties in Kansas in 2013–2015.

**Table B3.** Literature-based demographic rates from the Mixed Grass Prairie Ecoregion.

Source	Parameter	Mean	Precision
Lyons and others (2011)	Nesting rate	0.63	SE $\pm$ 0.09
Lyons and others (2011)	Re-nesting rate	0.14	SE $\pm$ 0.13
S. Robinson (Kansas State University, written commun., 2017)	Winter survival <sup>1</sup>	0.782	SE $\pm$ 0.0503
Lyons and others (2009)	Winter survival <sup>2</sup>	0.96	SE $\pm$ 0.01
McDonald and others (2016)	Abundance	6,891	90% CI (4,579–9,793)

<sup>1</sup>Winter survival was estimated from September 16 to March 8.

<sup>2</sup>Winter survival was estimated monthly.

## Sand Shinnery Oak Prairie Ecoregion

Research on demographic rates in the Sand Shinnery Oak Prairie Ecoregion was conducted by Davis (2009) (table B4). Patten and others (2006) and Davis (2009) conducted research on nesting and re-nesting rates, and Merchant (1982) estimated nesting rates in Roosevelt County, New Mexico. Davis (2009) collected 21 nesting and 6 re-nesting observations in 2004–2005 while Merchant (1982) collected in 27 nesting observations in 1997–1980. Patten and others (2006) collected 151 nesting and 70 re-nesting observations in 2001–2005. Grisham (2012) collected 51 and 35 nesting and re-nesting observations in 2008–2011 from Cochran, Hockley, Terry, and Yoakum Counties, Texas, while Lyons and others (2011) collected 52 nesting and 20 re-nesting observations in 2003–2007.

Lyons and others (2009) studied winter survival rates collecting 73 observations in the southwest portion of the Texas panhandle from 2003 to 2005. Pirius and others (2013) also studied winter survival rates collecting 53 observations in in the southwestern portion of the Texas panhandle from 2008 to 2011. Lusk (2016) studied winter survival rates in 2013 and 2014, collecting 23 observations in 2013 and 40 observations in 2014 in southeastern New Mexico.

**Table B4.** Literature-based demographic rates from the Sand Shinnery Oak Ecoregion.

Source	Parameter	Mean	Precision
Davis (2009)	Nesting rate	1.00	SE $\pm$ 0.00
Merchant (1982)	Nesting rate	0.81	SE $\pm$ 0.07
Patten and others (2006)	Nesting rate	0.72	SE $\pm$ 0.04
Grisham (2012)	Nesting rate	0.71	SE $\pm$ 0.06
Lyons and others (2011)	Nesting rate	0.62	SE $\pm$ 0.07
Davis (2009)	Re-nesting rate	0.50	SE $\pm$ 0.20
Patten and others (2006)	Re-nesting rate	0.07	SE $\pm$ 0.03
Grisham (2012)	Re-nesting rate	0.07	SE $\pm$ 0.04
Lyons and others (2011)	Re-nesting rate	0.15	SE $\pm$ 0.08
Lyons and others (2009)	Winter survival <sup>1</sup>	0.93	SE $\pm$ 0.03
Pirius and others (2013)	Winter survival <sup>2</sup>	0.72	SE $\pm$ 0.08
Lusk (2016)	Winter survival (2013 estimate) <sup>1</sup>	0.93	SE $\pm$ 0.03
	Winter survival (2014 estimate) <sup>2</sup>	0.99	SE $\pm$ 0.01
McDonald and others (2016)	Abundance	3,255	90% CI (2,035–6,198)

<sup>1</sup>Winter survival was estimated monthly.

<sup>2</sup>Winter survival was estimated from September 1 to February 28.

**Table B5.** Years of demographic rate observations used for literature based (nesting rate, re-nesting rate, and winter survival) and modeled demographic rates (nest success, brood success, summer survival).

<b>Ecoregion</b>	<b>Rate</b>	<b>Years</b>	<b>Number of observations</b>
Short Grass Prairie Ecoregion	Nesting rate	2002–2003	40
	Re-nesting rate	2002–2003	13
	Winter survival	2013–2014	88
	Nest success	2013–2015	98
	Brood success	2013–2015	30
	Summer survival	2013–2015	97
Sand Sagebrush Prairie Ecoregion	Nesting rate	1997–2002	227
	Re-nesting rate	1997–2002	112
	Winter survival	1997–2003	227
	Nest success	1998–2002	159
	Brood success	1997–2002	37
	Summer survival	1997–2002	236
Mixed-Grass Prairie Ecoregion	Nesting rate	2001–2007	40
	Re-nesting rate	2001–2007	7
	Winter survival	2001–2005, 2013–2014	192
	Nest success	1999–2006, 2008, 2009, 2013, 2014	163
	Brood success	2013–2015	30
	Summer survival	1999–2010, 2013, 2014	256
Sand Shinnery Oak Prairie Ecoregion	Nesting rate	1979–1980, 2001–2011	302
	Re-nesting rate	2001–2011	61
	Winter survival	2001–2005, 2008–2011, 2013–2014	188
	Nest success	1999–2012	209
	Brood success	2006–2010	26
	Summer survival	1999–2012	391



## Appendix C. Weather Covariate Definitions and Weather Data Sources

**Table C1.** Weather station used for each ecoregion.

[**Ecoregion:** SGPE, Short Grass Prairie Ecoregion; SSBPE, Sand Sagebrush Prairie Ecoregion; MGPE, Mixed Grass Prairie Ecoregion; SSOPE, Sand Shinnery Oak Prairie Ecoregion. km, kilometer]

<b>Ecoregion</b>	<b>Station</b>	<b>Station name</b>	<b>Latitude</b>	<b>Longitude</b>	<b>Estimated occupied range center</b>
SGPE	GHCND:USC00143554	Healy, Kansas,	38.601	-100.62	33 km NE
SSBPE	GHCND:USC00144114	Johnson, Kansas,	37.567	-101.75	22 km NW
MGPE	GHCND:USC00343489	Gate, Oklahoma,	36.85	-100.05	30 km SE
SSOPE	GHCND:USC00416074	Morton, Texas,	33.717	-102.75	41 km W

**Table C2.** Weather covariate definitions.

Group	Demographic rate	Covariate name	Description	Dates
1 Pre-season precipitation	All	APrecip	Total annual precipitation: sum of daily precipitation values (cm)	3/1–2/28
		ASnow	Total annual snowfall: sum of daily snowfall values (cm)	3/1–2/28
		WPrecip	Total winter precipitation: sum of daily precipitation values (cm)	12/1–2/28
		PSPrecip	Total precipitation the prior summer: sum of daily precipitation values (cm)	3/1–7/31
2 In-season precipitation	Nest Success	NPrecip	Total nesting season precipitation: sum of daily precipitation values (cm)	5/1–6/29
		NWet	Nesting season wet days: count of the number of days the daily rainfall reached or exceeded 2.5cm (days)	5/1–6/29
	Brood Success	BPrecip	Total brooding season precipitation: sum of daily precipitation values (cm)	6/1–7/30
		BWet	Brooding season wet days: count of the number of days the daily rainfall reached or exceeded 2.5cm (days)	6/1–7/30
		BPrecipF2W	Total precipitation during the first two weeks of the brooding season: sum of daily precipitation values (cm)	6/1–6/14
	Summer Survival	SPrecip	Summer precipitation: sum of daily precipitation values (cm)	3/1–9/12
		SWet	Summer wet days: count of the number of days the daily rainfall reached or exceeded 2.5cm (days)	3/1–9/12
	3 In-season hot weather	Nest Success	NTemp	Average nesting season maximum temperature: average of daily maximum temperature values (°C)
NHot			Nesting season hot days: count of the number of days the maximum temperature reached or exceeded 32.2°C (days)	5/1–6/29
Brood Success		BTemp	Average brooding season maximum temperature: average of daily maximum temperature values (°C)	6/1–7/30
		BTempF2W	Average maximum temperature during the first two weeks of the brooding season : average of daily maximum temperature values (°C)	6/1–6/14
		BHot	Brooding season hot days: count of the number of days the maximum temperature reached or exceeded 32.2°C (days)	6/1–7/30
		BHotF2W	Brooding season first two weeks hot days: count of the number of days the maximum temperature reached or exceeded 32.2°C (days)	6/1–6/14

Group	Demographic rate	Covariate name	Description	Dates
	Summer Survival	STemp	Average summer maximum temperature: average of daily maximum temperature values (°C)	3/1–9/12
		SHot	Summer hot days: count of the number of days the maximum temperature reached or exceeded 32.2°C (days)	3/1–9/12
4 In-season cold weather	Nest Success	NCold	Nesting season cold days: count of the number of days the minimum temperature was 0°C or below (days)	5/1–6/29
		BCold	Brooding season cold days: count of the number of days the minimum temperature was 0°C or below (days)	6/1–7/30
	Brood Success	BColdF2W	Brooding season first two weeks cold days: count of the number of days the minimum temperature was 0°C or below (days)	6/1–6/14
		SCold	Summer cold days: count of the number of days the minimum temperature was 0°C or below (days)	3/1–9/12

## Appendix D. Demographic Modeling Outputs

This appendix contains a summary of the weather covariates with the lowest AICc scores in each covariate group (table D1), the AICc scores from the full set of models for each demographic rate, and the beta estimates from the best model for each demographic rate in program MARK, and from the MCMC chains. The MCMC analysis settings used in JAGS are also reported in table D35.

**Table D1.** Outcome of single-covariate selection process, by ecoregion, demographic rate, and covariate group.

[**Ecoregion:** SGPE, Short Grass Prairie Ecoregion; SSBPE, Sand Sagebrush Prairie Ecoregion; MGPE, Mixed Grass Prairie Ecoregion; SSOPE, Sand Shinnery Oak Prairie Ecoregion. Covariate(s) indicated in **bold** represent membership in the best model for ecoregion and demographic rate, as determined by a second-step model comparison step (C2–C13). In some cases, cold days were not observed in the demographic dataset, so group 4 covariates were excluded (noted with NA).]

Demographic rate	Group	Ecoregion			
		SGPE	SSBPE	MGPE	SSOPE
Nest Success	1	APrecip	APrecip	<b>WPrecip</b>	APrecip
	2	NPrecip	NPrecip	NWet	NPrecip
	3	<b>NTemp</b>	<b>NTemp</b>	NHot	NHot
	4	NCold	NA	NCold	NA
Brood Success	1	WPrecip	PSPrecip	WPrecip	PSPrecip
	2	BPrecip	<b>BWet</b>	BPrecip	BPrecipF2W
	3	<b>BHotF2W</b>	BTempF2W	BTemp	BTempF2W
	4	NA	NA	BCold	NA
Summer Survival	1	<b>APrecip</b>	WPrecip	<b>WPrecip</b>	APrecip
	2	SPrecip	SWet	<b>SWet</b>	SPrecip
	3	SHot	STemp	SHot	<b>STemp</b>
	4	SCold	<b>SCold</b>	SCold	SCold

## Short Grass Prairie Ecoregion

### Nest Success

**Table D2.** AIC<sub>c</sub> scores from each weather covariate for the nest success model evaluated in program MARK.

Model	AICc	Δ AICc	AICc weight	K	Deviance
NTemp	530.12	0.00	0.12	2	526.12
APrecip	530.25	0.13	0.12	2	526.25
NCold	530.50	0.37	0.10	2	526.49
NHot	530.68	0.55	0.09	2	526.67
LSPrecip	530.81	0.69	0.09	2	526.80
NPrecip	531.64	1.52	0.06	2	527.63
APrecip+NPrecip	532.10	1.98	0.05	3	526.09
APrecip+NCold	532.10	1.98	0.05	3	526.09
APrecip+NTemp	532.10	1.98	0.05	3	526.09
NPrecip+NTemp	532.10	1.98	0.05	3	526.09
NPrecip+NCold	532.10	1.98	0.05	3	526.09
NTemp+NCold	532.10	1.98	0.05	3	526.09
APrecip+NPrecip+NTemp	534.11	3.98	0.02	4	526.09
APrecip+NPrecip+NCold	534.11	3.98	0.02	4	526.09
APrecip+NTemp+NCold	534.11	3.98	0.02	4	526.09
NPrecip+NTemp+NCold	534.11	3.98	0.02	4	526.09
WPrecip	534.15	4.03	0.02	2	530.15
ASnow	534.49	4.37	0.01	2	530.48
Constant	534.70	4.58	0.01	1	532.70
NWet	534.89	4.77	0.01	2	530.89
APrecip+NPrecip+NTemp+NCold	536.12	5.99	0.01	5	526.09

The top nest success model in the Short Grass Prairie Ecoregion models nest success as a function of the average maximum temperature during the nesting period.

**Table D3.** Logit link function parameter estimates for the top nest success model in the Short Grass Prairie Ecosystem (SGPE) from program MARK.

Parameter	Beta	Standard error	Lower 95% CI	Upper 95% CI
Intercept	3.40	0.13	3.14	3.66
NTemp	-0.33	0.13	-0.59	-0.07

**Table D4.** Logit link function parameter estimates for the nest success model in the Short Grass Prairie Ecosystem (SGPE) from program JAGS.

[n, effective sample size. f Probability that a sample in the MCMC chain has the same sign (+ or -) as the point estimate]

Parameter	Beta	Standard deviation	Lower 95% CI	Upper 95% CI	$\hat{R}$	n	f
Intercept	3.43	1.78	-1.03	7.43	1.05	3,725	0.96
NTemp	-0.32	1.57	-3.79	3.56	1.04	550	0.73
$\sigma$	1.17	2.47	0.05	8.81	1.02	151	1

### Brood Success

**Table D5.** AIC<sub>c</sub> scores from each weather covariate for the brood success model evaluated in program MARK.

Model	AICc	$\Delta$ AICc	AICc weight	K	Deviance
BHotF2W	91.92	0.00	0.13	2	87.90
WPrecip+BPrecip	92.43	0.50	0.10	3	86.37
WPrecip+BHotF2W	92.43	0.50	0.10	3	86.37
BPrecip+BHotF2W	92.43	0.50	0.10	3	86.37
BTemp	92.69	0.77	0.09	2	88.67
WPrecip	93.23	1.31	0.07	2	89.21
BHot	93.81	1.88	0.05	2	89.78
ASnow	93.91	1.98	0.05	2	89.88
APrecip	94.09	2.17	0.05	2	90.06
WPrecip+BPrecip+BHotF2W	94.46	2.54	0.04	4	86.37
BPrecip	94.57	2.65	0.04	2	90.54
BTempF2W	94.94	3.02	0.03	2	90.91
BPrecipF2W	95.90	3.98	0.02	2	91.88
Bwet	96.98	5.06	0.01	2	92.96
Constant	99.84	7.92	0.00	1	97.84
LSPrecip	101.01	9.09	0.00	2	96.99

The top brood success model in the Short Grass Prairie Ecoregion models brood success as a function of the number of hot days in the first two weeks of brooding.

**Table D6.** Logit link function parameter estimates for the top brood success model in the Short Grass Prairie Ecosystem (SGPE) from program MARK.

Parameter	Beta	Standard error	Lower 95% CI	Upper 95% CI
Intercept	3.20	0.24	2.72	3.68
BHotF2W	-0.82	0.25	-1.31	-0.34

**Table D7.** Logit link function parameter estimates for the brood success model in the Short Grass Prairie Ecosystem (SGPE) from program JAGS.

[n, effective sample size. f, Probability that a sample in the MCMC chain has the same sign (+ or -) as the point estimate]

Parameter	Beta	Standard deviation	Lower 95% CI	Upper 95% CI	$\hat{R}$	n	f
Intercept	3.22	2.38	-2.83	8.14	1.03	381	0.92
BHotF2W	-0.81	2.08	-5.69	3.88	1.03	792	0.77
$\sigma$	1.98	2.61	0.10	9.15	1.01	371	1

## Summer Survival

**Table D8.** AIC<sub>c</sub> scores from each weather covariate for the summer survival model evaluated in program MARK.

Model	AICc	$\Delta$ AICc	AICc weight	K	Deviance
APrecip	359.32	0.00	0.12	2	355.30
SPrecip	359.51	0.20	0.10	2	355.50
SHot	359.64	0.33	0.10	2	355.63
LSPrecip	359.87	0.55	0.09	2	355.85
SCold	360.15	0.84	0.08	2	356.14
Constant	360.80	1.49	0.05	1	358.80
WPrecip	360.93	1.61	0.05	2	356.91
ASnow	361.17	1.85	0.05	2	357.16
APrecip+SPrecip	361.33	2.01	0.04	3	355.30
APrecip+SCold	361.33	2.01	0.04	3	355.30
APrecip+SHot	361.33	2.01	0.04	3	355.30
SPrecip+SHot	361.33	2.01	0.04	3	355.30
SHot+SCold	361.33	2.01	0.04	3	355.30
SPrecip+SCold	361.33	2.01	0.04	3	355.30
STemp	362.23	2.91	0.03	2	358.22
SWet	362.61	3.29	0.02	2	358.59
APrecip+SPrecip+SHot	363.35	4.03	0.02	4	355.30
APrecip+SPrecip+SCold	363.35	4.03	0.02	4	355.30
APrecip+SHot+SCold	363.35	4.03	0.02	4	355.30
SPrecip+SHot+SCold	363.35	4.03	0.02	4	355.30
APrecip+SPrecip+SHot+SCold	365.38	6.06	0.01	5	355.30

The top survival model in the Short Grass Prairie Ecoregion models summer survival as a function of annual precipitation during the year preceding the summer survival period.

**Table D9.** Logit link function parameter estimates for the top summer survival model in the Short Grass Prairie Ecosystem (SGPE) from program MARK.

Parameter	Beta	Standard error	Lower 95% CI	Upper 95% CI
Intercept	2.61	0.15	2.32	2.90
APrecip	0.28	0.15	-0.02	0.58

**Table D10.** Logit link function parameter estimates for the summer survival model in the Short Grass Prairie Ecosystem (SGPE) from program JAGS.

[n, effective sample size. f, Probability that a sample in the MCMC chain has the same sign (+ or -) as the point estimate]

Parameter	Beta	Standard deviation	Lower 95% CI	Upper 95% CI	$\hat{R}$	n	f
Intercept	2.46	2.34	-3.94	6.73	1.05	67	0.88
APrecip	0.37	2.10	-3.61	6.19	1.04	294	0.68
$\sigma$	1.87	2.53	0.29	9.08	1.01	214	1



## Sand Sagebrush Prairie Ecoregion

### Nest Success

**Table D11.** AIC<sub>c</sub> scores from each weather covariate for the nest success model evaluated in program MARK.

Model	AIC <sub>c</sub>	Δ AIC <sub>c</sub>	AIC <sub>c</sub> weight	K	Deviance
NTemp	960.84	0.00	0.16	2	956.84
APrecip+NPrecip+NTemp	960.91	0.07	0.15	4	952.90
APrecip+NTemp	961.15	0.31	0.14	3	955.15
NHot	961.46	0.62	0.12	2	957.45
NPrecip	962.11	1.27	0.09	2	958.10
NPrecip+NTemp	962.58	1.74	0.07	3	956.57
APrecip	963.30	2.46	0.05	2	959.30
Constant	963.74	2.90	0.04	1	961.74
NWet	963.77	2.93	0.04	2	959.77
APrecip+NPrecip	964.06	3.21	0.03	3	958.05
ASnow	964.12	3.28	0.03	2	960.12
WPrecip	965.11	4.27	0.02	2	961.11
LSPrecip	965.59	4.75	0.01	2	961.59

The top nest success model in the Sand Sagebrush Prairie Ecoregion models nest success as a function of average maximum temperature during the nesting period.

**Table D12.** Logit link function parameter estimates for the top nest success model in the Sand Sagebrush Prairie Ecoregion (SSBPE) from program MARK.

Parameter	Beta	Standard error	Lower 95% CI	Upper 95% CI
Intercept	3.08	0.09	2.89	3.26
NTemp	-0.20	0.09	-0.38	-0.02

**Table D13.** Logit link function parameter estimates for the nest success model in the Sand Sagebrush Prairie Ecoregion (SSBPE) from program JAGS.

[n, effective sample size. f, Probability that a sample in the MCMC chain has the same sign (+ or -) as the point estimate]

Parameter	Beta	Standard deviation	Lower 95% CI	Upper 95% CI	$\hat{R}$	n	f
Intercept	3.12	0.24	2.70	3.64	1.00	2,327	1
NTemp	-0.20	0.23	-0.67	0.27	1.00	6,057	0.88
$\sigma$	0.26	0.39	0.04	1.43	1.00	5,982	1

## Brood Success

**Table D14.** AIC<sub>c</sub> scores from each weather covariate for the brood success model evaluated in program MARK.

Model	AIC <sub>c</sub>	Δ AIC <sub>c</sub>	AIC <sub>c</sub> weight	K	Deviance
BWet	74.54	0.00	0.16	2	70.52
BPrecip	75.45	0.91	0.10	2	71.43
Constant	75.49	0.95	0.10	1	73.48
LSPrecip+BWet	76.47	1.93	0.06	3	70.44
BHotF2W	76.52	1.98	0.06	2	72.51
BWet+BPrecip	76.53	1.99	0.06	3	70.50
BWet+BTempF2W	76.55	2.01	0.06	3	70.52
LSPrecip	76.79	2.25	0.05	2	72.77
WPrecip	76.94	2.41	0.05	2	72.93
BTempF2W	76.97	2.43	0.05	2	72.95
BPrecipF2W	77.04	2.50	0.05	2	73.03
BTemp	77.21	2.68	0.04	2	73.20
ASnow	77.33	2.80	0.04	2	73.32
BHot	77.38	2.84	0.04	2	73.37
APrecip	77.38	2.85	0.04	2	73.37
LSPrecip+BWet+BTempF2W	78.16	3.62	0.03	4	70.11
LSPrecip+BTempF2W	78.80	4.26	0.02	3	72.77

The top brood success model in the Sand Sagebrush Prairie Ecoregion models brood success as a function of the number of days with heavy rain.

**Table D15.** Logit link function parameter estimates for the top brood success model in the Sand Sagebrush Prairie Ecoregion (SSBPE) from program MARK.

Parameter	Beta	Standard error	Lower 95% CI	Upper 95% CI
Intercept	4.19	0.29	3.63	4.75
BWet	0.48	0.29	-0.08	1.04

**Table D16.** Logit link function parameter estimates for the brood success model in the Sand Sagebrush Prairie Ecoregion (SSBPE) from program JAGS.

[n, effective sample size. f, Probability that a sample in the MCMC chain has the same sign (+ or -) as the point estimate]

Parameter	Beta	Standard deviation	Lower 95% CI	Upper 95% CI	$\hat{R}$	n	f
Intercept	4.31	0.50	3.49	5.47	1.01	1,547	1.00
BWet	0.51	0.52	-0.44	1.56	1.01	875	0.90
$\sigma$	0.42	0.71	0.04	2.55	1.02	590	1

## Summer Survival

**Table D17.** AIC<sub>c</sub> scores from each weather covariate for the summer survival model evaluated in program MARK.

Model	AICc	$\Delta$ AICc	AICc weight	K	Deviance
SCold	484.61	0.00	0.24	2	480.61
STemp+SCold	486.48	1.87	0.09	3	480.47
WPrecip+SCold	486.49	1.87	0.09	3	480.47
SWet+SCold	486.50	1.88	0.09	3	480.49
WPrecip+STemp	487.62	3.01	0.05	3	481.61
SWet+STemp	487.66	3.05	0.05	3	481.65
SWet	487.84	3.23	0.05	2	483.84
WPrecip+STemp+SCold	487.91	3.30	0.05	4	479.89
SWet+STemp+SCold	488.04	3.42	0.04	4	480.02
SPrecip	488.11	3.50	0.04	2	484.10
WPrecip+SWet+SCold	488.49	3.88	0.03	4	480.47
WPrecip	488.58	3.97	0.03	2	484.57
WPrecip+SWet+STemp	489.40	4.79	0.02	4	481.39
Constant	489.74	5.13	0.02	1	487.74
WPrecip+SWet	489.84	5.23	0.02	3	483.83
WPrecip+SWet+STemp+SCold	489.92	5.31	0.02	5	479.89
STemp	490.65	6.04	0.01	2	486.65
LSPrecip	490.69	6.08	0.01	2	486.68
SHot	491.52	6.90	0.01	2	487.51
APrecip	491.73	7.12	0.01	2	487.73
ASnow	491.73	7.12	0.00	2	487.72

The top survival model in the Sand Sagebrush Prairie Ecoregion models summer survival as a function of the number of cold days during the summer breeding season.

**Table C18.** Logit link function parameter estimates for the top summer survival model in the Sand Sagebrush Prairie Ecoregion (SSBPE) from program MARK.

Parameter	Beta	Standard error	Lower 95% CI	Upper 95% CI
Intercept	3.77	0.15	3.47	4.07
SCold	0.40	0.16	0.10	0.71

**Table D19.** Logit link function parameter estimates for the summer survival model in the Sand Sagebrush Prairie Ecoregion (SSBPE) from program JAGS.

[n, effective sample size. f, Probability that a sample in the MCMC chain has the same sign (+ or -) as the point estimate]

Parameter	Beta	Standard deviation	Lower 95% CI	Upper 95% CI	$\hat{R}$	n	f
Intercept	3.86	1.06	1.64	6.29	1.01	324	0.99
SCold	0.38	1.11	-1.51	3.41	1.04	127	0.76
$\sigma$	1.25	1.71	0.11	6.85	1.01	574	1

## Mixed Grass Prairie Ecoregion

### Nest Success

**Table D20.** AIC<sub>c</sub> scores from each weather covariate for the nest success model evaluated in program MARK.

Model	AICc	Δ AICc	AICc weight	K	Deviance
WPrecip	674.77	0.00	0.21	2	670.77
WPrecip+NWet	675.34	0.57	0.16	3	669.33
WPrecip+NHot	676.45	1.68	0.09	3	670.44
WPrecip+NCold	676.70	1.92	0.08	3	670.69
ASnow	676.79	2.02	0.08	2	672.78
WPrecip+NWet+NHot	677.34	2.57	0.06	4	669.32
WPrecip+NWet+NCold	677.34	2.57	0.06	4	669.33
WPrecip+NHot+NCold	678.46	3.69	0.03	4	670.44
NWet+NCold	678.69	3.91	0.03	3	672.67
NWet	678.86	4.09	0.03	2	674.86
NHot+NCold	678.87	4.10	0.03	3	672.86
NCold	679.13	4.36	0.02	2	675.12
Constant	679.23	4.46	0.02	1	677.23
WPrecip+NWet+NHot+NCold	679.35	4.58	0.02	5	669.32
NWet+NHot+NCold	679.80	5.03	0.02	4	671.78
NHot	679.88	5.11	0.02	2	675.88
NTemp	680.17	5.40	0.01	2	676.17
NWet+NHot	680.51	5.73	0.01	3	674.49
APrecip	681.09	6.32	0.01	2	677.09
NPrecip	681.11	6.34	0.01	2	677.10
LSPrecip	681.24	6.46	0.01	2	677.23

The top nest success model in the Mixed Grass Prairie Ecoregion models nest success as a function of winter precipitation during the preceding winter.

**Table D21.** Logit link function parameter estimates for the top nest success model in the Mixed Grass Prairie Ecoregion (MGPE) from program MARK.

Parameter	Beta	Standard error	Lower 95% CI	Upper 95% CI
Intercept	3.06	0.10	2.86	3.26
WPrecip	0.26	0.11	0.06	0.47

**Table D22.** Logit link function parameter estimates for the nest success model in the Mixed Grass Prairie Ecoregion (MGPE) from program JAGS.

[n, effective sample size. f, Probability that a sample in the MCMC chain has the same sign (+ or -) as the point estimate]

Parameter	Beta	Standard deviation	Lower 95% CI	Upper 95% CI	$\hat{R}$	n	f
Intercept	3.07	0.12	2.83	3.31	1.00	27,000	1
WPrecip	0.26	0.12	0.03	0.51	1.00	3,905	0.98
$\sigma$	0.13	0.12	0.03	0.46	1.00	11,780	1

### Brood Success

**Table D23.** AIC<sub>c</sub> scores from each weather covariate for the brood success model evaluated in program MARK.

Model	AIC <sub>c</sub>	$\Delta$ AIC <sub>c</sub>	AIC <sub>c</sub> weight	K	Deviance
Constant	79.68	0.00	0.15	1	77.67
WPrecip	81.53	1.85	0.06	2	77.51
LSPrecip	81.57	1.90	0.06	2	77.55
ASnow	81.58	1.90	0.06	2	77.56
BPrecip	81.58	1.91	0.06	2	77.56
BTemp	81.59	1.92	0.06	2	77.57
APrecip	81.64	1.96	0.06	2	77.62
BHot	81.64	1.96	0.06	2	77.62
BWet	81.66	1.98	0.06	2	77.64
BHotF2W	81.66	1.98	0.06	2	77.64
BCold	81.66	1.98	0.06	2	77.64
BTempF2W	81.66	1.99	0.06	2	77.64
BPrecipF2W	81.68	2.00	0.05	2	77.65
WPrecip+BPrecip	83.54	3.86	0.02	3	77.50
WPrecip+BCold	83.54	3.86	0.02	3	77.50
WPrecip+BTemp	83.54	3.86	0.02	3	77.50
BPrecip+BTemp	83.54	3.86	0.02	3	77.50
BPrecip+BCold	83.54	3.86	0.02	3	77.50
BTemp+BCold	83.54	3.86	0.02	3	77.50
WPrecip+BPrecip+BTemp	85.57	5.89	0.01	4	77.50
WPrecip+BPrecip+BCold	85.57	5.89	0.01	4	77.50
WPrecip+BTemp+BCold	85.57	5.89	0.01	4	77.50
BPrecip+BTemp+BCold	85.57	5.89	0.01	4	77.50
WPrecip+BPrecip+BTemp+BCold	87.60	7.92	0.00	5	77.50

The top brood success model in the Mixed Grass Prairie Ecoregion models brood success as a constant rate irrespective of weather.

**Table D24.** Logit link function parameter estimates for the top brood success model in the Mixed Grass Prairie Ecoregion (MGPE) from program MARK.

Parameter	Beta	Standard error	Lower 95% CI	Upper 95% CI
Intercept	3.78	0.27	3.25	4.31

**Table D25.** Logit link function parameter estimates for the brood success model in the Mixed Grass Prairie Ecoregion (MGPE) from program JAGS.

[n, effective sample size. f, Probability that a sample in the MCMC chain has the same sign (+ or -) as the point estimate]

Parameter	Beta	Standard deviation	Lower 95% CI	Upper 95% CI	$\hat{R}$	n	f
Intercept	3.84	1.04	1.87	5.86	1.07	777	0.99
$\sigma$	0.55	1.46	0.05	5.67	1.01	1,289	1

## Summer Survival

**Table D26.** AIC<sub>c</sub> scores from each weather covariate for the summer survival model evaluated in program MARK.

Model	AIC <sub>c</sub>	$\Delta$ AIC <sub>c</sub>	AIC <sub>c</sub> weight	K	Deviance
WPrecip+SWet	620.19	0.00	0.11	3	614.17
WPrecip	620.37	0.18	0.10	2	616.36
WPrecip+SWet+SHot	620.68	0.49	0.08	4	612.66
WPrecip+SWet+SCold	620.68	0.50	0.08	4	612.66
WPrecip+SWet+SHot+SCold	620.85	0.66	0.08	5	610.81
WPrecip+SCold	621.01	0.83	0.07	3	615.00
SWet	621.48	1.29	0.06	2	617.47
WPrecip+SHot	621.60	1.41	0.05	3	615.58
SWet+SHot	621.82	1.63	0.05	3	615.81
SWet+SHot+SCold	622.04	1.85	0.04	4	614.02
APrecip	622.07	1.88	0.04	2	618.06
WPrecip+SHot+SCold	622.14	1.95	0.04	4	614.11
Constant	622.36	2.17	0.04	1	620.36
SWet+SCold	622.40	2.21	0.04	3	616.39
LSPrecip	623.13	2.94	0.02	2	619.12
SPrecip	623.48	3.29	0.02	2	619.47
SCold	623.58	3.39	0.02	2	619.57
SHot	623.82	3.63	0.02	2	619.81
STemp	624.33	4.15	0.01	2	620.33
ASnow	624.36	4.17	0.01	2	620.35
SHot+SCold	624.85	4.66	0.01	3	618.84

The top survival model in the Mixed Grass Prairie Ecoregion models summer survival as a function of winter precipitation during the preceding winter and number of days of heavy rain during the summer survival period.

**Table D27.** Logit link function parameter estimates for the top survival model in the Mixed Grass Prairie Ecoregion (MGPE) from program MARK.

Parameter	Beta	Standard error	Lower 95% CI	Upper 95% CI
Intercept	3.15	0.12	2.91	3.39
WPrecip	-0.21	0.11	-0.43	0.02
SWet	0.18	0.13	-0.06	0.43

**Table D28.** Logit link function parameter estimates for the summer survival model in the Mixed Grass Prairie Ecoregion (MGPE) from program JAGS.

[n, effective sample size. f, Probability that a sample in the MCMC chain has the same sign (+ or -) as the point estimate]

Parameter	Beta	Standard deviation	Lower 95% CI	Upper 95% CI	$\hat{R}$	n	f
Intercept	3.41	0.23	2.97	3.91	1.00	1,315	1
WPrecip	-0.28	0.22	-0.78	0.10	1.00	789	0.92
SWet	0.09	0.21	-0.33	0.52	1.00	12,000	0.68
$\sigma$	0.46	0.26	0.26	1.18	1.02	278	1



## Sand Shinnery Oak Prairie Ecoregion

### Nest Success

**Table D29.** AIC<sub>c</sub> scores from each weather covariate for the nest success model evaluated in program MARK.

Model	AICc	Δ AICc	AICc weight	K	Deviance
Constant	869.25	0.00	0.18	1	867.25
APrecip	870.18	0.92	0.12	2	866.17
NHot	870.34	1.08	0.11	2	866.33
NTemp	870.78	1.52	0.09	2	866.77
LSPrecip	870.99	1.74	0.08	2	866.99
NPrecip	871.15	1.90	0.07	2	867.15
ASnow	871.24	1.98	0.07	2	867.23
NWet	871.25	2.00	0.07	2	867.25
WPrecip	871.25	2.00	0.07	2	867.25
APrecip+NHot	871.78	2.53	0.05	3	865.77
NPrecip+NHot	872.09	2.84	0.04	3	866.08
APrecip+NPrecip	872.18	2.92	0.04	3	866.17
APrecip+NPrecip+NHot	873.47	4.22	0.02	4	865.46

The top nest success model in the Sand Shinnery Oak Prairie Ecoregion models nest success as a constant rate irrespective of weather.

**Table D30.** Logit link function parameter estimates for the top survival model in the Sand Shinnery Oak Prairie Ecoregion (SSOPE) from program MARK.

Parameter	Beta	Standard error	Lower 95% CI	Upper 95% CI
Intercept	3.07	0.09	2.90	3.25

**Table D31.** Logit link function parameter estimates for the nest success model in the Sand Shinnery Oak Prairie Ecoregion (SSOPE) from program JAGS.

[n, effective sample size. f, Probability that a sample in the MCMC chain has the same sign (+ or -) as the point estimate]

Parameter	Beta	Standard deviation	Lower 95% CI	Upper 95% CI	$\hat{R}$	n	f
Intercept	3.08	0.11	2.87	3.31	1.00	6,493	1
$\sigma$	0.15	0.13	0.03	0.49	1.02	102	1

## Brood Success

**Table D32.** AIC<sub>c</sub> scores from each weather covariate for the brood success model evaluated in program MARK.

Model	AIC <sub>c</sub>	Δ AIC <sub>c</sub>	AIC <sub>c</sub> weight	K	Deviance
Constant	97.84	0.00	0.12	1	95.83
BPrecipF2W	98.00	0.15	0.11	2	93.95
LSPrecip	98.06	0.22	0.11	2	94.02
WPrecip	98.10	0.25	0.10	2	94.06
BTempF2W	98.60	0.76	0.08	2	94.56
BPrecip	98.72	0.88	0.08	2	94.68
BHotF2W	98.83	0.99	0.07	2	94.79
APrecip	98.98	1.13	0.07	2	94.94
BWet	99.02	1.17	0.07	2	94.98
ASnow	99.24	1.39	0.06	2	95.19
BHot	99.64	1.79	0.05	2	95.60
BTemp	99.76	1.92	0.05	2	95.72

The top brood success model in the Sand Shinnery Oak Prairie Ecoregion models nest success as a constant rate irrespective of weather.

**Table D33.** Logit link function parameter estimates for the top brood success model in the Sand Shinnery Oak Prairie Ecoregion (SSOPE) from program MARK.

Parameter	Beta	Standard error	Lower 95% CI	Upper 95% CI
Intercept	2.74	0.22	2.30	3.18

**Table D34.** Logit link function parameter estimates for the brood success model in the Sand Shinnery Oak Prairie Ecoregion (SSOPE) from program JAGS.

[n, effective sample size. f, Probability that a sample in the MCMC chain has the same sign (+ or -) as the point estimate]

Parameter	Beta	Standard deviation	Lower 95% CI	Upper 95% CI	$\hat{R}$	n	f
Intercept	2.66	0.48	1.54	3.54	1.00	8,757	1
$\sigma$	0.59	0.64	0.05	2.44	1.01	559	1

## Summer Survival

**Table D35.** AIC<sub>c</sub> scores from each weather covariate for the summer survival model evaluated in program MARK.

Model	AIC <sub>c</sub>	Δ AIC <sub>c</sub>	AIC <sub>c</sub> weight	K	Deviance
STemp	707.49	0.00	0.26	2	703.48
SHot	708.45	0.96	0.16	2	704.45
STemp+SCold	708.93	1.45	0.13	3	702.92
SPrecip+STemp	709.16	1.68	0.11	3	703.16
APrecip+STemp	709.29	1.80	0.11	3	703.28
SPrecip+STemp+SCold	710.83	3.34	0.05	4	702.82
APrecip+STemp+SCold	710.94	3.45	0.05	4	702.92
APrecip+SPrecip+STemp	711.06	3.57	0.04	4	703.04
APrecip+SPrecip+STemp+SCold	712.84	5.35	0.02	5	702.82
APrecip	713.44	5.95	0.01	2	709.43
APrecip+SPrecip	713.89	6.40	0.01	3	707.88
SPrecip	713.97	6.48	0.01	2	709.96
Constant	714.37	6.89	0.01	1	712.37
SPrecip+SCold	714.73	7.24	0.01	3	708.72
APrecip+SCold	715.41	7.93	0.00	3	709.40
WPrecip	715.76	8.28	0.00	2	711.76
APrecip+SPrecip+SCold	715.77	8.28	0.00	4	707.75
SCold	715.97	8.48	0.00	2	711.97
SWet	716.07	8.59	0.00	2	712.07
ASnow	716.10	8.61	0.00	2	712.10
LSPrecip	716.18	8.69	0.00	2	712.18

The top survival model in the Sand Shinnery Oak Prairie Ecoregion models summer survival as a function of average maximum temperature during the summer survival period.

**Table D36.** Logit link function parameter estimates for the top summer survival model in the Sand Shinnery Oak Prairie Ecoregion (SSOPE) from program MARK.

Parameter	Beta	Standard error	Lower 95% CI	Upper 95% CI
Intercept	3.50	0.12	3.26	3.74
STemp	0.36	0.12	0.12	0.60

**Table D37.** Logit link function parameter estimates for the summer survival model in the Sand Shinnery Oak Prairie Ecoregion (SSOPE) from program JAGS.

[n, effective sample size. f, Probability that a sample in the MCMC chain has the same sign (+ or -) as the point estimate]

Parameter	Beta	SD	Lower 95% CI	Upper 95% CI	$\hat{R}$	n	f
Intercept	3.72	0.18	3.38	4.11	1.00	2,551	1
STemp	0.48	0.18	0.14	0.85	1.00	12,000	1
$\sigma$	0.35	0.14	0.25	0.77	1.01	857	1

## MCMC Analysis Settings

**Table D38.** MCMC Analysis settings.

[All models were fit using three chains and an adaptation period of 100 iterations. **Ecoregion:** SGPE, Short Grass Prairie Ecoregion; SSBPE, Sand Sagebrush Prairie Ecoregion; MGPE, Mixed Grass Prairie Ecoregion; SSOPE, Sand Shinnery Oak Prairie Ecoregion]

Ecoregion	Demographic rate	Burn in	Iterations	Samples
SGPE	Nest Success	5,000	100,000	285,000
	Brood Success	1,000	50,000	147,000
	Survival	5,000	100,000	285,000
SSBPE	Nest Success	1,000	25,000	72,000
	Brood Success	1,000	25,000	72,000
	Survival	2,000	25,000	69,000
MGPE	Nest Success	1,000	10,000	27,000
	Brood Success	1,000	20,000	57,000
	Survival	1,000	5,000	12,000
SSOPE	Nest Success	500	5,000	13,500
	Brood Success	1,000	10,000	27,000
	Survival	1,000	5,000	12,000

Publishing support provided by the U.S. Geological Survey  
Science Publishing Network, Tacoma Publishing Service Center

For more information concerning the research in this report, contact the  
Leader, Washington Cooperative Fish and Wildlife Research Unit  
U.S. Geological Survey  
Fishery Sciences Building, Box 355020  
University of Washington  
Seattle, Washington, 98195  
<https://www.coopunits.org/Washington/>

