Analyses of the distribution and population of lesser prairie-chicken (*Tympanuchus pallidicinctus*): With special reference to Kansas populations

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Introduction

In 1995, a petition was presented to the U.S. Fish and Wildlife Service (USFWS) to list the lesser prairie-chicken as threatened under the Endangered Species Act of 1973 (U.S. Fish and Wildlife Service, 2002). After review, the USFWS determined that the listing of the lesser prairie-chicken was "warranted but precluded" by other species priorities. In 2008, the species was reviewed again and was again classified as "warranted but precluded" (U.S. Fish and Wildlife Service, 2008). With no action by the USFWS on behalf of the lesser prairie-chicken, the Kansas Ornithological Society (KOS) petitioned the Kansas Department of Wildlife and Parks (KDWP) to list the lesser prairie-chicken populations in Kansas as threatened under the Kansas Nongame and Endangered Species Act of 1975 (KOS, 2009). I was asked by the Threatened and Endangered Species Task Force, as part of the review process, to examine the distribution and population data associated with the lesser prairie-chicken. The specific questions I was asked to address were:

1. Are the methods and conclusions reported in previous documents valid?
2. How is the lesser prairie-chicken data limited?
3. What assumptions are being made when analyzing this data?

4. What is the proper method to analyze lek and population count data?
5. Does this data set show a trend?
6. What changes should be made in sampling and analysis to improve trend detection in the lesser prairie-chicken?

During my examination of the lesser prairie-chicken, I have added other objectives, but answering these questions is the primary impetus for this review.

Kansas Lek Survey Data

To evaluate the methods and conclusions of previous research, we need to consider some of the data that is central to understanding the status of the lesser prairie-chicken in Kansas: the Kansas lek survey data. The Kansas lek survey data represents a relatively long term attempt to measure the population of the lesser prairie-chicken throughout Kansas. The survey is conducted in late March and April, the time period when males are most likely to visit leks. More males are at leks in the early morning, so this time is used to conduct surveys. The survey consists of different routes. The position of each route is fixed (does not vary year-to-year). Each route is 10 miles long. Surveyors begin the route by listening for 3 minutes and use the booming calls of the males to identify leks and their relative position. The weather can impact the ability of the surveyors to detect leks, so the weather conditions under which the surveys are conducted are specified. After listening for 3 minutes, the surveyor moves 1 mile down the route and then conducts the another 3 minute listening segment. This is repeated until the surveyor has completed the route. After completing the listening portion of the survey, the surveyor returns to each identified lek and flushes the birds on the lek. The position of the lek is noted and the number of birds flushed is counted. If the lek has less than 3 birds, it is not counted. The listening survey is completed twice for each route and, if possible, each lek is flushed and counted twice. This results in a count of leks and flushed birds for each route each year. This description of the surveys was summarized from KDWP (2009).

The survey began in 1964 with 3 routes (Finney, Meade, and Morton Counties)(Rodgers, 2009a). Additional routes were added over time: Clark County, 1966; Kearny, 1978; Hamilton County, 1979; Ford County, 1988; Comanche County, 1991; Barber County, 2000; Kiowa and Hodgeman Counties, 2001; Gove County, 2004; and Ness County, 2006 (Rodgers, 2009a). Two smaller survey routes are also included: Sandsage Bison Range, 1977; and Pratt Sandhills, 1980 (Rodgers, 2009a).

The counts of individuals and leks along these different routes represent samples of the larger population of lesser prairie-chickens in Kansas. Before analyzing these data it is important to recognize the properties of the sample. Three properties of samples that are most often considered are representation, independence, and size. A representative sample is one that effectively describes the population from which it is drawn. The most common sampling method for obtaining a representative sample is random sampling. There is nothing special about random sampling, other than it can produce representative samples (Motulsky, 1995; Ruxton, and Colgreave, 2003). Other sampling methods can also produce representative samples and often with more efficiency (Motulsky, 1995; van Belle, 2002). Random sampling of lesser prairie-chickens in Kansas would not be efficient. With a true random sample, most sampled sites would not have a population of prairie-chickens. To get an adequate sample of places with prairie-chickens we would need a prohibitively large sampling effort. The greatest concern about the routes being representative is that the routes were situated in areas with known populations of lesser prairie-chickens. This will tend to over-represent large and established populations in the analyses. However, it is easier to detect long, sustained trends in large populations, than in small populations that are more prone to high variability.

The limited number of routes surveyed in each time period makes the overall sample sensitive to changes on the routes that are not representative of the changes in the overall population of lesser prairie-chickens. When manipulating the data it is important to consider if the manipulation makes the data more or less representative of the population.

When each datum is a complete measurement and is unrelated to any other datum in the dataset, the sample has independence. When a sample does not have independence, it is said to be autocorrelated. The most common types of autocorrelation in ecological studies are spatial and temporal autocorrelation. Spatial autocorrelation occurs when measurements are similar because they are taken from locations in close proximity to one another. Temporal autocorrelation occurs when measurements are similar because they were taken near the same time. Most of the routes are separated enough in space that they probably are not subject to spatial autocorrelation (though Kearny and Finney County routes and the Sandsage Bison Range are fairly close to one another). Temporal autocorrelation does seem to be an issue with this dataset. The flush count or number of leks on one route during one year is more similar than would be expected by chance to the flush count or number of leks on the same route during the next year. Data resulting from taking the same measurements at the same site over time represents a time series. Each of the routes is a time series. Traditional analyses can not be used on time series data. Traditional analyses performed on time series data tend to overestimate the degrees of freedom and could produce spurious results. Specific analyses are necessary to effectively cope with the temporal autocorrelation found in time series data.

Sample size is another major property of a sample. To a degree, this is related to being representative. The larger the sample size, the more representative the sample is likely to be. The sample size varies over time with the addition of routes. During the earliest part of the lek surveys, there are relatively few routes and we cannot do much with that small sample. Although we currently have more routes, the most recent additions (Gove and Ness Counties) have few measurements. Sample size will influence our ability to make inferences about different time periods.

Another sampling issue of concern is the shape of the routes themselves. Ideally, the routes would have the same shape. However, examination of the routes (Figure 1) shows they vary greatly in configuration. This has an effect on the detectability of leks on the route. For example, consider a route where the route passes under the south edge of a section and then turns north along the east edge of the same section. There would be three listening stops associated with this configuration (one at the southwestern corner, one at the southeastern corner, and one at the northeastern corner). All three of these stops could observe the section in question. In a route with no turns, each section would be observed by only two listening stops. Any lek in the scenario with the turn would have a 50% greater chance of being detected relative to a lek on the section with a straight route. However, this will only be an issue if we try to make comparisons among routes. If we limit our comparisons within routes (e.g. trends), this will not be an issue because the configuration is an intrinsic property of the route and consistency in sampling is the important issue.

<u>Review of Previous Documents</u>

I selected to review three documents that I think are important to the discussion on the listing of the lesser prairie-chickens in Kansas: Jensen et al. (2000), Rodgers (2009), and KOS (2009). I did not select these documents because they were the best or the worst; but because they typified problems of data and analyses associated with this species. I will refer to other documents that also illustrate similar issues. This review will focus on issues of data, analysis, and interpretation relative to data and analysis.

Jensen et al. (2000)

This article examines the status of lesser prairie-chickens in Kansas as it existed in 1998. The bulk of the data used in Jensen et al. (2000) is derived from the Kansas Lek Survey. Data from 8 different survey routes were used. They used lek count per survey route from 1978-1998 and individual count per survey route from 1964-1998. They analyze these data using simple linear regression over time. They also present a map illustrating the historical and current distribution of lesser prairie-chickens in Kansas. They do not indicate the source of the data for the map.

Two of the most commonly used techniques to examine trends in species populations are linear regression and year-to-year comparison by hypothesis testing. Both of these techniques are probably inappropriate for the task.

Jensen et al. (2000) is typical in its use of linear regression. The population or lek data is used as the dependent variable and graphed on the vertical axis, and time is used as the independent variable/predictor/factor and is graphed on the horizontal axis. A simple linear regression resulting in a positive slope would indicate an increasing population, a non-significant or zero slope would indicate no trend or a stable population, and a negative slope would indicate a decreasing population.

There are several problems with this approach. First, linear regression assumes that the independent variable directly influences the dependent variable (Zar, 1999). However, in this usage, it is clear that time does not directly influence the population, rather other variables (available habitat, amount of resources, weather, etc.) that occurred during that time period impact the population, and time is our frame of reference. Second, linear regression assumes that the individual data points are independent of one another (Zar, 1999). Jensen et al. (2000) treated each of the lek and population counts as separate measurements. However, each count is a part of a time series, as discussed above. Their treatment of the time series data as independent points strongly violates the assumptions of the procedure. Third, linear regression assumes linearity (Zar, 1999; Hair et al., 2006). This is most often interpreted as meaning that the relationship between the dependent and independent variable is a straight line. A more correct interpretation of this assumption is that the relationship does not vary with value of the independent variable (the slope is constant). This is clearly not the case when applied to populations over time. As habitat or environmental conditions improve, we expect the population to increase in size, and when habitat and environmental conditions deteriorate, we expect the population to decrease in size. Over a period of time, we might expect several increases and several decreases. Thus, the slope (representing in this approach the relationship between time and the population) would not be constant but would fluctuate. When very few time periods are included in such an analysis, the slope can change radically from one time period to the next with no real indication of a true trend. When there are many time periods in the analysis, the bulk of the older data might hide a recent developing trend or under-represent the magnitude of the recent change.

Despite the inappropriateness of this technique for this type of analysis, its appeal is undeniable. It produces simple to interpret results (scatter points and a trend line) and generalizes the data to a pattern that can be used to describe different populations over a region. However, the technique is inappropriate for the task, and its results should be viewed with skepticism.

Rodgers (2009)

This report reviews the historical and current status of lesser prairie-chicken in Kansas and critiques Jensen et al. (2000) in their use of the Kansas lek survey data. These criticisms should inform any analysis of the Kansas lek survey data.

Rodgers (2009) identifies two major concerns regarding the use of the Kansas lek survey data by Jensen et al. (2000). First, Rodgers critiques the use of data from the Finney and Kearny County survey routes from 1968-1983. Rodgers suggested that the conversion of the sandsage habitat to center pivot irrigated fields during this time period displaced individuals to the remaining native habitat. These displaced individuals inflated the counts of individuals and leks along the Finney and Kearny County survey routes. Rodgers further suggests that use of inflated numbers from this period of time along these routes would produce a greater apparent declining trend than actually occurred. Questions arising from this critique that impact the analysis of the data are the following:

1. Can we confirm the habitat conversion in the area neighboring the Finney and Kearny county survey routes?
2. Did habitat conversion end in 1983 and can we salvage any data prior to 1983?
3. Is it reasonable to assume that individuals displaced from the converted habitat would inflate the numbers of the remaining natural habitat?
4. Is excluding the data from the analyses the proper way to treat the data?

To answer these questions, I requested Landsat Multispectral Scanner data from the USGS Earth Resource Observation and Science Center (USGS EROS) for Finney and Kearny County for 1972-1986. Georeferencing errors in images from 1972-1974 precluded their use in this analysis. From the remaining images, I constructed false color composite images. I also obtained GIS files showing the position of lek survey routes from Mike Houts of Kansas Applied Remote Sensing (KARS). Overlaying the routes and the false color composite images, I was able to illustrate the extent of encroachment by the center pivot irrigated agriculture on the routes in question (Figure 2). The images clearly indicate that the center pivot irrigation fields did encroach on the Finney and Kearny County survey routes. Robel (2001) estimated that by 2001 37% of the sandsage prairie in Finney, Hamilton and Kearny Counties had been converted to other uses. The habitat conversion progressed until 1983 and was complete in 1983. While it can not be determined by the data provided, I think it is reasonable to assume that individuals displaced by the habitat conversion would move to and inflate the population sizes in the remaining native habitat. Rodgers suggests that excluding the Kearny and Finney County data prior to 1984 is the proper way to treat these questionable numbers. Rodgers acknowledges that the losses due to this habitat conversion are real, but justifies the exclusion by noting that while the habitat conversion heavily impacted these two routes, it did not impact the whole population of lesser prairie-chickens in Kansas to the same degree, and including them would misrepresent the changes in that larger population. I concur. Excluding the questionable data probably does make the dataset more representative of the overall population of lesser prairie-chickens in Kansas.

Rodgers (2009) second major critique of the use of the Kansas Lek Survey data by Jensen et al. (2000) was that they combined datasets of different sizes into a single analysis. Rodgers argues that taking older routes with greater counts, and adding newer routes with lower counts, would exaggerate the decline in the lesser prairie-chickens. Again, Rodgers' reasoning is sound. The addition of new sites with a lower mean count can significantly impact the slope derived from linear regression. However, linear regression, as discussed above, is not an appropriate technique for this problem.

As an alternative to the analysis of Jensen et al. (2000) Rodgers offers a graphical approach. He graphs the yearly means for routes over time. This approach has the virtues of being intuitive and flexible, but it obscures the variation between routes and does not produce a general trend.

KOS (2009)

The petition to list the lesser prairie-chicken summarizes the changes in the species' distribution and abundance. The data supporting the petition are drawn from a variety of sources. The petition identifies three measures of threat to the lesser prairie-chicken populations in Kansas: 1. Changes in distribution (which I will examine later in this report); 2. Changes in abundance (which I will examine below); and 3. Hybridization (which I will examine later in this report). The petition also identifies three potential future threats to the lesser prairie-chicken: 1. Conservation Reserve Program (CRP) contract expiration; 2. Continuing development and degradation of native habitats (grazing, fragmentation, and energy development); and 3. Global climate change. The first two of the developing threats depends on human action not yet taken and thus is not amenable to statistical analysis (though modelling such activities could greatly aid conservation efforts). The effect of the loss of CRP and the continued loss and degradation of natural habitats is serious and should be minimized. The third developing threat, global climate change, will be addressed later in this report.

To demonstrate the decline in abundance of lesser prairie-chickens in Kansas, the petition points to four different measures: 1. Population estimates from Cimarron National Grasslands (CNG); 2. Counts from the Christmas Bird Count (CBC) from CNG; 3. Densities derived from the Kansas Lek Survey for Finney County; and 4. A year-to-year statistical comparison derived from the Kansas Lek Survey data (2006-2007). Each of these is examined below.

The petitioners claim that the population estimates in 2005 were 249 individuals, 124 individuals in 2006, and 86 individuals in 2007. The petitioners further claim that this represents a 65% decline in 2 years. This is based on a misinterpretation of the data. In 2005, the yearly status report of lesser prairie-chickens on CNG provided a population estimate. The population estimate was arrived at by multiplying the lek flushes counts by 0.95 to estimate the number of males on the lek, and doubling the estimated number of males to estimate the size of the total population (Augustine, 2005). Since 2005, the yearly status reports of lesser prairie-chickens are of lek flush counts without the calculation of estimated population size (Chappel, 2006). Thus, the comparison in the petition is comparing different measures. Even if the flush counts from two years were the same, the two different techniques for handling the numbers would result in a 48% difference. It should also be noted that the most recent federal review of the lesser prairie-chicken makes the same error (U.S. Fish and Wildlife Service, 2008). Because I have not examined Smith and Smith (1999), I cannot say how their numbers were derived and how they compare to the numbers from 2004-2009. The measures of lesser prairie-chicken abundance for CNG are noted in Table 1. These numbers do suggest some degree of variability, but there is no clear trend, though the decline in 2009 is of concern.

The petition also uses the Audubon Christmas Bird Count data from Cimarron National Grasslands to suggest that there has been a decline. The petition points to the most recent high point in the data, 58 birds in 1989 (though the online database suggests that this value was in 1990 and that there is no measurement for 1989), and then points to lower numbers that have occurred since then. This type of reasoning is found throughout the petition and the recent federal review by the Fish and Wildlife Service (2008). High numbers are noted, and declines from that high are identified as a trend. This is a common error in reasoning called regression to the mean (Motulsky, 2010). In a naturally varying system, once a value has reached a relatively high point, it is much more likely that variation will be downward rather than continuing upward, and it might continue downward past its mean value, without assuming any causation other than natural variation. A more reasonable approach is to ask if the high point could be the result of random variation. If we assume a normal distribution with a mean of 16.8 birds per count period (the long term mean of the CNG CBC data) and a standard deviation of 38.6 birds per count period (the long term standard deviation of the CNG CBC data), then resampling from this distribution suggests that we can expect a value of 58 birds or greater in a count 14% of the time. This suggests that the high point identified in the petition is probably random variation around the mean, and the decrease to lower numbers is due to regression to the mean. However, it should be noted that the 58 birds counted in 1990 and the 212 birds counted in 1979 have a large impact on the long term mean and the long term standard deviation -- making the possibility of large counts more likely. If we exclude these two values as outliers, no trend in the data is evident and the remaining data has a mean of 8.4 birds per count and a standard deviation of 7.2 birds per count. Relative to this mean and standard deviation none of the remaining values are very extreme. Lastly and belatedly, we need to consider if the CBC is adequate to make any statistical inferences. I would suggest it is not. The sampling protocol for CBC is unstructured. A central point is determined and birds within 15 miles of that central point are counted between the 14 December and 5 January. There are no rules on how the habitat is to be sampled, the time of day observations should occur, the total time spent sampling (beyond the minimum requirement of eight hours), how time should be divided between habitats, the expertise of the observers, the number of observers, or the weather conditions under which observations should occur (Francis et al., 2004). Without the guidance of such rules, observers are left to follow their own instincts and interests, which leads to variability in the data (Francis et al., 2004). At large spatial extents, sites can be combined and the variation between observers can be factored out as residual error. At the local level, however, such variation could be mistaken for patterns or trends in the data. Bock and Root (1981) succinctly state "The Christmas Bird Count (CBC) is an enormous but weakly standardized avian count … CBC data are an inappropriate substitute for more controlled census work associated with local projects. Scientists would ignore CBC data altogether, were it not for their potential application to large scale studies."

The Finney County portion of the Kansas Lek Survey Route data is also used in the petition (KOS, 2009) to illustrate the decline of lesser prairie-chickens in Kansas. For the reasons discussed above, this time series is not really representative of the Kansas population as a whole. The encroachment of center pivot irrigation development on this survey route probably inflates the numbers from the late-1960s through the mid-1980s. This would exaggerate the apparent decline. Because the rest of the populations in the state did not experience this type of habitat conversion, extrapolating from this route to the rest of the state would be inappropriate.

The final approach the petition (KOS, 2009) uses to illustrate the decline of lesser prairie-chickens in Kansas is year-to-year comparisons. As mentioned above, this, along with linear regression, is one of the most common ways to demonstrate a trend in population data (e.g. Rodgers, 2007, 2008, 2009b). This approach, like linear regression discussed above, is also not appropriate. There are two different ways that such analyses can be misleading. First, imagine a population that demonstrates no trend, but fluctuates considerably around the mean. Each year we could note a significant difference relative to the prior year, but there would be no real trend. Second, imagine a population with a definite descending trend with a low slope (the population difference between consecutive years is small) and a modest amount of variation around the trend. In such a situation, we might never note a significant difference even as the species goes extinct. The problem with this approach is that we need to compare samples not to one another where small differences might elude us, but to the long term mean (or other measure of central tendency). However, the greater variability associated with the long term values might also hide significant differences. The lack of independence of the data from the same time series is a further complication.

While there are issues with each of the petition's illustrations of decline in the lesser prairie-chicken, the preponderance of the evidence presented, despite its imperfections, does suggest that populations of lesser prairie-chickens in Kansas have declined.

In the remainder of this report I will: 1. Examine the decline in distribution of lesser prairie-chickens; 2. Explore how climate change might influence the distribution of the lesser prairie-chicken in the future; 3. Demonstrate trends that exist in the population and lek data; and 4. Examine the status of hybridization in the lesser prairie-chicken.

Methods and Materials

Changes in Distribution

Data

Data on the historical and current distribution of lesser prairie-chickens was obtained from Megan McLachlan, GIS Analyst, Playa Lakes Joint Venture. The distribution data was provided in the form of shapefiles and represents the consensus distributions determined by the Lesser Prairie-Chicken Interstate Working Group (Davis et al., 2008). Two sets of historical and current maps were provided (referred to here as 2007 and 2008). The 2008 maps are considered to be a more accurate representation of the historical and current distributions of the lesser prairie chicken. The 2007 maps are presented here because they have been used in several other documents and to aid in comparison. Despite being considered more accurate, there is an issue with the 2008 maps. In portions of New Mexico and Texas, the current distribution of the 2008 maps is depicted as overlapping polygons. Analyzing such maps would result in the area of overlap being measured twice – potentially overstating the current distribution. As a conservative remedy, I merged (union) the overlapping polygons to form single polygons in which the area in the formerly overlapping regions would only be measured once. To aid in the discussion of distribution dynamics in Kansas, a map on the recognized distribution of lesser prairie-chickens in Kansas during the 1950s was digitized from a paper copy (Schwilling, 1955).

To examine how the decline in distribution of lesser prairie-chickens compares to other species that have experienced declines, data from 446 species was obtained from the International Union for the Conservation of Nature (IUCN, 2001, 2009) Red List category (critically endangered, endangered, vulnerable, near threatened, and least concerned) and combined with my own data on the distributional decline of those species.

Analysis

Distributional data was imported into ArcGIS 9.2 (ESRI, 2006). Maps were converted to Albers equal area projection and the area of the historical and current distribution was computed for the overall distribution and for the individual states. Maps were produced for visual inspection.

I used logistic regression to examine how the decline in distribution of lesser prairie-chickens compares with the conservation category of other species that have undergone declines in distribution. In this logistic model, area of remaining distribution and percent of historical distribution remaining are used to predict conservation classification. Once the model has been built using the 446 species, it can be applied to the lesser prairie-chicken to predict its IUCN classification based solely on change in distribution.

Climate Change

Data

Historical climate data (1950-2000) and predicted climate data for two green house gas emission scenarios (maximum expected emissions – A2a, minimum expected emissions – B2a; based on the Canadian Centre of Climate Modelling and Analysis (CCCMA) general circulation model (GCM)) for 2050 were downloaded from WorldClim (1 km resolution)(Hijmans et al., 2005). To generate predictions on the effect of climate change on the distribution of a species, it is necessary to construct a species distribution model. In a species distribution model, the environmental conditions (habitat, climate, etc.) at places a species is known to have occurred are used to develop a mathematical model of the environmental conditions under which the species could likely occur. The distributional data to develop the model is most often drawn from large databases. I attempted to download distributional data on lesser prairie-chickens from the Global Biodiversity Information Facility (GBIF). GBIF had 167 records of the lesser prairie-chicken, and most of these represent specimens catalogued in natural history museums. Unfortunately, all of these specimens were collected after serious changes in the distribution of species had already occurred (all collection dates are more recent than 1950). Species distribution models constructed from data limited to times after contractions in the distribution of a species are often biased, and underestimate the historical distribution of the species (Channell, pers. obs.). To overcome this problem, I selected 682 random points within the historical map (2008 version) of the species (Davis et al., 2008) to represent locations where the species potentially occurred (Lawler et al., 2006).

Analysis

Using the historical climate data, and the potential locations of lesser prairie-chickens, I constructed a maximum entropy species distribution model (Maxent 3.3.1, Philips et al., 2006, 2009). Maximum entropy modeling has been shown to perform well under most conditions (Elith et al., 2006; Philips and Dudik, 2008). The model produces a mathematical function that predicts the probability of a species occurring under certain combinations of climate conditions. The function can then be applied to mapped climate data to produce a map of the probability of occurrence of the species over a region. By assigning a threshold probability (below which the species is thought not to occur and above which the species is thought to occur) and applying it to the species' probability map, I can construct a predicted distribution for the species. I set the threshold at the probability at which the 10% of the points the species was thought to occur would be excluded from the predicted distribution (fixed cumulative value 10). This threshold value is a good balance between total area included in the predicted distribution and inclusion of the original potential locations of the species. To predict the future distribution of a species, the model function can be applied to the predicted climate maps to generate a probability of occurrence map and, by applying the same threshold that was used to predict the species' historical distribution, we can predict the distribution of the species in the future for a climate change scenario.

Population Trends

Data

I obtained the Kansas Lek Survey data from Randy Rodgers, KDWP Wildlife Biologist. The population and lek density was graphed for visual inspection. For subsequent analyses, the data was manipulated in two ways: 1. Missing data values were estimated; 2. Separate data sets were constructed to represent specific time periods and differed in which routes were included. Missing values in a large dataset are common and can result from many different reasons (Hair et al., 2006). In this case, the missing data is the result of a route not having been run in a specific year. There are many ways to handle missing data depending on the analyses conducted. I chose to replace a missing datum with the mean of the datum prior to the gap and the datum after the gap. Generally, this would not be a good strategy for addressing missing data, as it would decrease the independence between individual measures. However, because the analytical procedure I have selected (discussed below) is able to handle this lack of independence, this is not an issue. This method of handling missing data will tend to decrease the variance (though not as much as using the long term mean to fill the gaps) and maintains trends that might occur in the time series (which using the long term might obscure). Both of these qualities improve our ability to detect statistical patterns. This technique can not be applied to fill in data prior to the route first being run – thus, gaps in the dataset prior to the start of a route remain gaps. To deal with these gaps, both the population and lek density data were divided into 5 data sets that represent combinations of different routes over the same time periods. These data sets are noted by letter.

A. 1966-2009 Clark, Meade, and Morton survey routes

B. 1984-2009 Clark, Finney, Hamilton, Kearny, Meade, and Morton survey routes

C. 1991-2009 Clark, Comanche, Finney, Ford, Hamilton, Kearny, Meade, and Morton survey routes

D. 2001-2009 Barber, Kiowa, and Hodgeman survey routes

E. 2006-2009 Gove and Ness survey routes

There are several things that need to be noted about these datasets. First, these groupings of data exclude the 1964-1983 data for the Finney and Kearny County survey routes. My reasons for doing this are explained above. Because of this exclusion, the results of this analysis (specifically those from dataset A) should be regarded as somewhat conservative. Second, grouping the routes into a few time-period specific datasets resulted in some data not being used. For example, the Ford County Survey route began in 1988, but only data from 1991 to present is used in any analysis. These exclusions probably have little effect on the results of the data analysis. Third, the datasets, with the exception of D and E, are cumulative. D and E are not cumulative because of the limitations of the analytical procedure (described below). Lastly, data for the Sandsage Bison Range Wildlife Area and the Pratt Sandhills Wildlife Area are not included in any of the datasets. I made this decision for two reasons:

1. The sampling of these routes differs from that of the other sites (they are smaller)
2. These sites are managed by KDWP and the management of these sites is not representative of what is happening to the habitat of lesser prairie-chickens in the rest of the state.

I think that the excluding these sites from the analysis is justified, but again, their exclusion tends to make the results we obtain more conservative.

Analysis

The time series structure of this dataset presents several challenges. Basic time series analysis comes in two types. The first type requires stationarity – the mean and the variability around the mean do not change in time. This is clearly inappropriate as we are interested in trends. The second type of basic time series analysis assumes that the variation in the dataset is the product of regular periodic functions. This does not describe our dataset. Furthermore, basic time series analyses are performed on a single time series and do not generalize across multiple time series. Ideally, the procedure selected should be able to handle time series data, generalize across several different time series, allow populations to grow or shrink over time (not expect a constant rate of increase or a constant rate of decline), it should have the intuitive and visual appeal of linear regression, and, most importantly, it should be able to identify trends.

The appropriate technique for this data analysis is min/max auto-correlation factor analysis (MAFA) (Shapiro and Switzer, 1989; Zuur et al., 2007). MAFA is similar to principal components analysis (PCA) in that it tries to develop new axes that are a composite of multiple different variables. However, with MAFA the different variables are separate time series. Also, rather than developing a new axis that maximizes the variation across variables as does PCA, MAFA develops its axes to maximize the variation explained with time – a trend. The significance of the trend is assessed with a permutation test. The fit of the trend to each of the time series can be assessed by examining its canonical correlation to the trend (similar to loadings in a PCA). The score of the axis can be graphed against time so that the trend can visualized. There are two limitations of the technique relative to its application with the Kansas Lek Survey Data. First, the data needs to cover a consistent time period. Hence, I have divided the analyses into several consistent time periods. Second, the number of time periods in the dataset has to be greater than the number of different routes. This is why the datasets D and E are not cumulative. They would have too many routes relative to the number of time periods. I used Brodgar, Version 2.6.1 to perform the MAFA (Highland Statistics Limited, 2009). Results of the analysis are presented in tables and graphed.

Hybridization

Data

Data on the status of hybridization between lesser and greater prairie-chickens in west-central Kansas was obtained from Matt Bain, KDWP District Biologist. He conducts the yearly survey of leks in the region where the distribution of the two species overlap and where hybridization might occur. He provided counts of the number of hybrids, lesser prairie-chickens, and greater prairie-chickens on mixed species leks 2004-2009.

Analysis

The small number of hybrids and the relatively short time series of the data rules out any statistical analysis. The data were graphed for visual inspection

Statistical significance was set at 0.05 for all statistical analyses. Unless otherwise indicated, I used R Version 2.10.1 for statistical procedures and graphing (R Foundation for Statistical Computing, 2009). I have reported my results using United States customary system of units rather than the scientifically preferred Standard International (metric) units for consistency with existing KDWP data and to facilitate discussion.

Results

Changes in Distribution

The historical distribution of the lesser prairie-chicken covered approximately 180,180 sq. miles. Only 23,000 sq. miles (12.8%) of that distribution remains (Table 3). Maps illustrating the decline in the distribution are presented in Figure 3. The historical distribution of the lesser prairie covered much of western Kansas (29,640 sq. miles or 16.4% of the historical distribution)(Figure 4). The distribution declined precipitously and was estimated in the 1950s to occupy 3,980 sq. miles of southwestern Kansas. Since the 1950s, the distribution has increased to occupy 11,230 sq. miles of western Kansas (Figure 4). Kansas has about half (48.8%) of the current distribution of the lesser prairie chicken.

There is no statistical treatment that can determine what constitutes a significant decline in a species or is sufficient for listing a species. To illustrate the degree of the decline in the species distribution, I chose to graphically and statistically compare the decline of lesser prairie-chickens with other species that have shown distributional declines that are listed by the International Union for the Conservation of Nature (IUCN). Figure 5 indicates that there is broad overlap between the five classifications based on the degree of decline in distribution as measured by remaining (current) distribution size and percent of historical distribution remaining. Despite the overlap illustrated in Figure 5, the logistic regression was able to separate the groups ($X^2 = 193.299$, df = 8, p <

0.001). However, the logistic regression only predicted the correct classification for species based only on distribution declines about one third of the time (Nagelkerke pseudo-r^2 = 0.368). When the remaining distribution size (23,000 sq. miles) and percent of historical distribution remaining (12.8%) for the lesser prairie chicken were applied to the logistic regression equation, it predicted that the lesser prairie chicken would be classified as endangered with a probability of 0.31. The lesser prairie-chicken is listed in the IUCN Red List as vulnerable (IUCN, 2009).

Climate Change

The probability maps generated by the maximum entropy model are included in Figure 6. The warmer colors (reds) represent areas with higher probability of the climate conditions being appropriate for the species. Areas represented in cooler colors (blues) have lower probability of climate conditions being appropriate for the species. The maps do not represent the availability of habitat or the occupancy of the species. The species is unlikely to occur in areas with inappropriate climatic conditions, but it might not occupy all of the areas with appropriate environmental conditions for any of a variety of reasons (e.g. lack of habitat). For example, there are many areas in Figure 6a which are red, indicating appropriate climatic conditions, but are currently not occupied by the species (Figure 3a). Climatic variables that were important in determining the distribution of lesser prairie-chickens were April precipitation (contributing

16.7% to the model), May precipitation (14.3%), July maximum temperature (14%), and February maximum temperature (12.2%). These variables' percent contribution to the model should be interpreted with caution as there was considerable correlation between climatic variables. A threshold of 0.370 (fixed cumulative value 10) was applied to the probability maps to generate the predicted distributions. Areas with a probability less than 0.370 were not included in the predicted distribution. Areas with a probability greater than 0.370 were included in the predicted distribution of the species. Predicted distribution maps are present in Figure 7. The generated historical distribution (Figure 7a) was significantly better than random at predicting sites thought to have been occupied by lesser prairie-chickens in the past (AUC = 0.861, $p < 0.001$). In Figure 7b, the consensus historical range (Davis et al., 2008) is presented with the Maxent predicted historical distribution for comparison. With the minimum expected climate change scenario for 2050 (Figure 7c), the appropriate climatic conditions expand to the north, holes develop in southwest Kansas and the panhandles of Oklahoma and Texas because of drier conditions, and the southern edge shifts north. With the maximum expected climate change scenario for 2050 (Figure 7d), western and northern portions of the species historical distribution are expected to be too hot and too dry for lesser prairie-chickens, the distribution shifts slightly to the east, and the southern edge moves north.

<u>Population Trends</u>

Lesser prairie-chicken density and lek density are graphed for each route on Figures 8 and 9 respectively. Temporal scales and density scales are constant to facilitate comparisons. The densities seem low (compared to occasional highs values) and relatively constant, but punctuated with some variability. There is some variability between routes.

The density trend for the Clark, Meade, and Morton County survey routes 1966-2009 (Figure 10a) suggests that populations rose in the late 1960s, were relatively high and steady through the 1970s and 1980s, declined in the 1990s, rose through the early and mid-2000s, and have recently and sharply declined. This trend is statistically significant ($p < 0.001$) and best describes the Clark and Meade County survey routes (Table 4). Lek density trends for the same routes over the same time period (Figure 11a) show a different pattern. Lek density on these routes is relatively high during the late 1960s and early 1970s and declines fairly consistently over the next 40 years. The trend is statistically significant ($p < 0.001$) and effectively describes the Morton County survey route, but is ineffective at describing the Clark and Meade County survey routes (Table 5).

The density trend for Clark, Meade, Morton, Finney, Hamilton, and Kearny County survey routes 1984-2009 (Figure 10b) suggests that populations were relatively high in the mid-1980s, declined in the late 1980s, remained relatively low until increasing again in the early 2000s, and have recently and sharply declined. This trend is statistically significant ($p < 0.001$), best describes the Meade, Morton, and Kearny County routes, and poorly describes the Hamilton county route (Table 4). Lek density trends for these routes over the same time period (Figure 11b) were steady through the late 1980s, declined during the 1990s, rose and were relatively high in the 2000s and sharply declined in recent years. This trend is statistically significant ($p = 0.004$) and best describes the Hamilton County survey route (Table 5).

The density trend for Clark, Meade, Morton, Finney, Hamilton, Kearny, Comanche and Ford County survey routes 1991-2009 (Figure 10c) reveals densities that were relatively low in the 1990s, rising until 2000, and declining since. This trend is statistically significant ($p = 0.009$), best describes the Hamilton County survey route, and poorly describes the Finney and Comanche County routes (Table 4). Lek density trends for the same routes over the same time period (Figure 11c) are high in the early 1990s, declined until the mid-1990s, rose until the early 2000s, and have been declining since. This trend is statistically significant ($p = 0.014$) and best describes the Finney and Ford County survey routes.

The density and lek density trends for Barber, Kiowa, and Hodgeman County survey routes 2001-2009 and Gove and Ness County survey routes 2006-2009 will not be considered further here. Only 1 of the 4 trends is statistically significant and the time series are very short. The graphs are provided for completeness (Figures 10d-e and Figures 11d-e).

Hybridization

The data we have on hybridization (Figure 12) is a short time series and consists of relatively small numbers. The graphs indicate that only a small number of leks contain hybrid individuals and that those individuals are only a small percentage of the leks.

Discussion

Changes in Distribution

The distribution of the lesser prairie-chicken has changed considerably (87.2% decline). Fortunately, Kansas has been able to retain a relatively large portion of the species distribution (48.8% of the current distribution) However, the paired snapshots of the historical and current distributions do a poor job of capturing the dynamics of species' geographic ranges (Channell and Lomolino, 2000; Gaston, 2003). If we just focus on the historical and current distribution, the distribution in Kansas appears to have declined 62.0%, but we would fail to recognize that the distribution in the past had demonstrated a 86.6% decline (Schwilling, 1955; though see Hagen (2003) for a more complete historical review of the occurrence of lesser prairie-chicken in west-central Kansas).

The areas and related percentages that I have reported are slightly different from the numbers other researchers have reported. There are two reasons for these discrepancies. First, the map on which I based my calculations is more recent. Noteworthy changes to this map, compared to prior maps, are the extension of the historical distribution in central Colorado and changes to the representation of the current distribution in New Mexico, Oklahoma, and Texas. These changes are not thought to represent real changes in the distribution of the species from prior maps, but are refinements of our understanding of the species' spatial distribution.

While the logistic regression was statistically significant, its predictive power was somewhat weak. The results are, however, interesting. The logistic regression suggested that based only on distributional status that the lesser prairie chicken is most similar to species that are classified by IUCN as endangered. However, the lesser prairie-chicken is classified in the IUCN Red List database as vulnerable (one classification lower than endangered)(IUCN 2009). This suggests that the change in distribution of lesser prairie chicken is more severe than that of most other species classified as vulnerable.

Changes in the distribution of lesser prairie-chicken are often attributed to extreme weather and the expansion of agriculture (Schwilling, 1955; Bailey and Williams, 2000; Giesen, 2000; Woodward and Fuhlendorf, 2001; Fuhlendorf et al., 2002; Hagen, 2003; Robel et al., 2004; and Rodgers 2009). There is excellent research documenting the effect of agriculture and other forms of habitat degradation on the distribution and populations of lesser prairie-chickens. However, while the effect of weather on the lesser prairie-chickens is often cited, there is little research to demonstrate the effect of different types of weather on the distribution and populations of lesser prairie-chickens.

It is important to remember that the changes in the limits of the species distribution are a reflection of the loss of populations in those areas. While we do not know the population structure of those areas the species no longer occupies, the changes in the distribution of the lesser prairie-chicken represent major changes in the overall population.

Climate Change

The petition (KOS, 2009) generalizes from a previous study of the potential effect of climate change on grassland birds to suggest reductions in area of distribution and shifts in the appropriate habitat. In this report, I examined the effect of two different greenhouse gas emission scenarios on the distribution of prairie-chickens. For the minimum expected emission scenario, the climatic conditions appropriate for the lesser prairie-chicken (Figure 7c) shift northward. There are areas in the panhandles of Texas and Oklahoma and southwestern Kansas that are predicted to become too dry for the lesser prairie-chicken. For the maximum expected emission scenario, the distribution of climatic conditions appropriate for the lesser prairie-chicken changes dramatically. Much of the western and northern portions of the species historical range become too dry and warm for the species. These results are consistent with the model's recognition of spring precipitation and summer maximum temperatures as having strong impact on the historical distribution of the species.

There is no way to currently confirm the accuracy of the predictions generated from the species distribution model. However, the effect of spring precipitation and summer maximum temperatures on lesser prairie-chicken populations can be investigated using existing weather records and the Kansas Lek Survey data. If statistical relationships are found between weather and population dynamics, then the relationships used to develop the species distribution model might be supported.

If the climatic conditions appropriate for lesser prairie-chickens do shift as predicted by the species distribution model, then it is important to consider availability of habitats in those area to which the species might move. A broader view of lesser prairie-chicken habitats might also encourage the proper management of habitats now considered marginal, particularly on the east and possibly north edges of the species distribution. Research suggests that landscape factors play an important role in the populations of lesser prairie-chickens (Woodward and Fuhlendorf, 2001; Fuhlendorf et al., 2002). If the species distribution shifts to track changing environmental conditions, then it will be important to recognize how landscape features might hinder that movement and provide proactive management remedies.

Population Trends

The trends we see in the Kansas Lek Survey Route data are not as simple as the line of a linear regression. Populations rise with beneficial weather, fall with harsh weather, and are cut down by habitat loss. These factors vary across western Kansas and they vary with time. Despite this variation, patterns do emerge from the data. First, the little data we have from the 1960s and 1970s suggests that density and lek density were higher during this time period and have declined since. Incorporating the more recent data, we can see other consistent patterns and have greater confidence in those patterns. The trend data strongly suggests that density and lek density declined and stayed low in the 1990s, rose in the early 2000s, and has recently sharply declined. The question becomes, on which of these should we focus? The slow erosion since the 1960s has the smallest spatial extent and the least data for one specific time period. The losses of the 1990s were largely replaced by the gains of the 2000s. Ultimately, we have to focus on that part of the analysis where we have the best data and can be most confident of the pattern – the recent sharp declines. The declines in late 2000s are as steep as any other part of the trends and they are already almost as deep as any other part of the trends (indicating small populations or a low number of leks).

Throughout the trend analysis, I have grouped routes by time to make best use of the time series data. Another valuable approach would be to group the routes by region and trim the period to the shortest included time series.

This approach might generate stronger trends if population dynamics are strongly influenced by regional weather patterns or region specific landuse dynamics.

A complimentary approach to the trend analyses presented here would be to look at the factors that drive population dynamics. What trends do we see in habitat destruction or degradation? What is the frequency and intensity of environmental variation and do those measures have a trend? How do the trends in those factors contribute to the trends observed in the lesser prairie-chicken? With the appropriate data, these questions could be answered using a slight modification of the MAFA used here.

Hybridization

The current data show that hybridization is a relatively minor aspect of lesser prairie chicken populations in western Kansas. The data presented here almost certainly overstates the role of hybridization within this area. Most of the leks in the region of overlap between lesser and greater prairie-chickens consist of only one species and will not produce hybrids (Bain, pers. comm.). Focusing only on the leks where both species occur or that have hybrids tends to exaggerate the frequency of hybridization. However, the frequency and distribution of hybridization does merit continued observation.

The major threats associated with hybridization are introgression and lost reproductive potential. Introgression occurs when a hybrid mates with one of the parental species. If introgression occurred, a maladaptive allele or chromosomal configuration might be introduced into the parent population. Greater and lesser prairie chickens co-occurred throughout this region in the past and hybrids were probably produced. In a study that considered mate choice on leks with hybrids, no female was ever observed selecting a hybrid as a mate (Bain, 2002). Female mate choice might limit the potential for introgression. The only currently obvious negative aspect to the hybridization is the loss of reproductive potential. The potential production of lesser prairie-chicken offspring is reduced slightly whenever a lesser prairie-chicken mates with a greater prairie-chicken. However, given the small number of hybrids that have been observed, the lost reproductive potential would also be small. However, if hybridization was to become much more common, the decrease in reproductive potential could affect population sizes.

Survey Recommendation

I think that the current system of lek surveys is probably an effective measure of the status of lesser prairie chickens in Kansas. My only recommendation to improve the system is that a small number of random samples be conducted each year in likely lesser prairie chicken habitats. These samples should not be used to calculate population sizes or generate trends. The purpose of these samples would be to better understand the distribution of lesser prairie chickens in Kansas and monitor possible changes in the distribution.

Once identified, new areas with lesser prairie-chickens might be considered for permanent survey routes.

Research Recommendation

We need to better understand how habitat changes and weather impact the lesser prairie chicken populations in Kansas and more specifically along the lek survey routes. The effect of habitat destruction and degradation has been noted as having a strong effect on lesser prairie chicken populations (see references noted above). The effect of weather on lesser prairie chicken populations is often mentioned, but there is considerably less research on it (see references noted above). The lek survey routes are subject to both the effects of habitat alteration and weather. For example, the conversion of native habitats along a survey route to agricultural production will ultimately decrease the number of birds surveyed along the route, but the populations along the route are also subject to the variability of the weather which might also decrease the population. While the effects of the habitat conversion and weather in this example might have had similar short term effects, the long term effects are quite different. The population might recover from an ice storm, but is unlikely to recover from loss of habitat (unless there is habitat reclamation or remediation). In this case, the habitat loss is the signal that generates the trend and the weather is the noise that obscures the signal – we cannot tell if a decrease is due to habitat change (permanent) or due to weather (potentially recoverable). By better understanding the noise (weather's effect on lesser prairie chickens), we can statistically remove the effect of the noise and better detect the true trends in the data. The results of the climate change analysis above suggest we might be reaching a time where climate/weather becomes the signal. If we understand how weather influences the lesser prairie-chicken populations now we will be in better position to manage those populations in the future.

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Table 1. Abundance estimates for lesser prairie-chickens on Cimarron National Grasslands. The numbers used in the petition (KOS, 2009) are highlighted for comparison. The data presented are from Augustine (2004 and 2005) and Chappell (2005, 2006, 2007, 2008, 2009).

Year	Population Estimate	Lek Flush Counts*	Reference
2004	201-318	88	Augustine, 2004
2005	249 [a]	131[a], 109[b]	[a]Augustine, 2005; [b]Chappell, 2005
2006	Not reported	106	Chappell, 2006
2007	Not reported	86	Chappell, 2007
2008	Not reported	89	Chappell, 2008
2009	Not reported	53	Chappell, 2009

* Average number of birds

Table 2. Audubon Christmas Bird Count Data for Cimarron National Grasslands. Data was obtained by download from http://audubon2.org/cbchist/count_table.html. Only years with observer hours reported are shown.

Year	Number of lesser prairie-chickens	Observer hours
1976	28	15
1977	4	30
1978	7	33
1979	212	28
1980	3	38
1981	5	32
1982	3	39
1983	8	35.8
1984	3	41
1985	16	50.8
1986	4	24
1987	12	40
1988	7	27
1989	Not reported	Not reported
1990	58	45
1991	5	33
1992	Not reported	Not reported
1993	21	30
1994	12	69.8
1995	2	32
1996	2	34
1997	Not reported	Not reported
1998	4	38
1999	3	53
2000	20	20
2001	2	55
2002	3	47
2003	12	49
2004	22	50
2005	8	42
2006	5	40
2007	Not reported	Not reported
2008	0	31
2009	13	27

Table 3. Measures of the decline in distribution of lesser prairie-chicken. Areas are rounded to the nearest 10 sq. miles.

	2008			
	Historical		Current	
State	**sq. miles**	**% of total**	**sq. miles**	**% of total**
Colorado	12,540	7.0	1,620	7.0
Kansas	29,640	16.4	11,230	48.8
New Mexico	20,300	11.2	3,140	13.7
Oklahoma	26,430	14.7	2,930	12.7
Texas	91,270	50.7	4,080	17.7
Total	180,180	100	23,000	100

Table 4. Density trend significance and canonical correlations for each route to trends. Canonical correlations near 1 indicate that the variability of the route's density was similar to the overall trend. Canonical correlations near 0 indicate the variability of the route's density is not similar to the overall trend. Comparisons are only valid within a column.

	Density Trends				
	A	**B**	**C**	**D**	**E**
Survey Route	**1966-2009**	**1984-2009**	**1991-2009**	**2001-2009**	**2006-2009**
Clark	0.9199	0.4475	0.2074	-	-
Meade	0.8532	0.8715	0.3046	-	-
Morton	0.2769	0.8176	0.2850	-	-
Finney	-	0.4745	0.0989	-	-
Hamilton	-	-0.0066	0.9452	-	-
Kearny	-	0.7219	0.5900	-	-
Comanche	-	-	-0.0107	-	-
Ford	-	-	0.4647	-	-
Barber	-	-	-	0.4497	-
Kiowa	-	-	-	-0.5094	-
Hodgeman	-	-	-	0.6293	-
Gove	-	-	-	-	0.4280
Ness	-	-	-	-	0.9863
Significance	$p < 0.001$	$p < 0.001$	$p = 0.009$	$p = 0.097$	$p = 0.569$

Table 5. Lek density trend significance and canonical correlations for each route to trends. Canonical correlations near 1 indicate that the variability of the route's lek density was similar to the overall trend. Canonical correlations near 0 indicate the variability of the route's lek density is not similar to the overall trend. Comparisons are only valid within a column.

	Lek Density Trends				
	A	B	C	D	E
Survey Route	**1966-2009**	**1984-2009**	**1991-2009**	**2001-2009**	**2006-2009**
Clark	-0.0995	0.6705	0.3337	-	-
Meade	0.0816	0.5539	0.2713	-	-
Morton	0.9912	0.1345	0.6005	-	-
Finney	-	0.2725	0.8683	-	-
Hamilton	-	0.9766	0.4647	-	-
Kearny	-	0.4043	0.1679	-	-
Comanche	-	-	0.1378	-	-
Ford	-	-	0.7040	-	-
Barber	-	-	-	0.2072	-
Kiowa	-	-	-	-0.5465	-
Hodgeman	-	-	-	0.3987	-
Gove	-	-	-	-	0.9117
Ness	-	-	-	-	0.4109
Significance	$p < 0.001$	$p = 0.004$	$p = 0.014$	$p = 0.036$	$p = 0.514$

Figure 1. Location of the lesser prairie-chicken survey routes in Kansas. Individual routes are noted by letter.

A. Finney
B. Meade
C. Morton
D. Clark
E. Kearny
F. Hamilton
G. Ford
H. Comanche
I. Barber
J. Kiowa
K. Hodgeman
L. Gove
M. Ness
N. Sandsage Bison Range Wildlife Area
O. Pratt Sandhills Wildlife Area

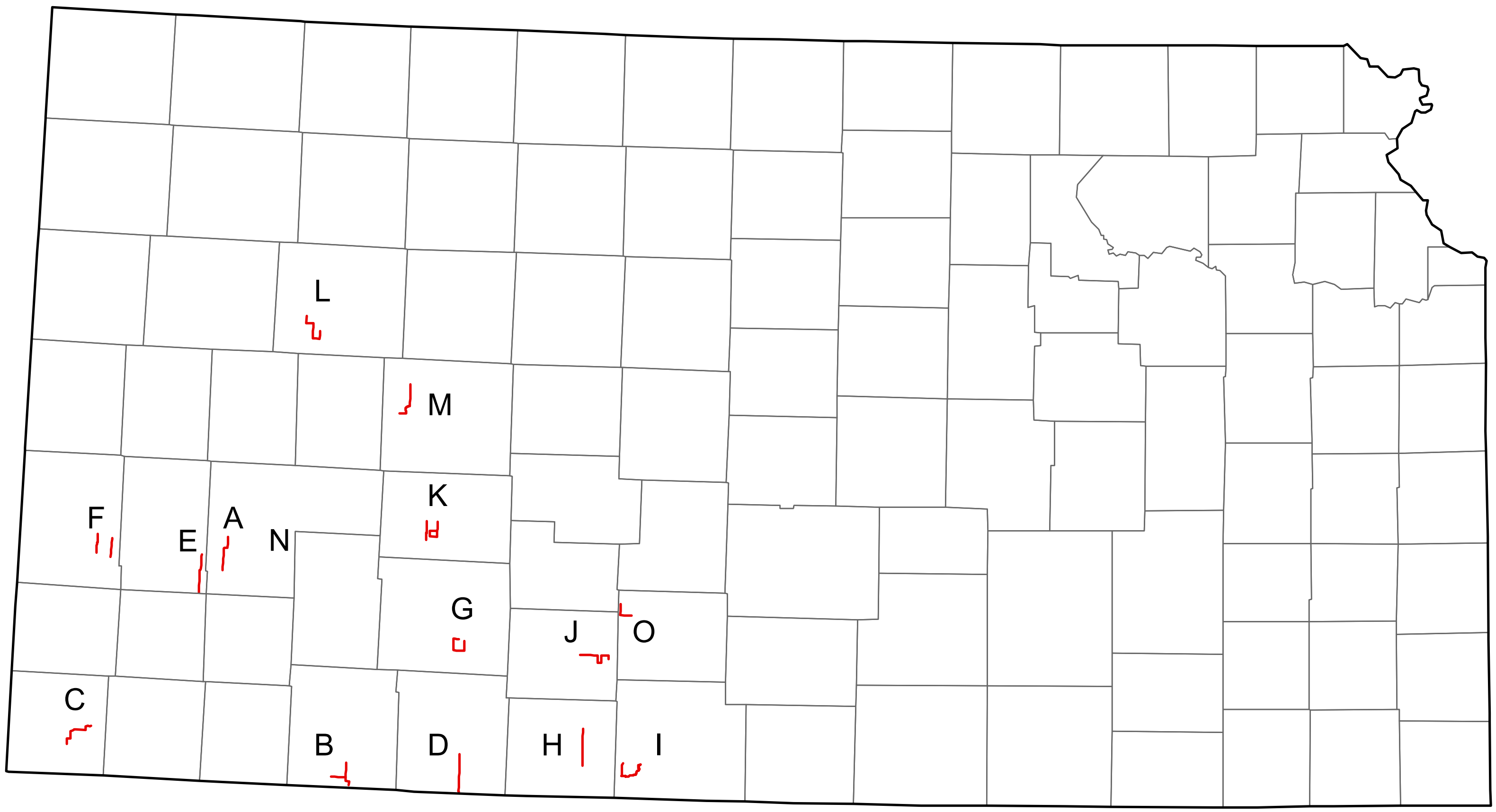
L
M
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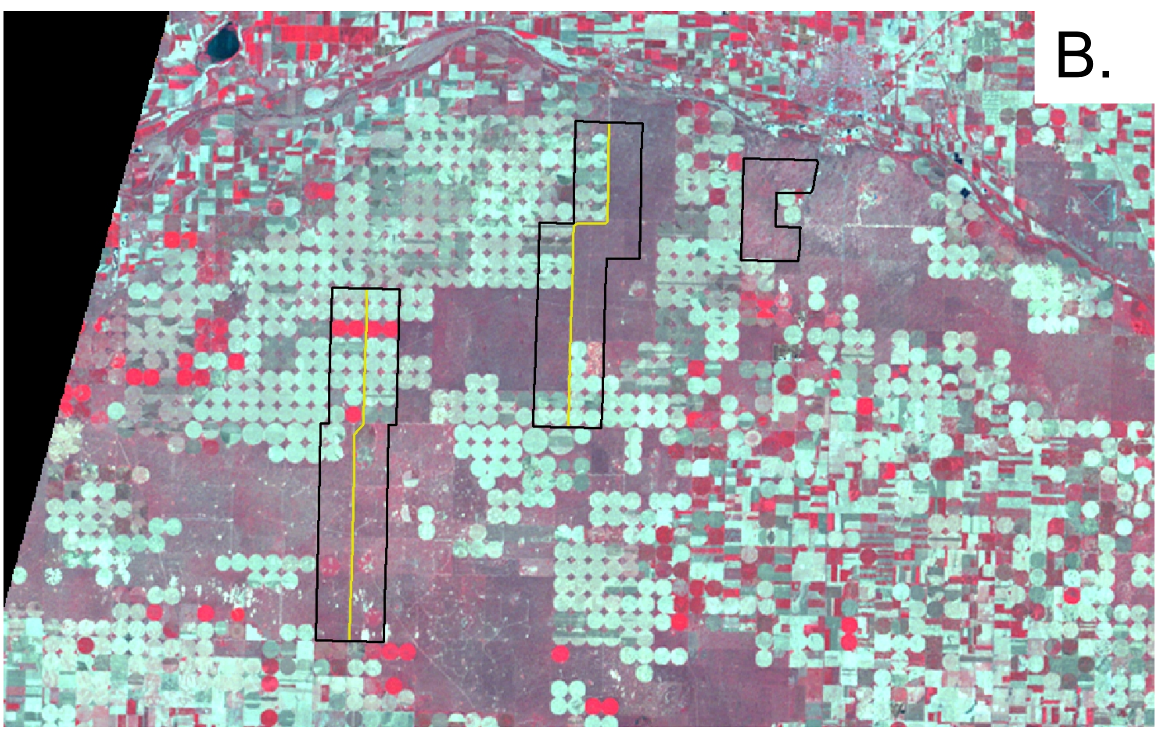
Figure 2. False color composite images (Multispectral Scanner – Landsat) of eastern Kearny County and western Finney County. The yellow lines represent the Kearny and Finney county survey routes respectively. The areas within the black lines represent the survey areas. The area outlined in black which does not contain a yellow survey route is the Sandsage Bison Range Wildlife Area. The red and green circles in the images are center pivot irrigation fields. Color differences between images are due to different crops planted, variation in growing conditions, and time of the year and the time of the day the images were taken. The black area on image B is the edge of the sensor scan. There is a slight georeferencing error in image C.

A. 13 July 1977
B. 14 June 1979
C. 10 December 1983
D. 9 November 1986


A.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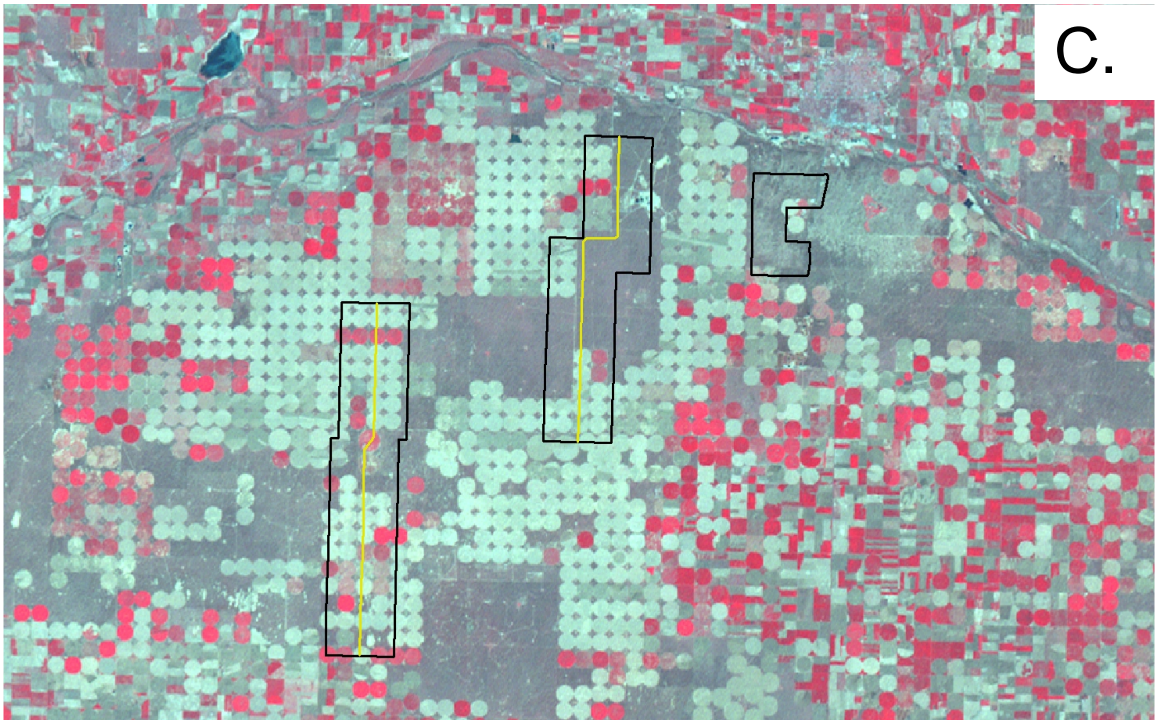
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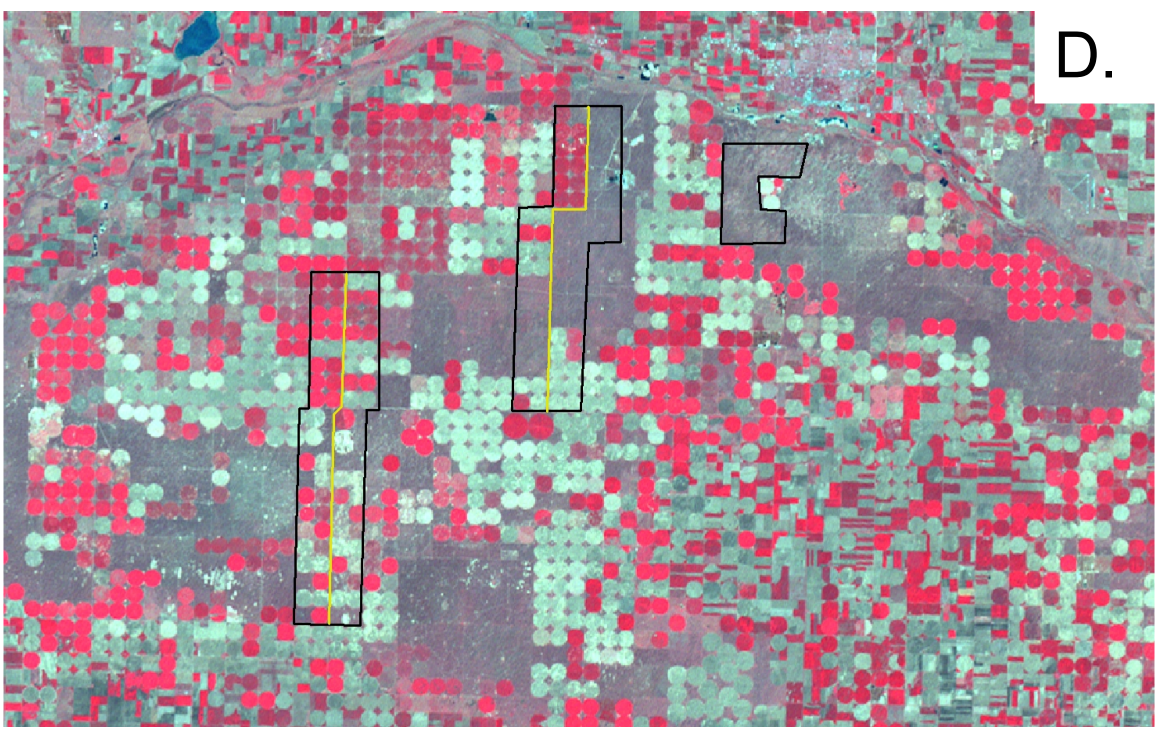
D.

Figure 3. The historical (red outline) and current (gray areas) distribution of lesser prairie-chickens. **A.** Distribution as considered in 2007. This map is the basis for many calculations prior to 2010 and provided here for comparison. **B.** Distribution as considered in 2008 by the Lesser Prairie Chicken Interstate Working Group (Davis et al., 2008). Note extension of historical range into central Colorado and changes in the current distribution in Oklahoma, Texas and New Mexico. It is not thought that the differences in the 2007 and 2008 maps represent actual changes in the distribution of the species, but rather improvement in our understanding of the distribution. Difficulties with the 2008 map are commented on in the text.

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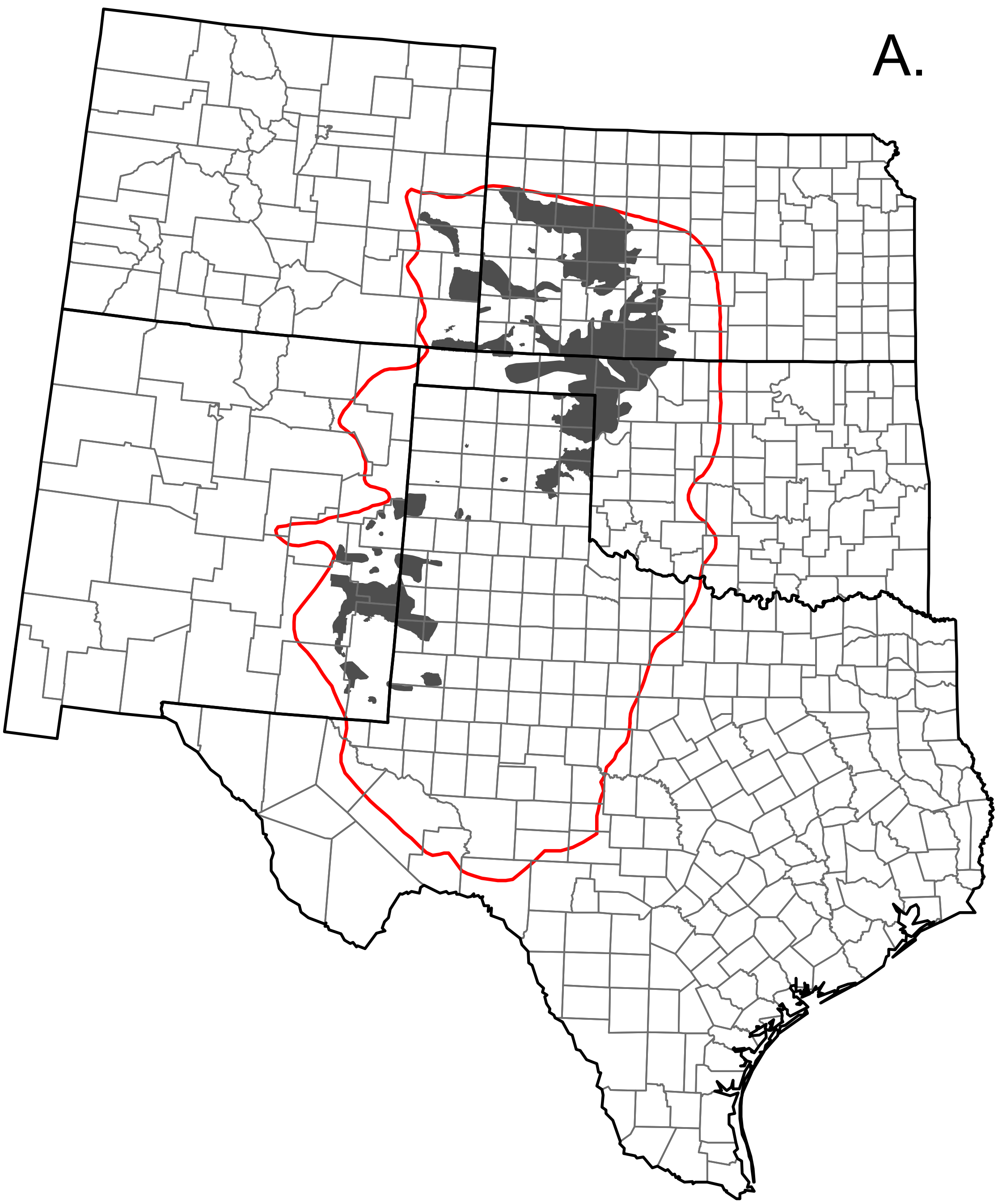

A.

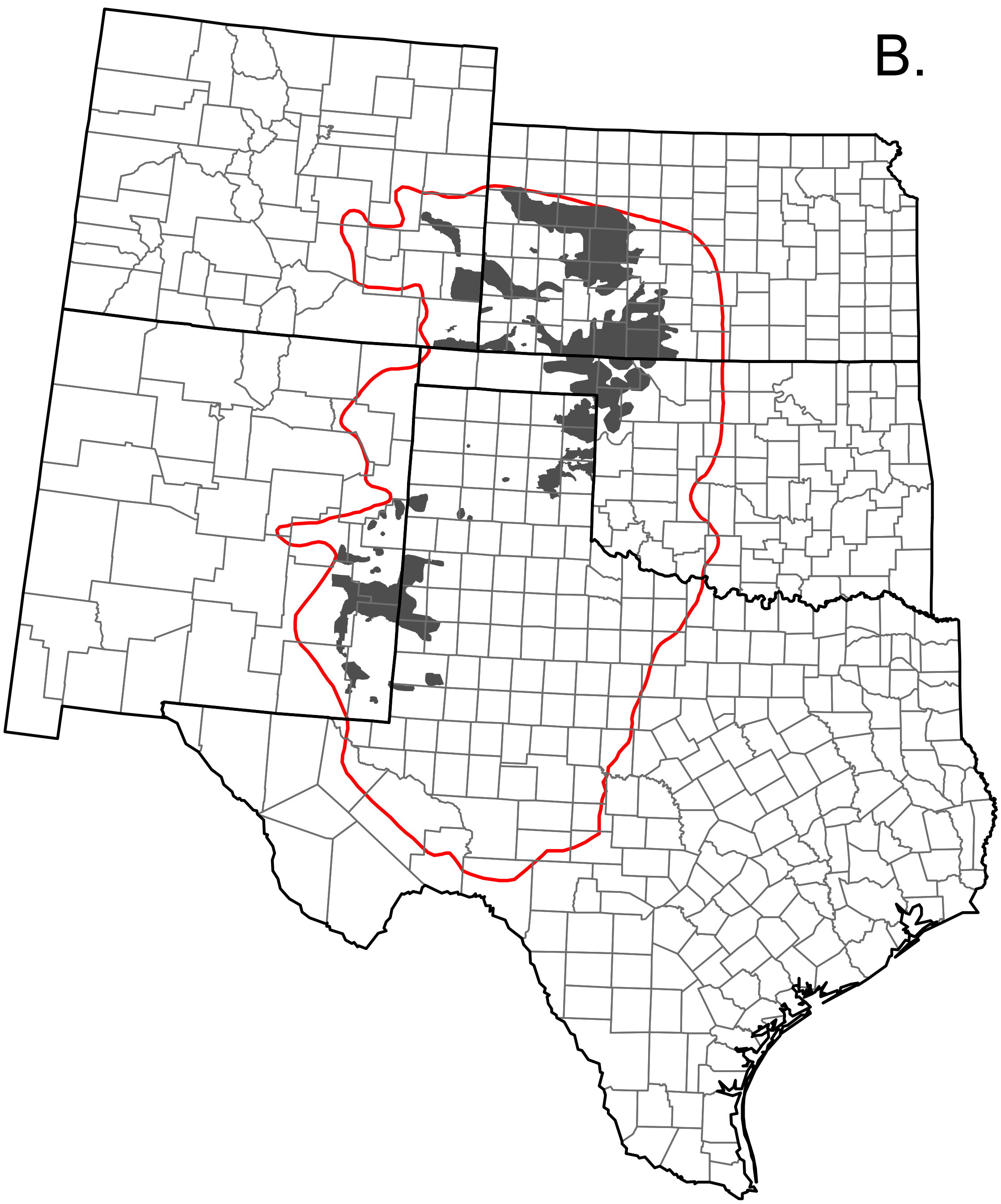
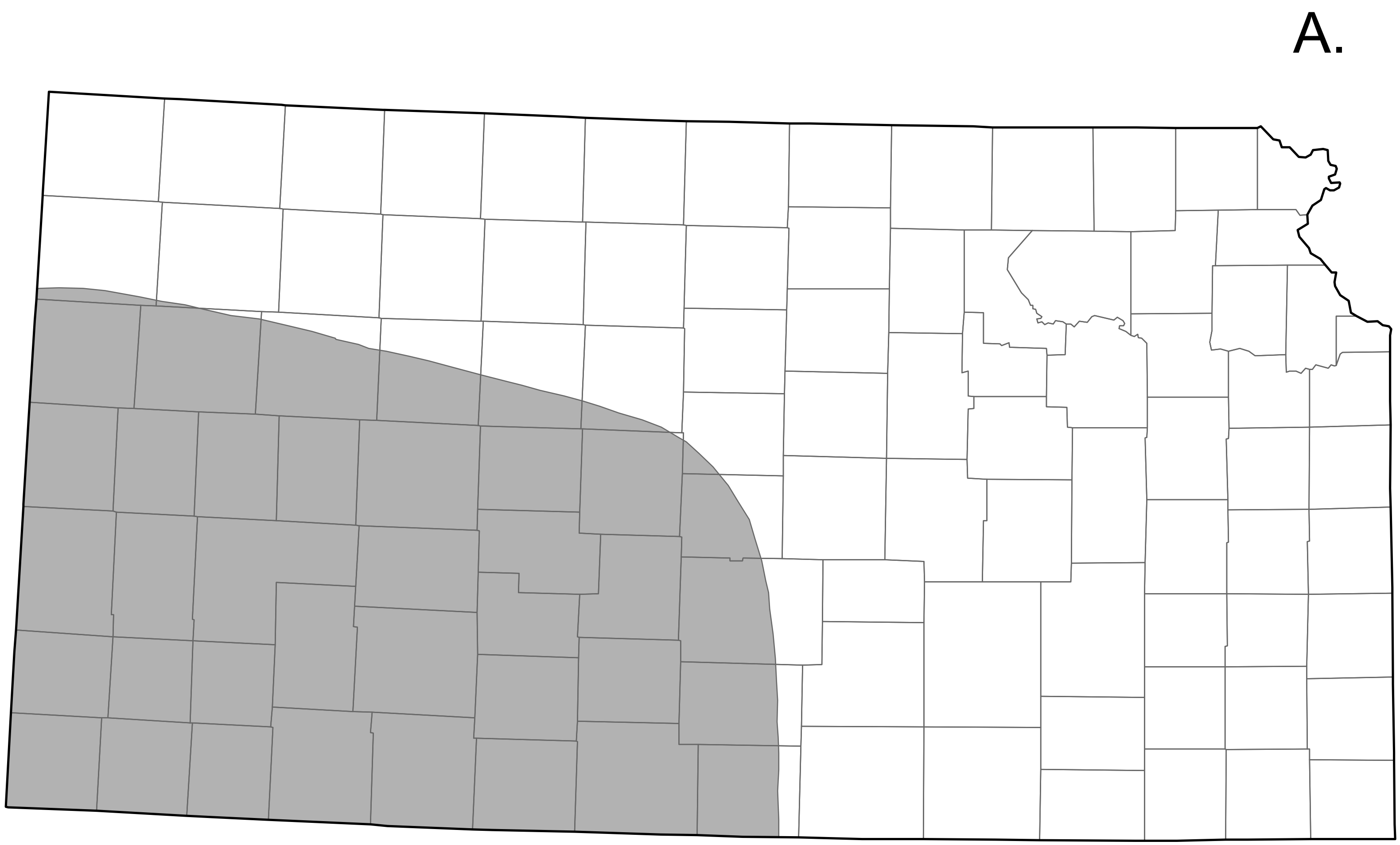
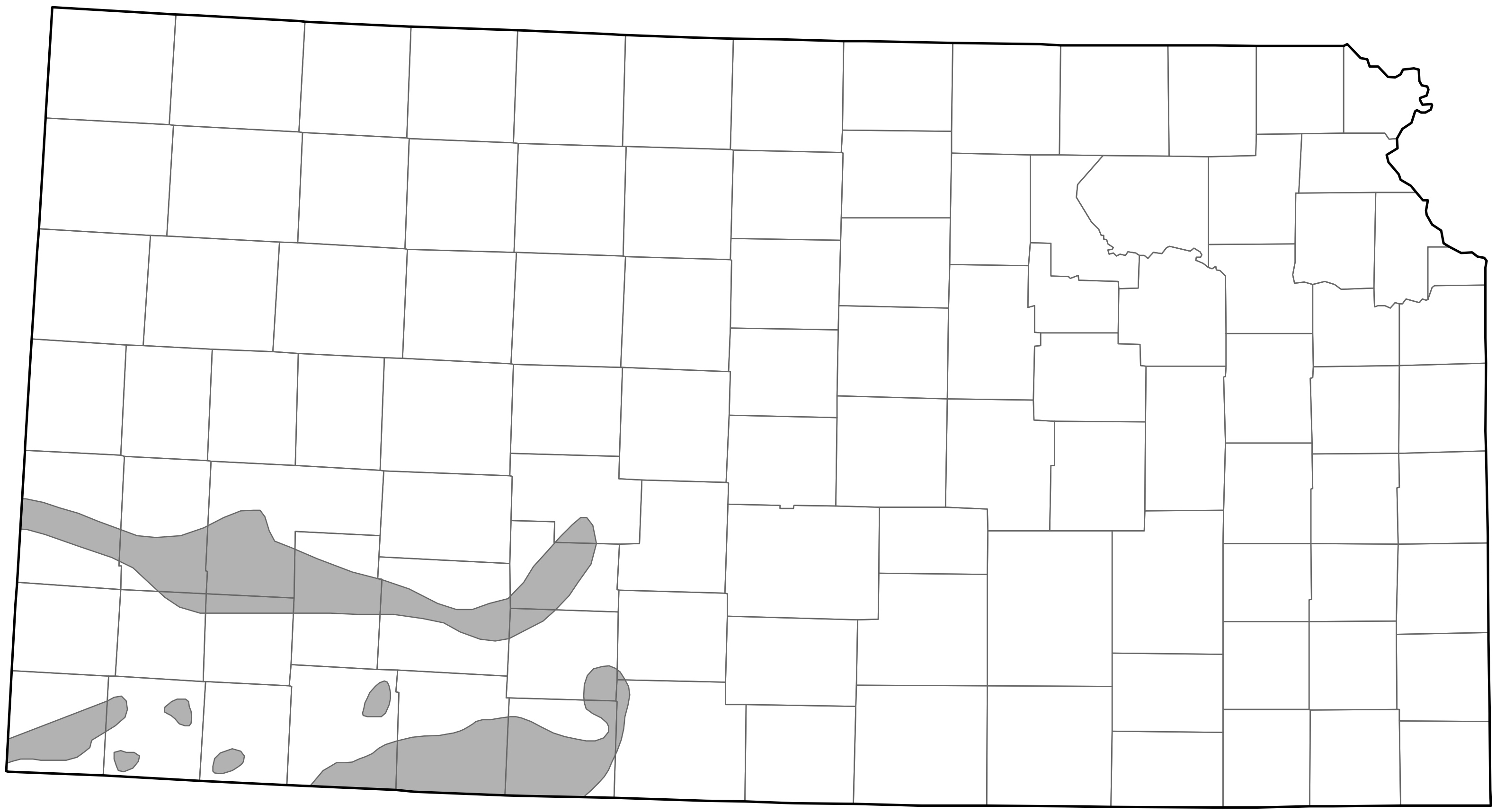

B.

Figure 4. The distribution of lesser prairie-chickens in Kansas. **A.** Historical distribution (Davis et al., 2008). **B.** Distribution in 1955 (Schwilling, 1955). **C.** Distribution in 2008 (Davis et al., 2008).


A.


B.

C.

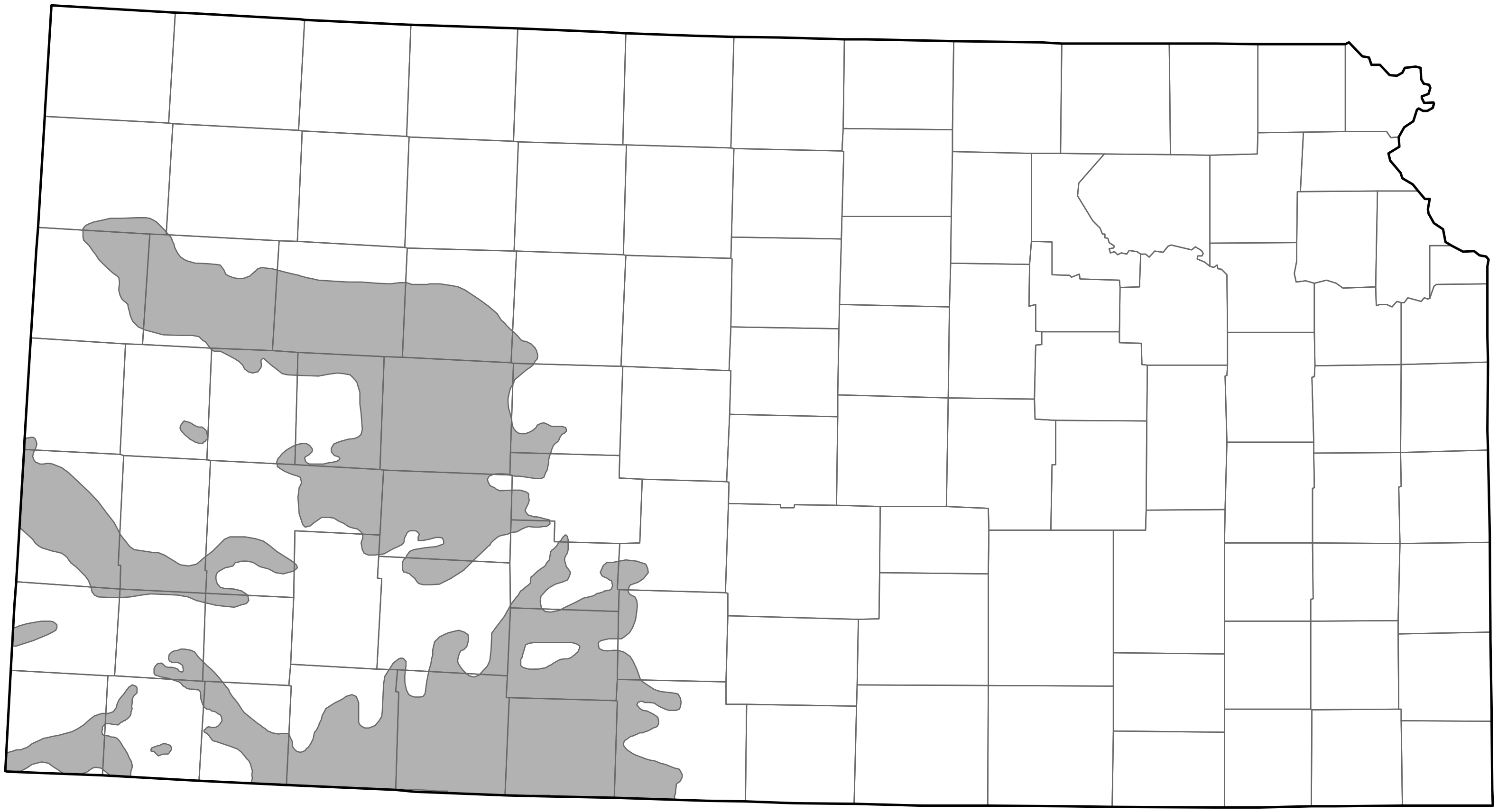
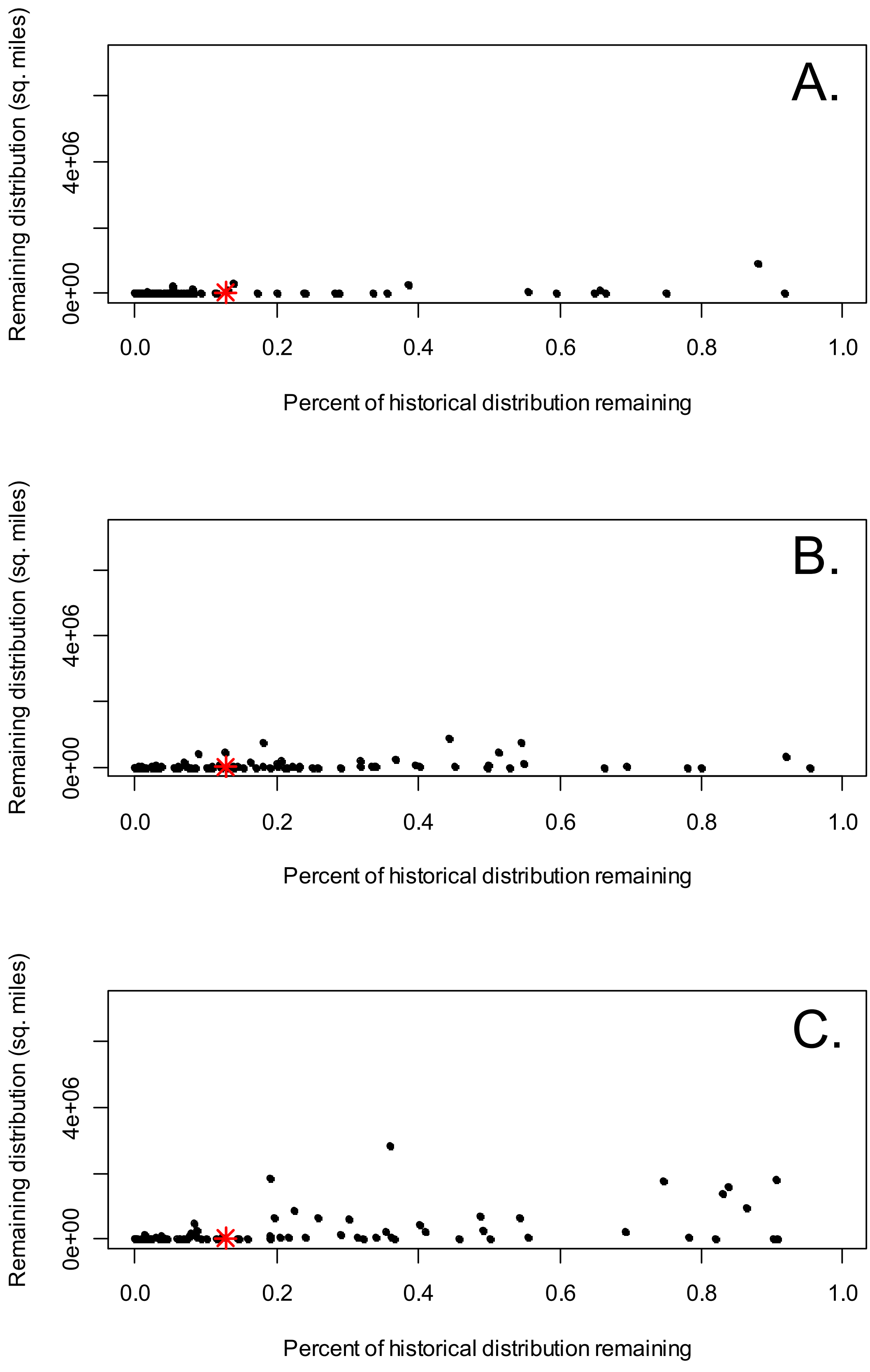
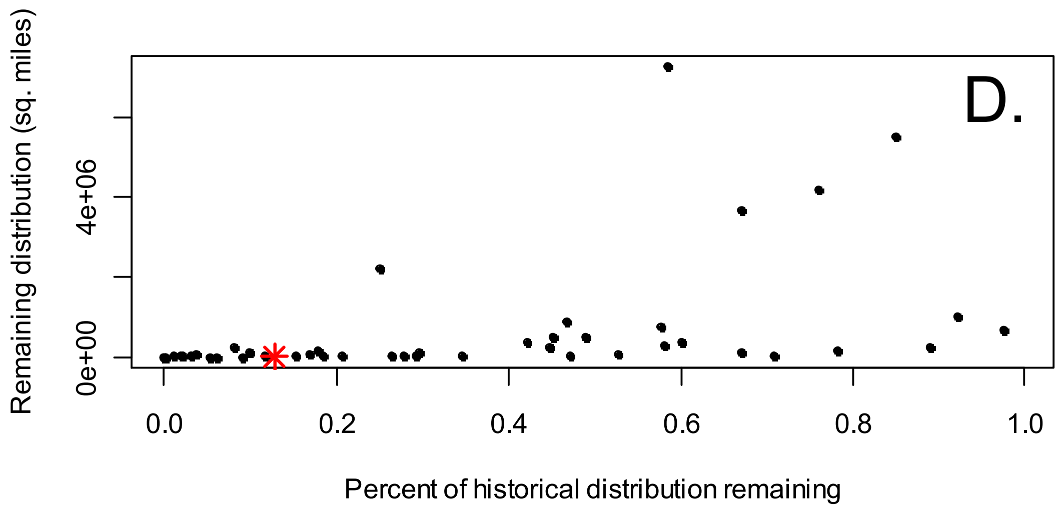


Figure 5. Comparisons of changes in distribution of species related to conservation status (IUCN, 2001). The red asterisk on each graph indicates the remaining distribution and percent of historical distribution remaining for the lesser prairie-chickens for comparison. **A.** Species classified as critically endangered. **B.** Species classified as endangered. **C.** Species classified as vulnerable. **D.** Species classified as near threatened. **E.** Species classified as of least concern.


A.
B.
C.
Remaining distribution (sq. miles)
0e+00
4e+06
0.0
0.2
0.4
0.6
0.8
1.0
Percent of historical distribution remaining


D.
Remaining distribution (sq. miles)
0e+00
4e+06
0.0
0.2
0.4
0.6
0.8
1.0
Percent of historical distribution remaining

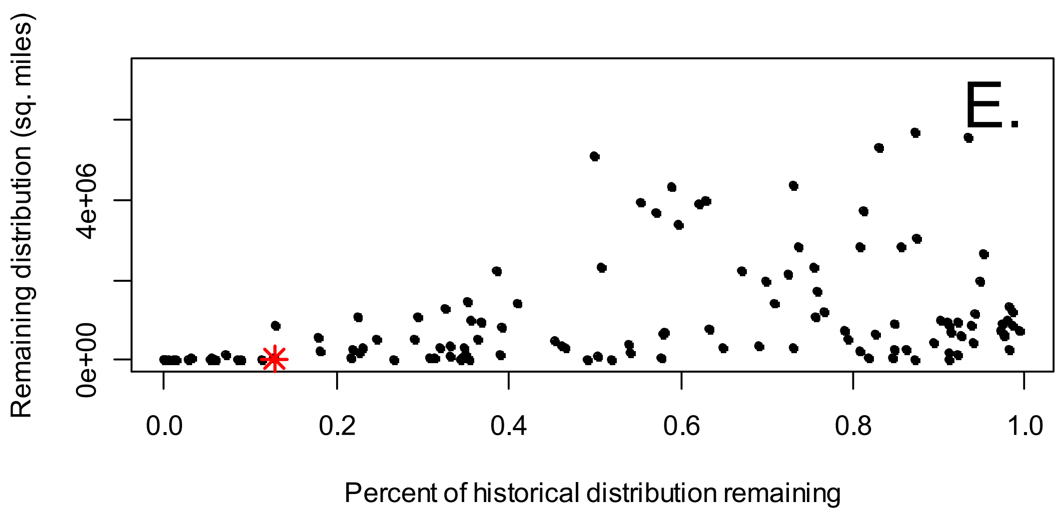
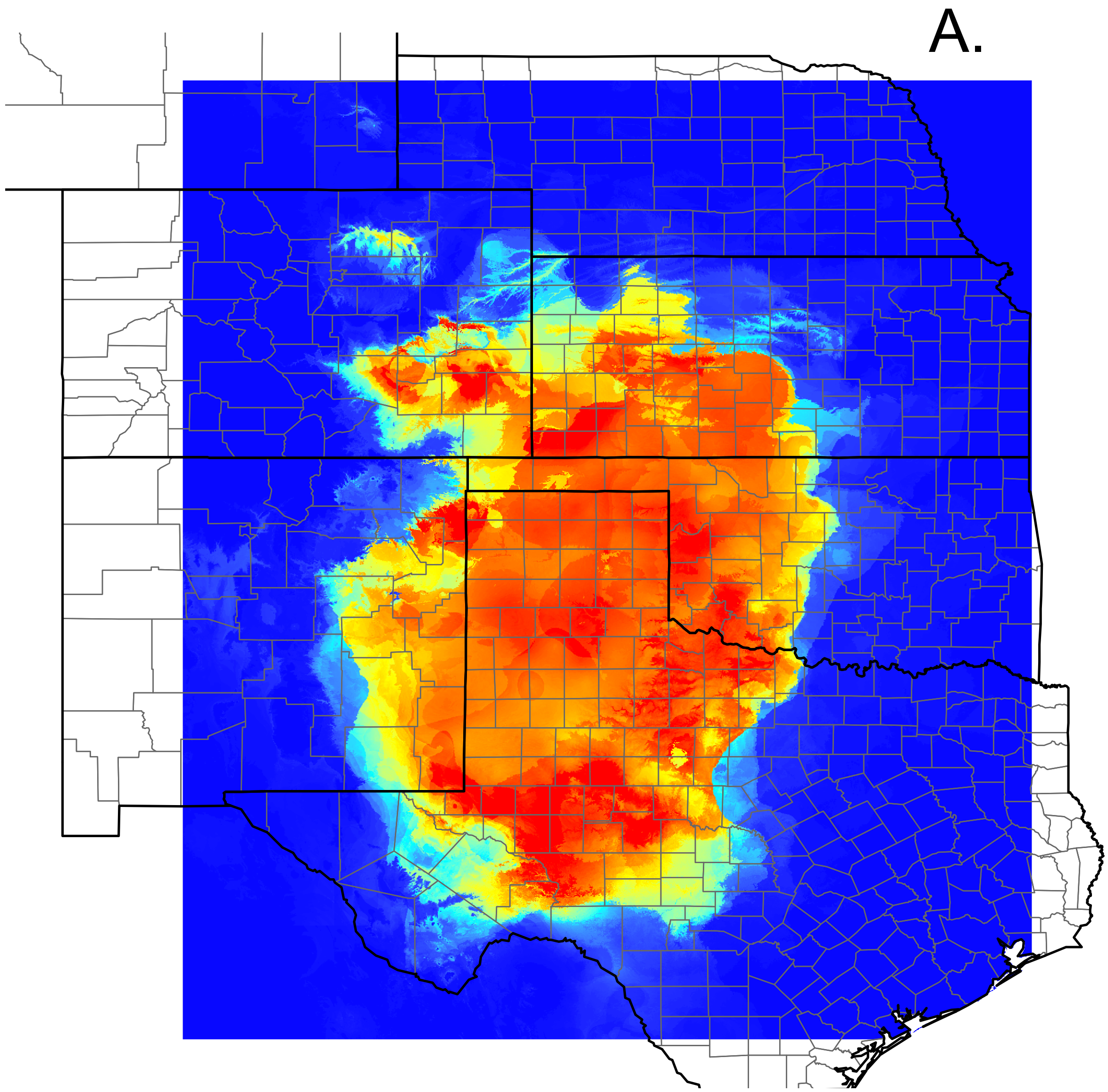
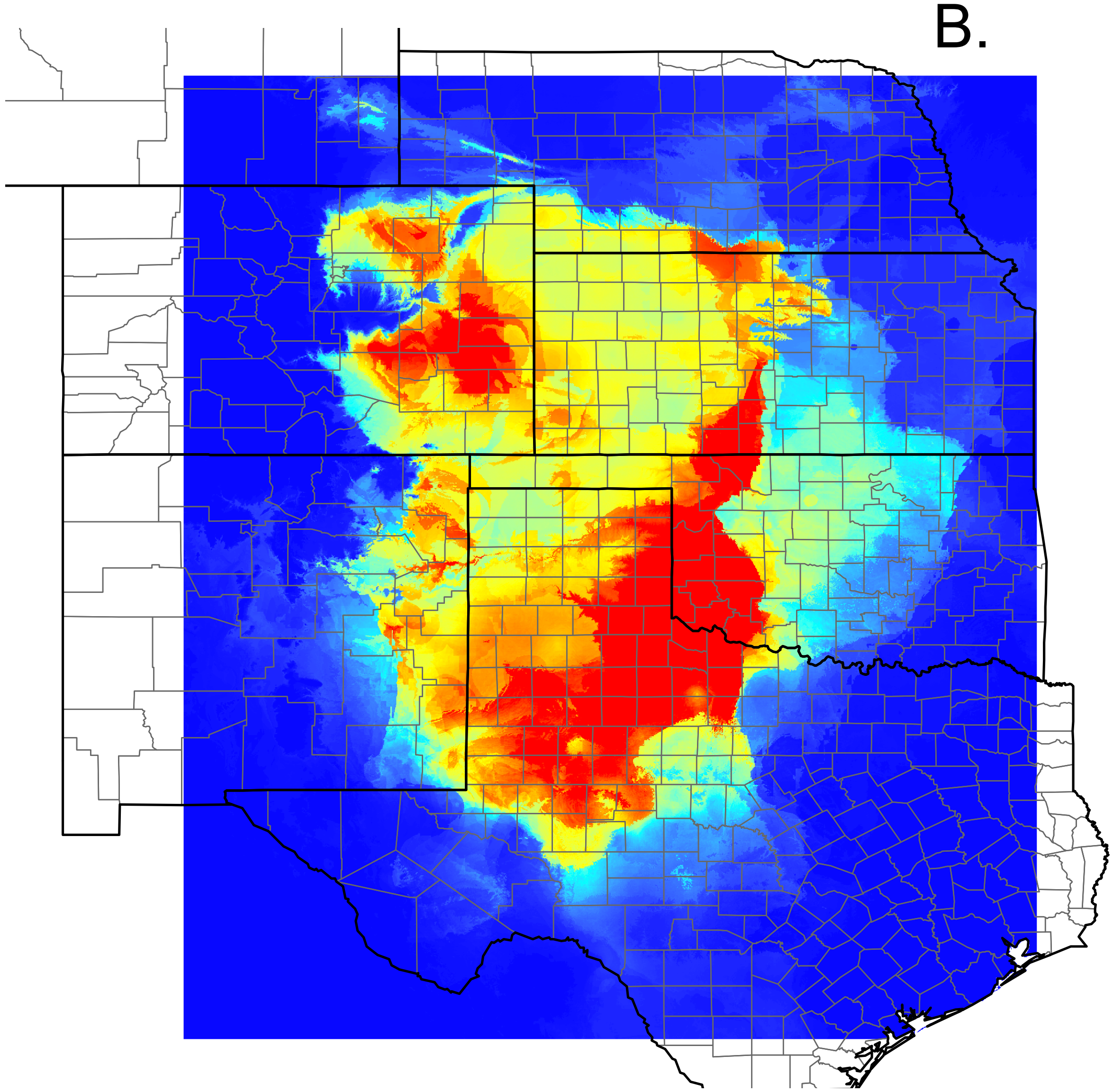

E.
Remaining distribution (sq. miles)
0e+00
4e+06
0.0
0.2
0.4
0.6
0.8
1.0
Percent of historical distribution remaining

Figure 6. Probability maps generated from maximum entropy modeling (Maxent). Warmer colors represent greater probability of climatic conditions appropriate for lesser prairie-chickens. The maps do not represent or illustrate the availability of habitat or the occupancy of the species. **A.** Predicted historical probability distribution based on historical climate data (1950-2000, WorldClim – Hijmans et al., 2005). **B.** Predicted probability distribution for minimum expected climate change scenario (b2a – CCCMA) in 2050 (WorldClim – Hijmans et al., 2005; IPCC, 2001). **C.** Predicted probability distribution for maximum expected climate change scenario (a2a – CCCMA) in 2050 (WorldClim – Hijmans et al., 2005; IPCC, 2001).


A.

B.



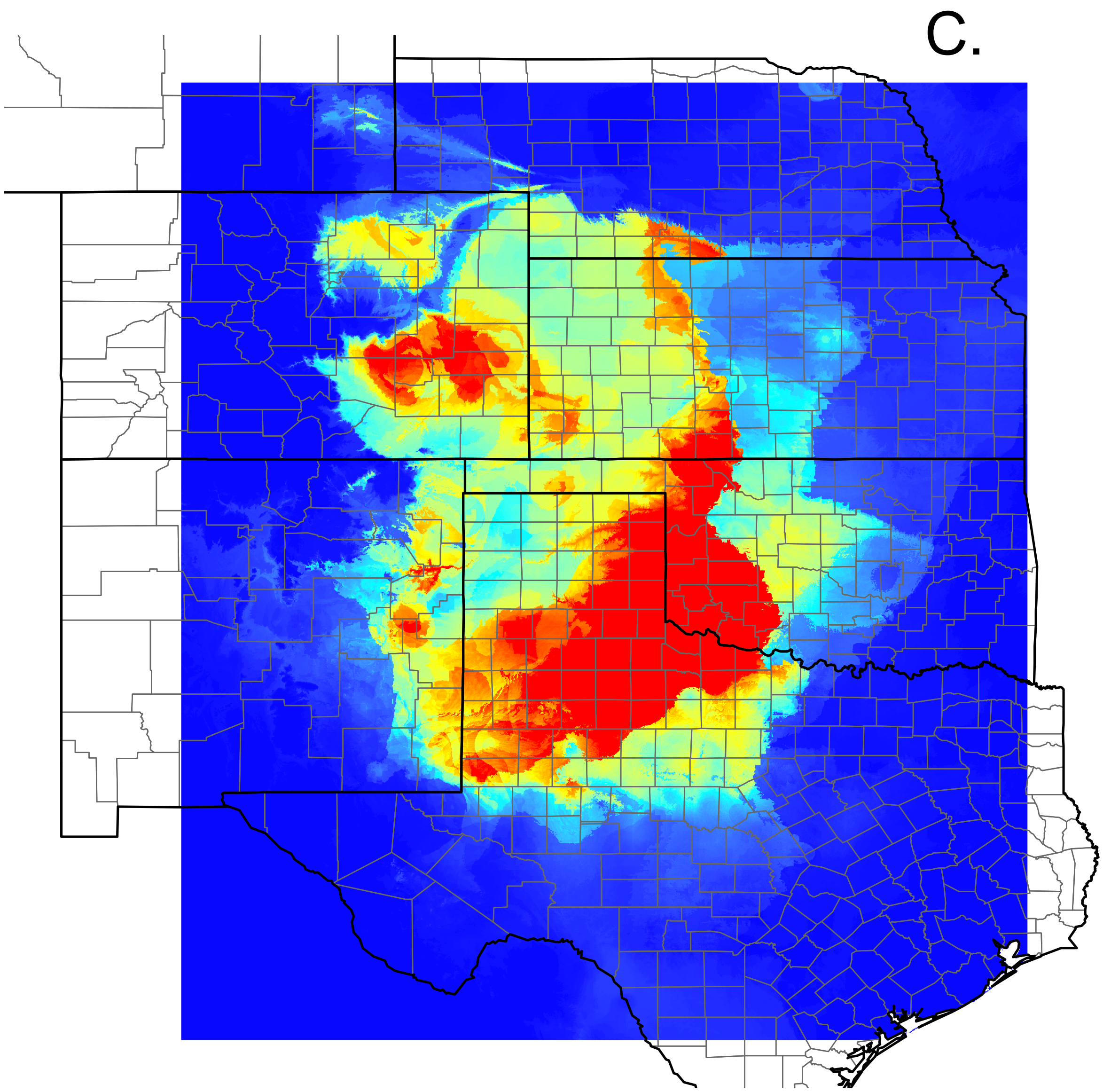
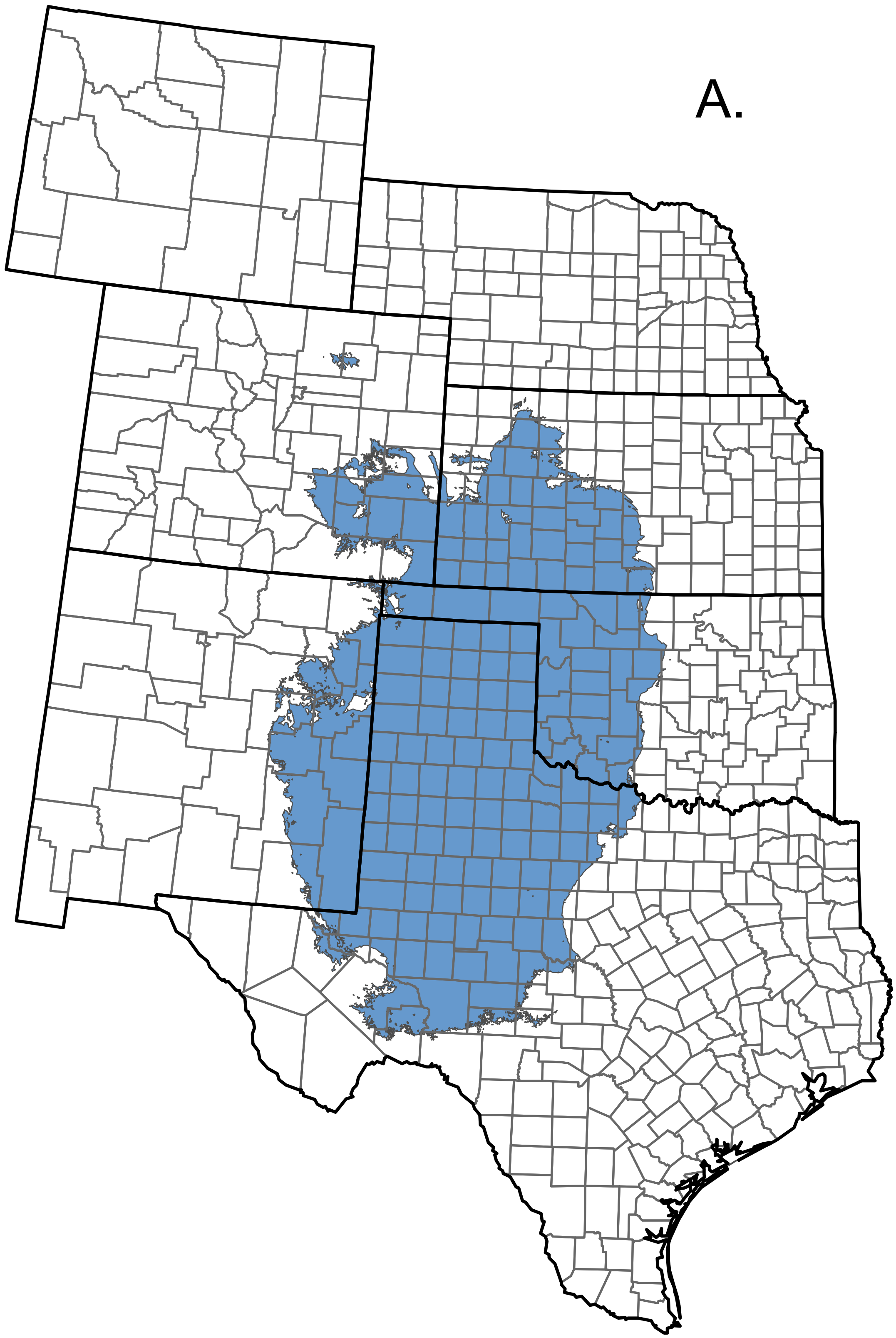
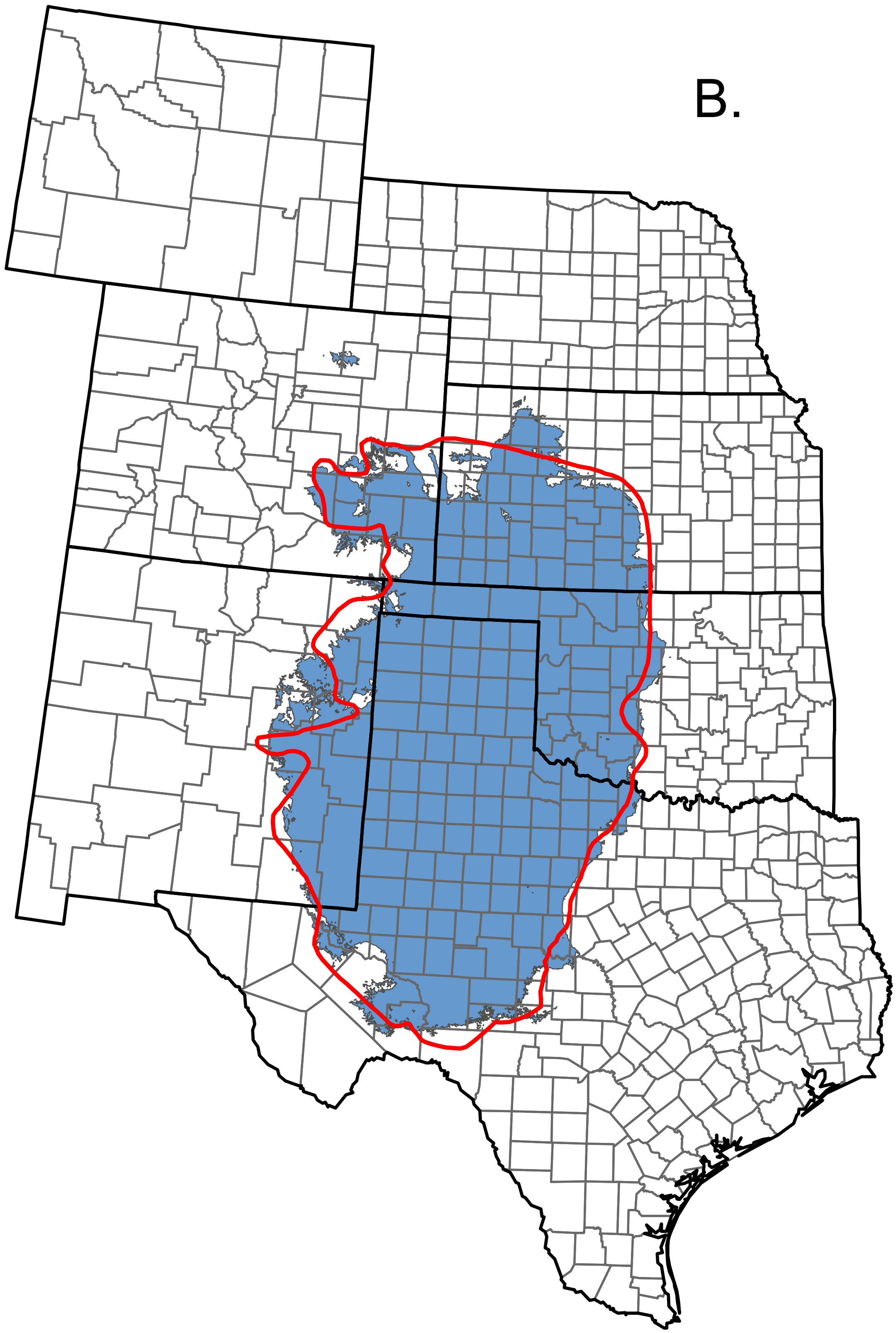
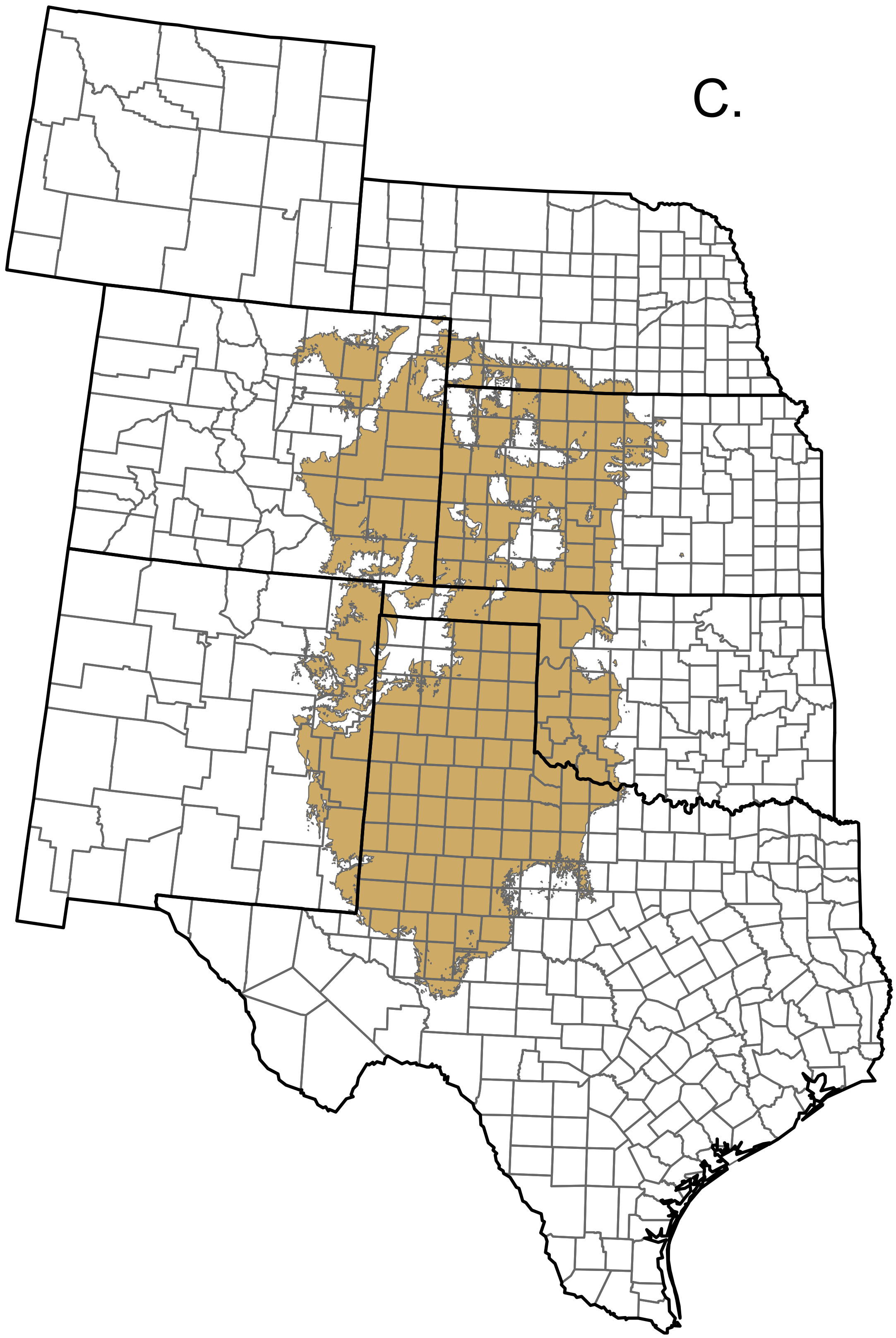

C.

Figure 7. Distribution maps generated from maximum entropy modeling (Maxent). The probability maps (Figure 4) were reclassified using a cumulative threshold value of 10 with a logistic threshold value of 0.370 (see text for explanation). The regions depicted represent areas with climatic conditions appropriate for lesser prairie-chickens. The maps do not represent or illustrate the availability of habitat or the occupancy of the species. **A.** Predicted historical distribution based on historical climate data (1950-2000, WorldClim – Hijmans et al., 2005) ($p < 0.001$). **B.** Comparison of the predicted historical distribution (blue area) with the hypothesized historical distribution (red line). **C.** Predicted distribution for minimum expected climate change scenario (b2a – CCCMA) in 2050 (WorldClim – Hijmans et al., 2005; IPCC, 2001). **D.** Predicted distribution for maximum expected climate change scenario (a2a – CCCMA) in 2050 (WorldClim – Hijmans et al., 2005; IPCC, 2001).


A.


B.


C.

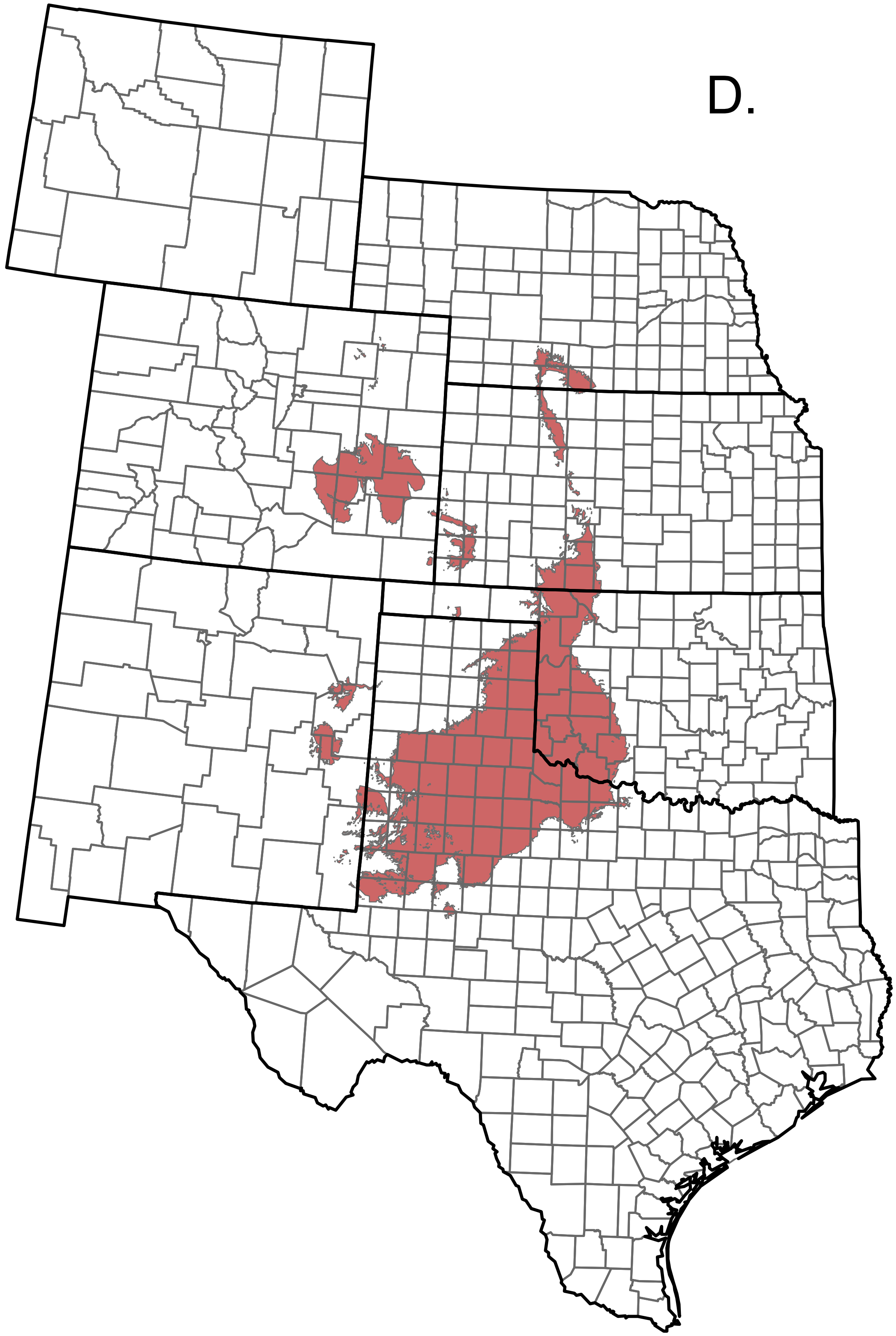
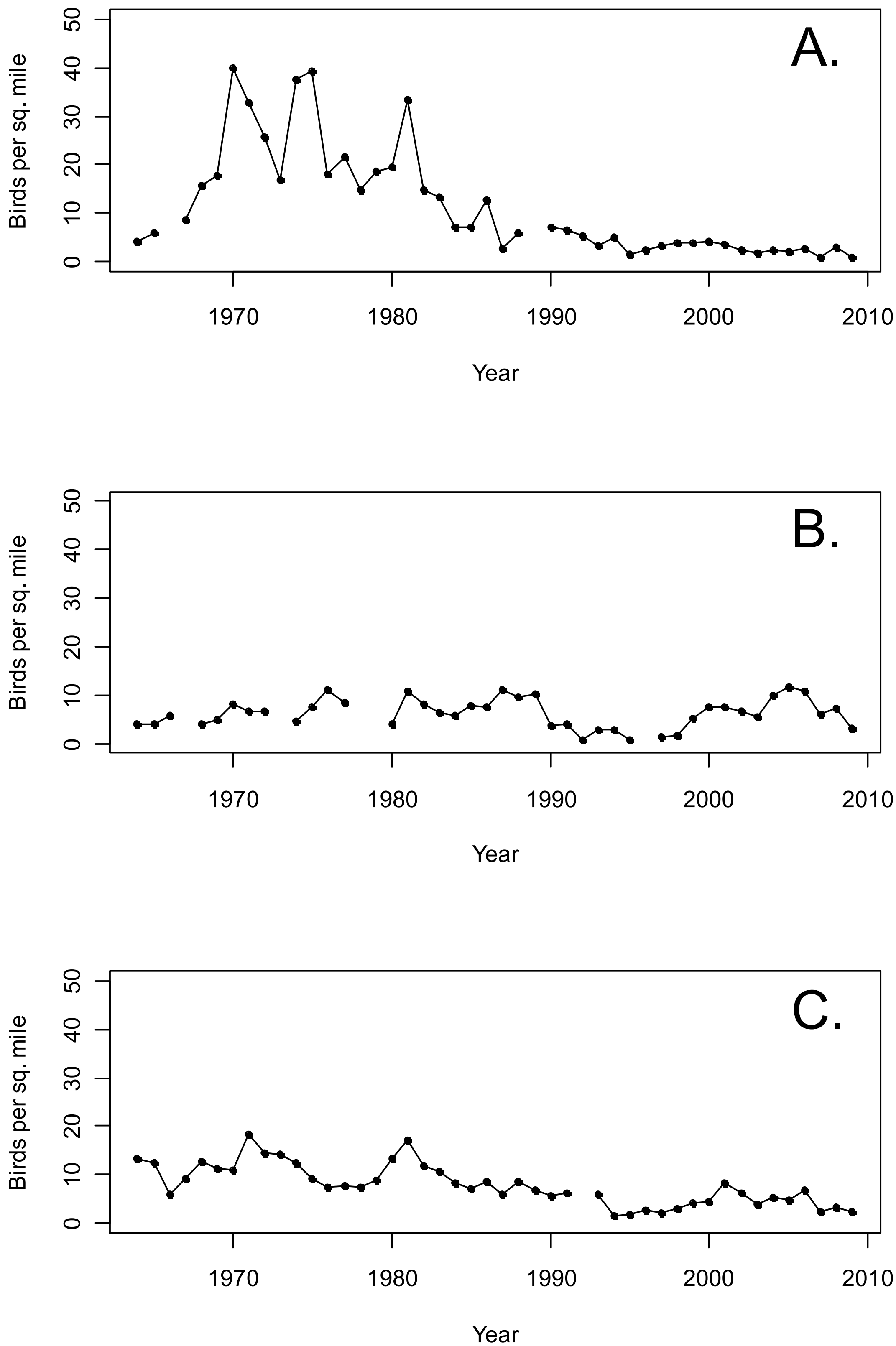
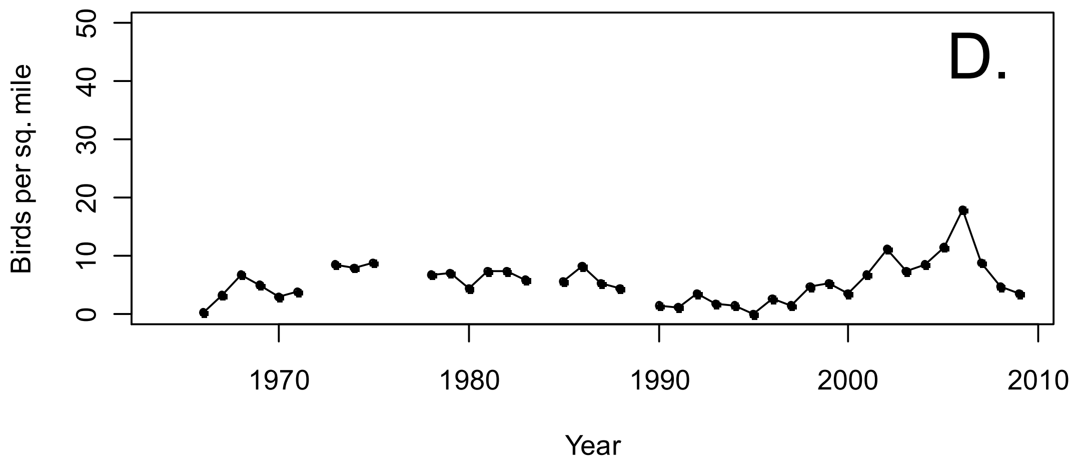
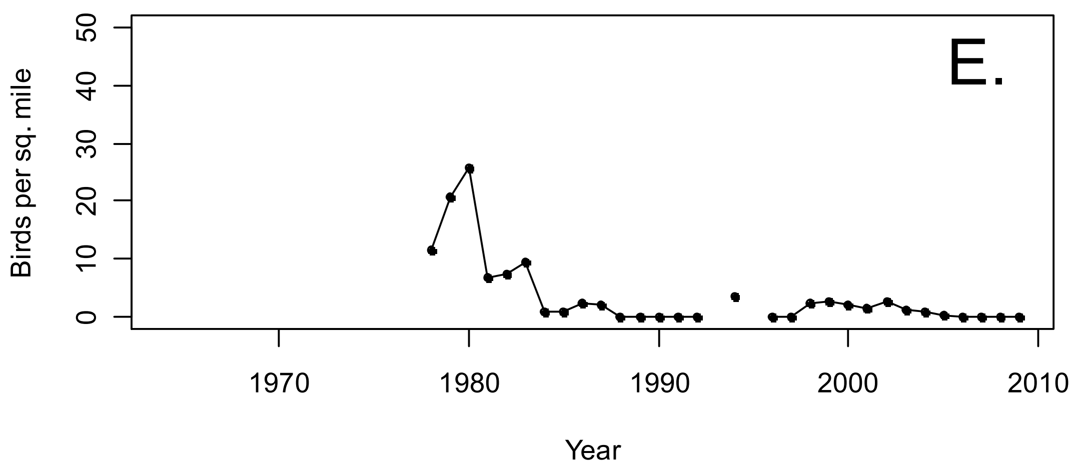

D.

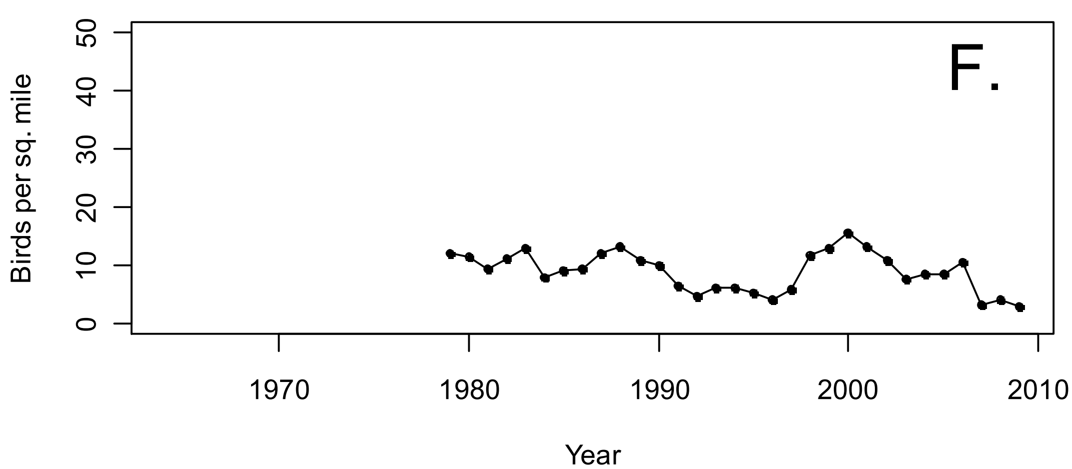
Figure 8. Observed density of lesser prairie-chicken along survey routes in Kansas. Individual routes are noted by letter.

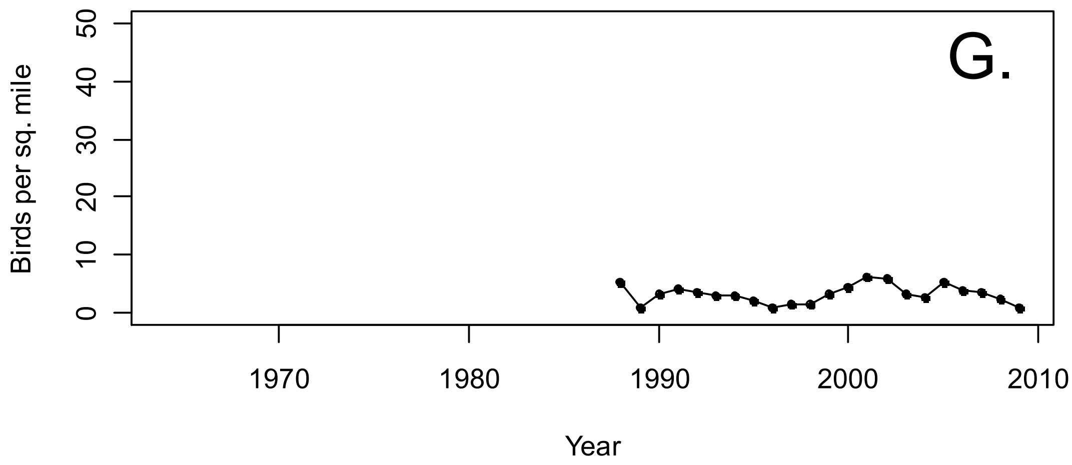
A. Finney
B. Meade
C. Morton
D. Clark
E. Kearny
F. Hamilton
G. Ford
H. Comanche
I. Barber
J. Kiowa
K. Hodgeman
L. Gove
M. Ness
N. Sandsage Bison Range Wildlife Area
O. Pratt Sandhills Wildlife Area

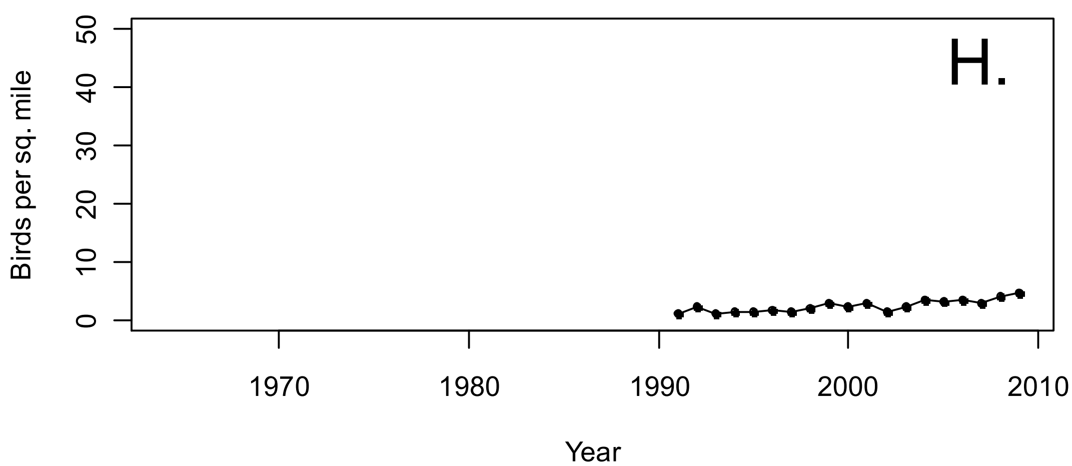

A.
B.
C.
Birds per sq. mile
Year
0
10
20
30
40
50
1970
1980
1990
2000
2010

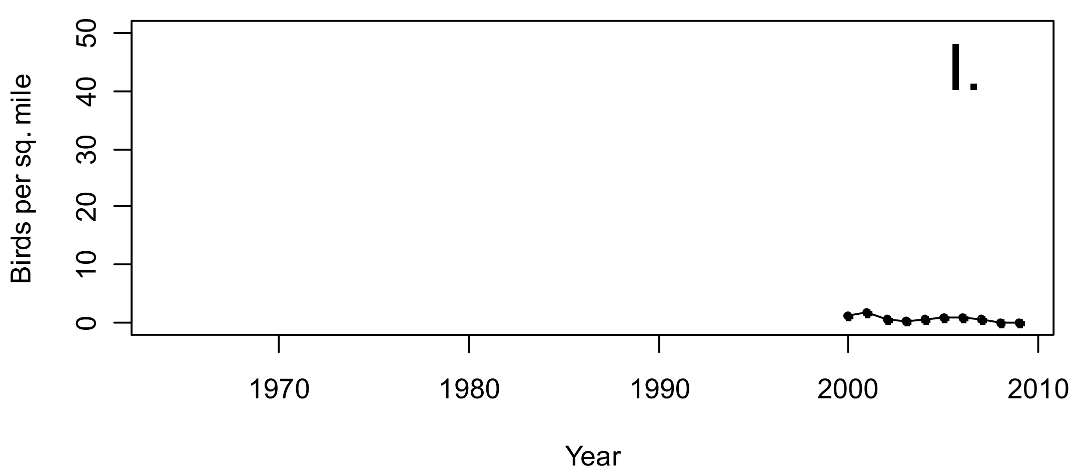

D.
Birds per sq. mile
0
10
20
30
40
50
1970
1980
1990
2000
2010
Year

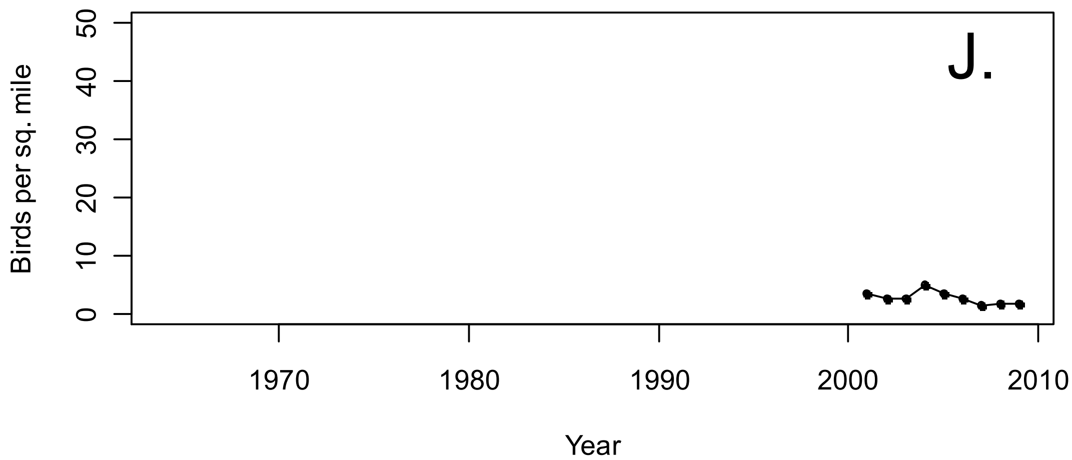

E.
Birds per sq. mile
0
10
20
30
40
50
1970
1980
1990
2000
2010
Year

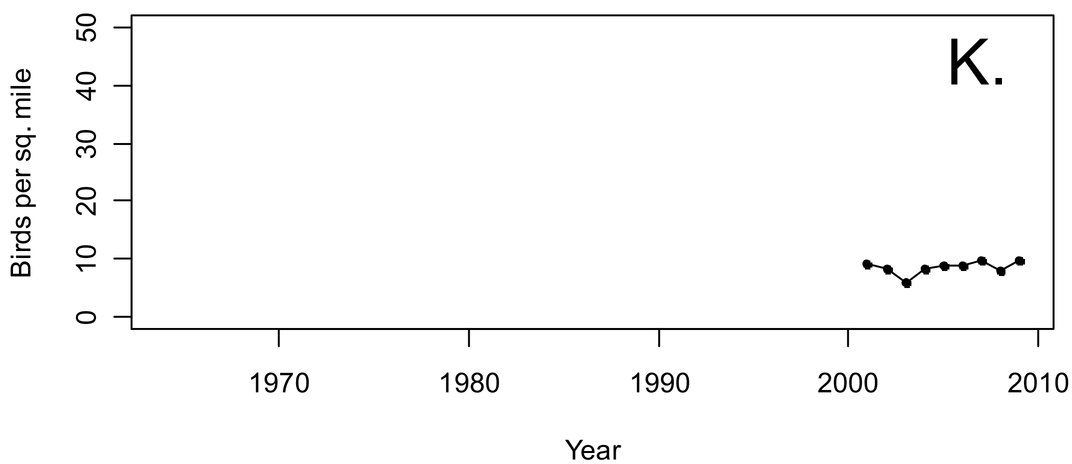

F.
Birds per sq. mile
0
10
20
30
40
50
1970
1980
1990
2000
2010
Year

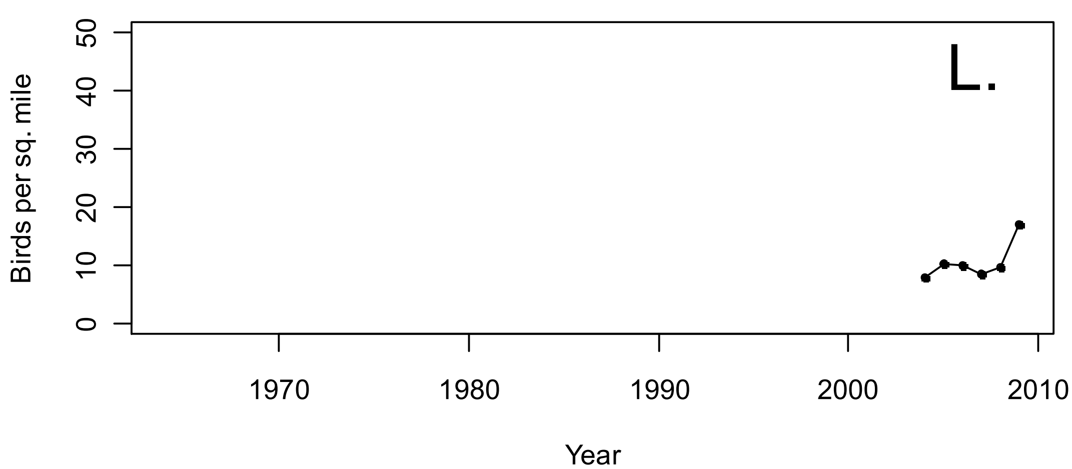

G.
Birds per sq. mile
0
10
20
30
40
50
1970
1980
1990
2000
2010
Year

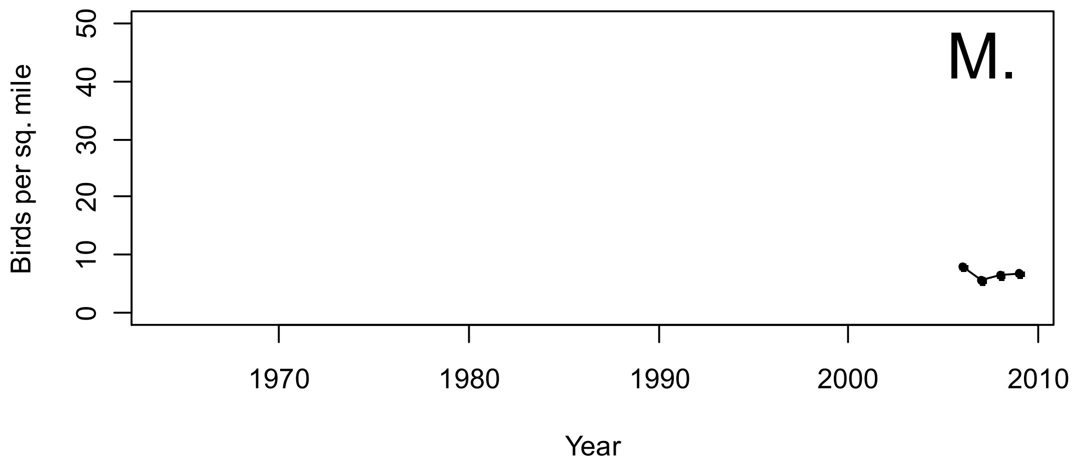

H.
Birds per sq. mile
0
10
20
30
40
50
1970
1980
1990
2000
2010
Year

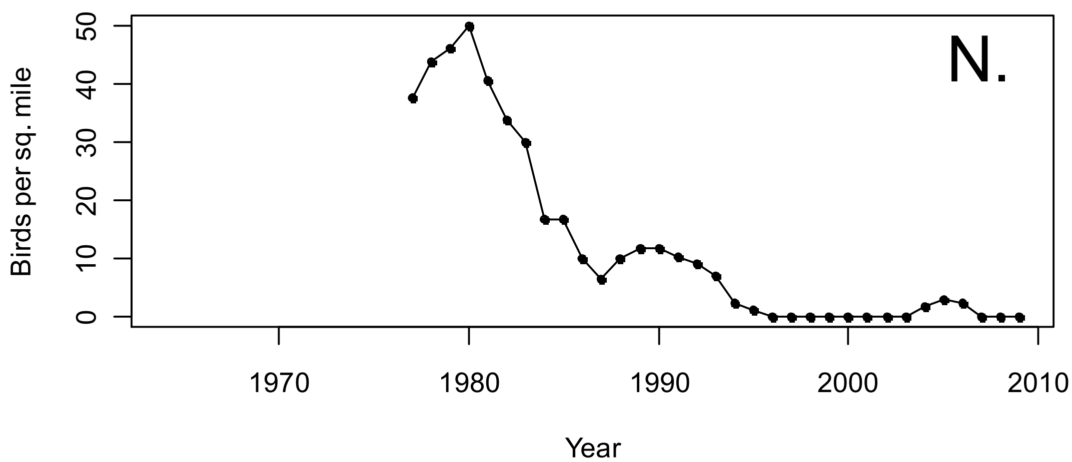

I.
Birds per sq. mile
0
10
20
30
40
50
1970
1980
1990
2000
2010
Year


J.
Birds per sq. mile
0
10
20
30
40
50
1970
1980
1990
2000
2010
Year


K.
Birds per sq. mile
0
10
20
30
40
50
1970
1980
1990
2000
2010
Year


L.
Birds per sq. mile
0
10
20
30
40
50
1970
1980
1990
2000
2010
Year


M.
Birds per sq. mile
0
10
20
30
40
50
1970
1980
1990
2000
2010
Year


N.
Birds per sq. mile
0
10
20
30
40
50
1970
1980
1990
2000
2010
Year

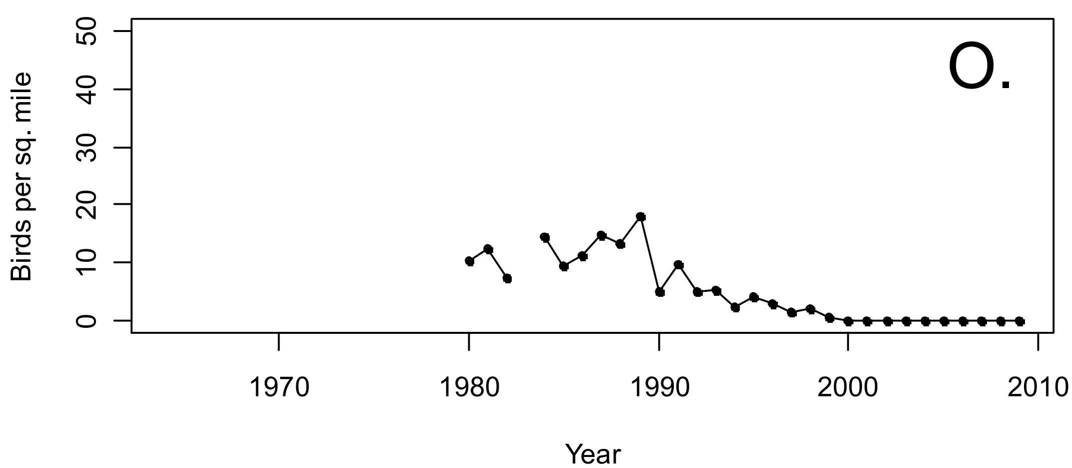
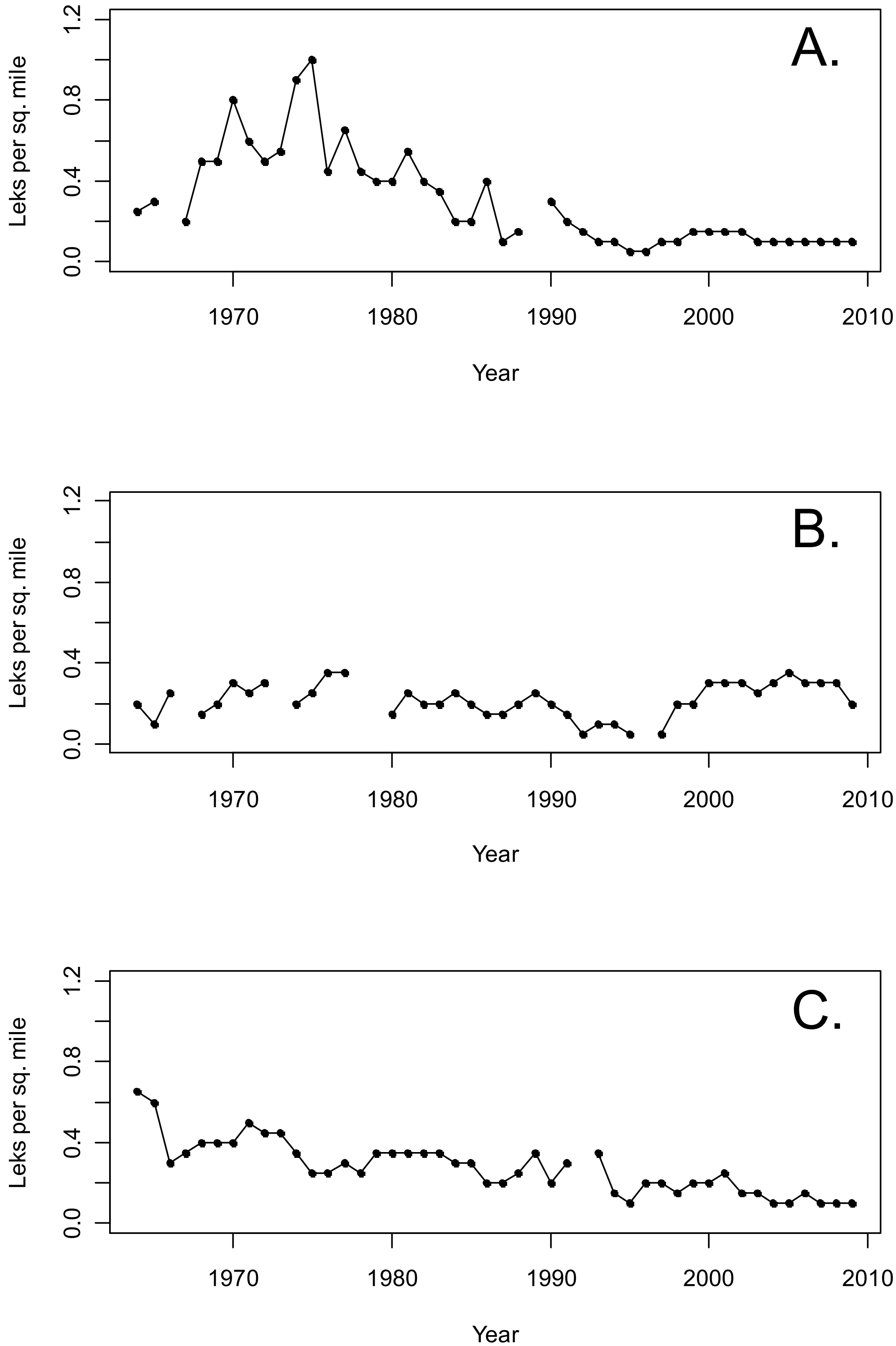
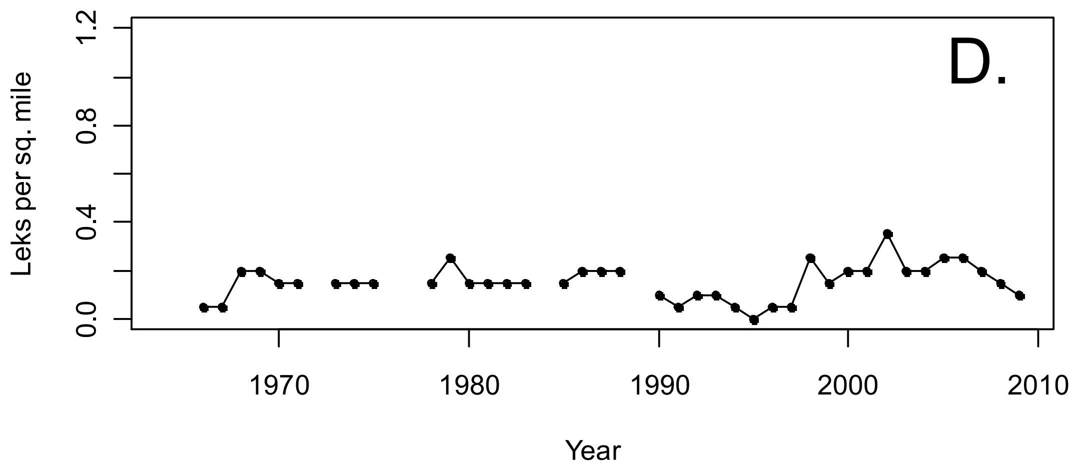

O.
Birds per sq. mile
0
10
20
30
40
50
1970
1980
1990
2000
2010
Year

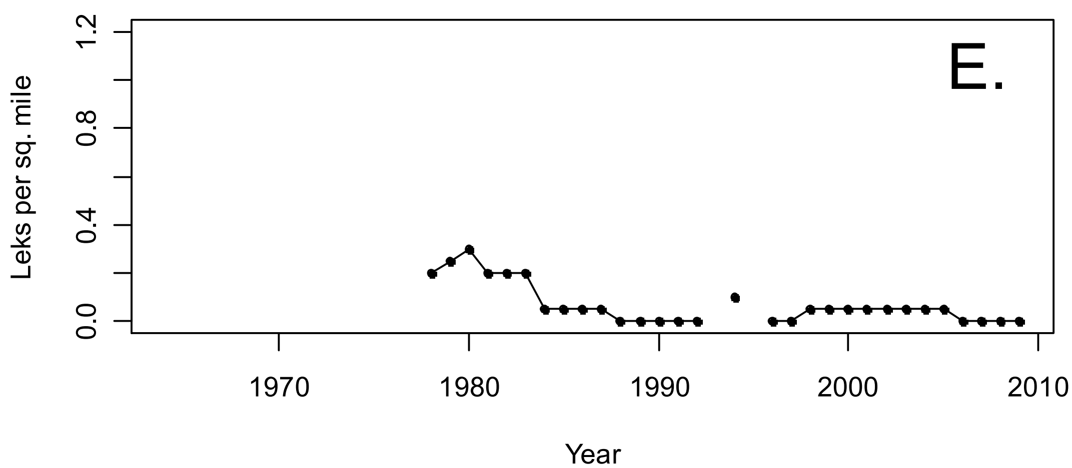
Figure 9. Observed density of lesser prairie-chicken leks along survey routes in Kansas. Individual routes are noted by letter.

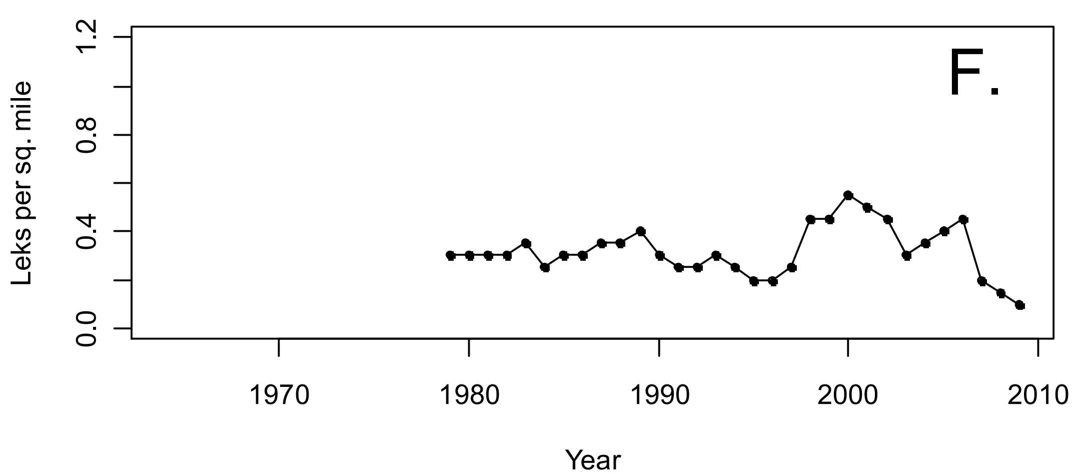
A. Finney
B. Meade
C. Morton
D. Clark
E. Kearny
F. Hamilton
G. Ford
H. Comanche
I. Barber
J. Kiowa
K. Hodgeman
L. Gove
M. Ness
N. Sandsage Bison Range Wildlife Area
O. Pratt Sandhills Wildlife Area

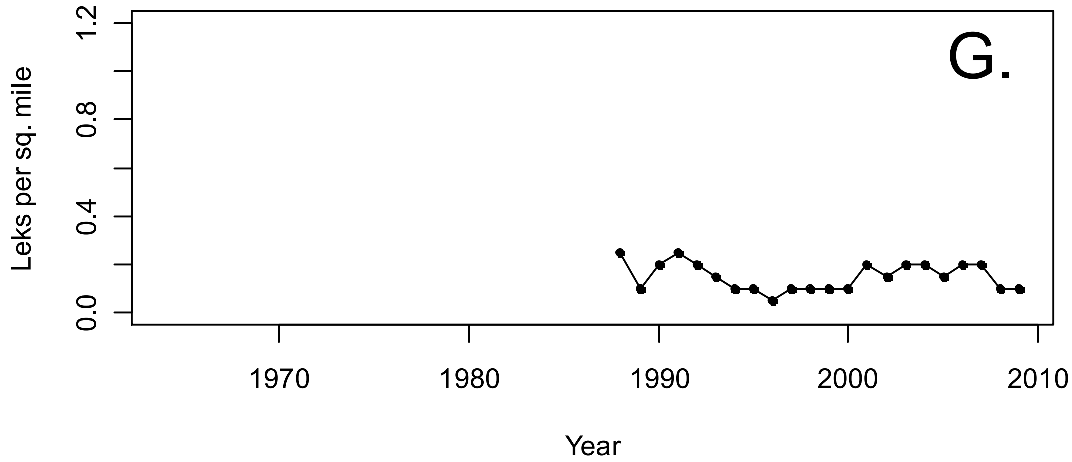


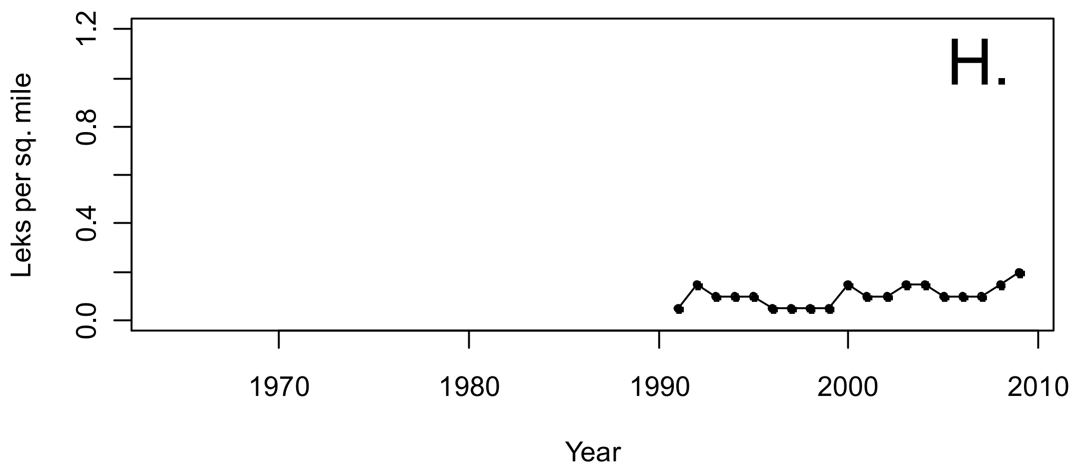
A.
B.
C.
Leks per sq. mile
0.0
0.4
0.8
1.2
1970
1980
1990
2000
2010
Year

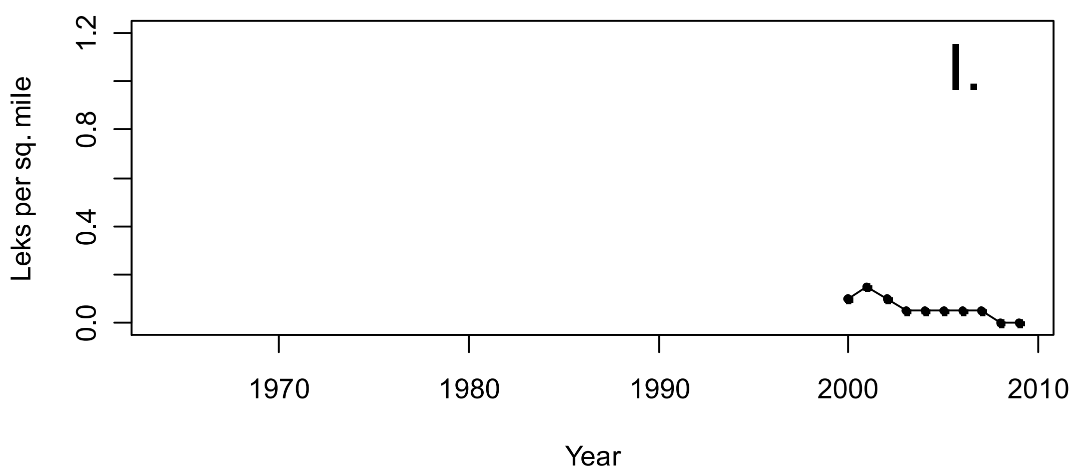

D.
Leks per sq. mile
0.0
0.4
0.8
1.2
1970
1980
1990
2000
2010
Year

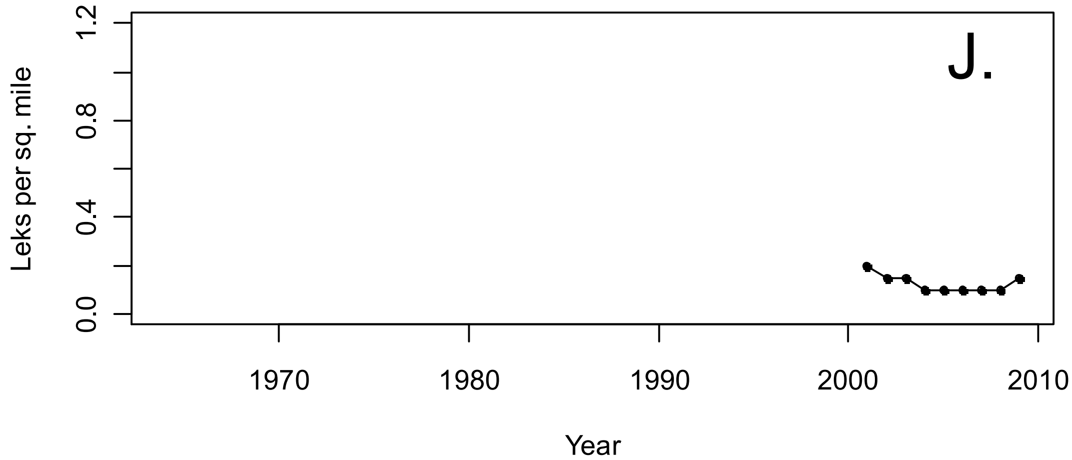

E.
Leks per sq. mile
0.0
0.4
0.8
1.2
1970
1980
1990
2000
2010
Year

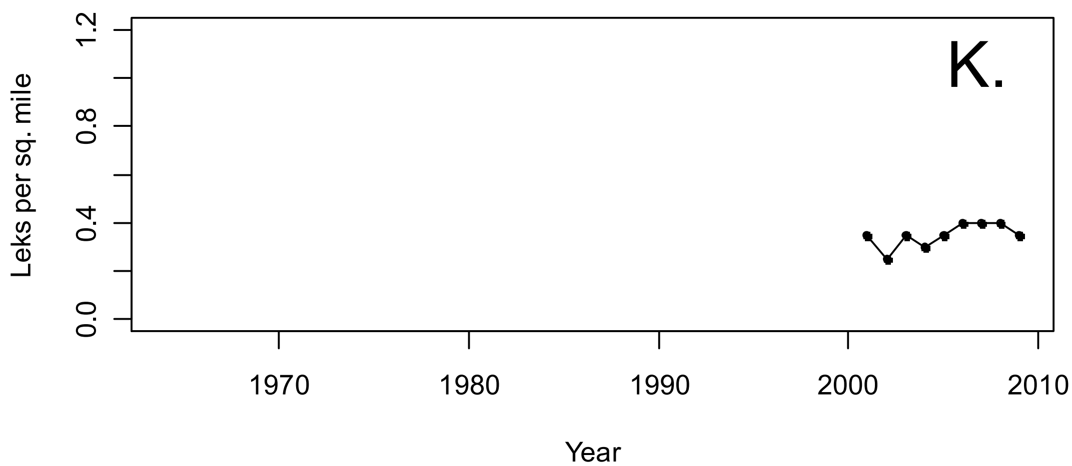

F.
Leks per sq. mile
0.0
0.4
0.8
1.2
1970
1980
1990
2000
2010
Year

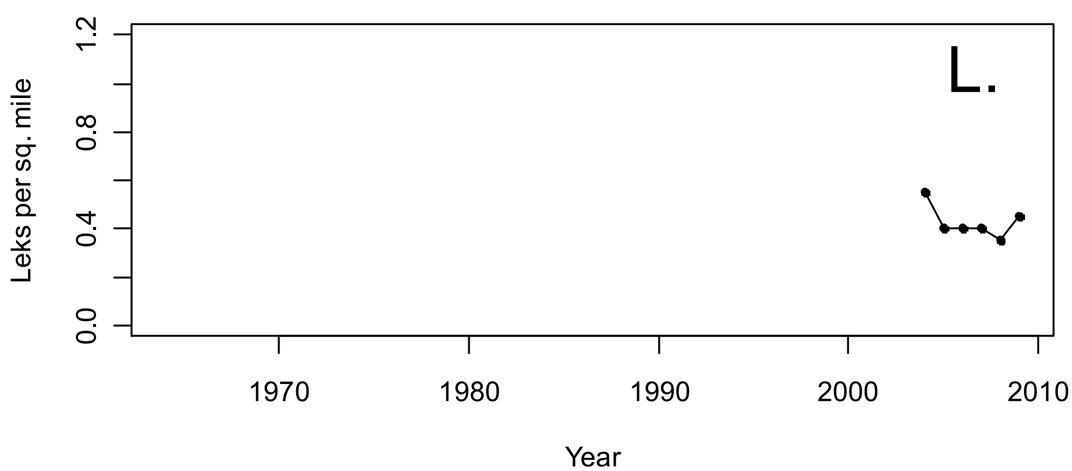

G.
Leks per sq. mile
0.0
0.4
0.8
1.2
1970
1980
1990
2000
2010
Year

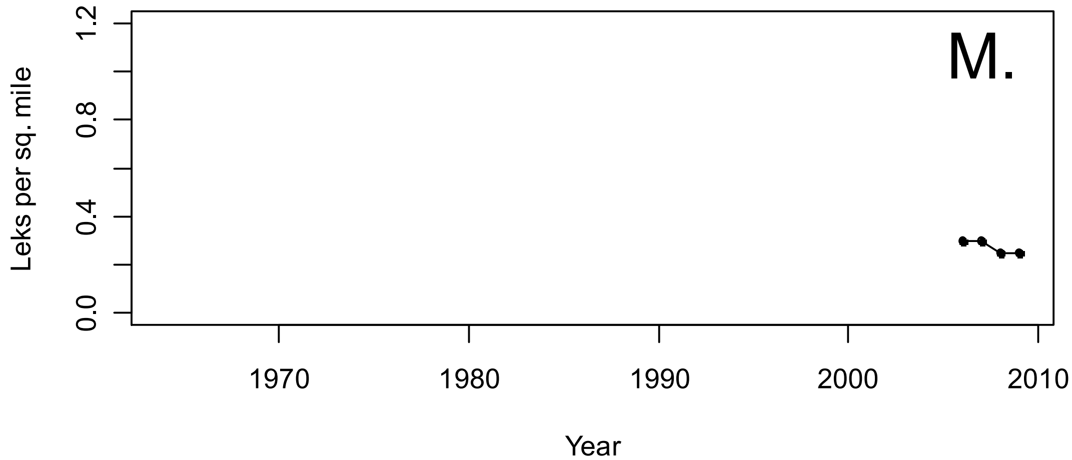

H.
Leks per sq. mile
0.0
0.4
0.8
1.2
1970
1980
1990
2000
2010
Year

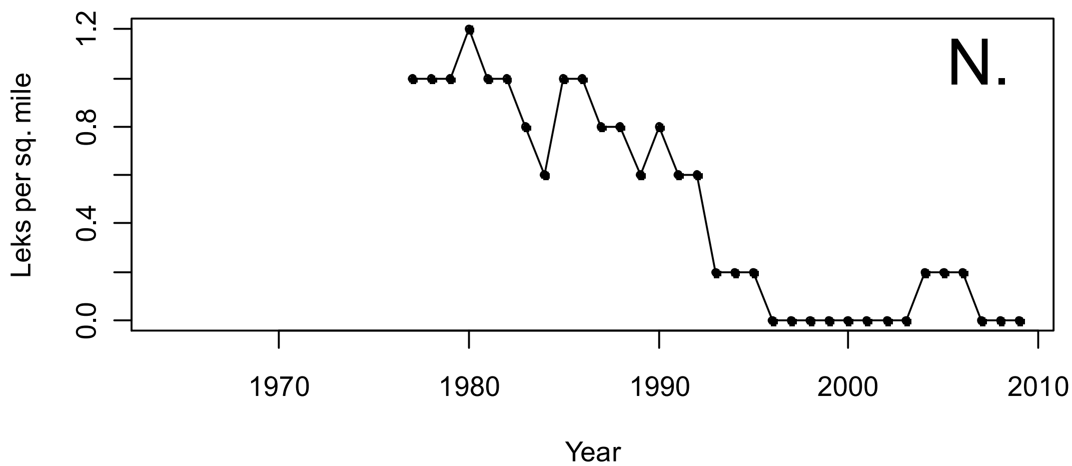

I.
Leks per sq. mile
0.0
0.4
0.8
1.2
1970
1980
1990
2000
2010
Year


J.
Leks per sq. mile
0.0
0.4
0.8
1.2
1970
1980
1990
2000
2010
Year


K.
Leks per sq. mile
0.0
0.4
0.8
1.2
1970
1980
1990
2000
2010
Year


L.
Leks per sq. mile
0.0
0.4
0.8
1.2
1970
1980
1990
2000
2010
Year


M.
Leks per sq. mile
0.0
0.4
0.8
1.2
1970
1980
1990
2000
2010
Year


N.
Leks per sq. mile
0.0
0.4
0.8
1.2
1970
1980
1990
2000
2010
Year

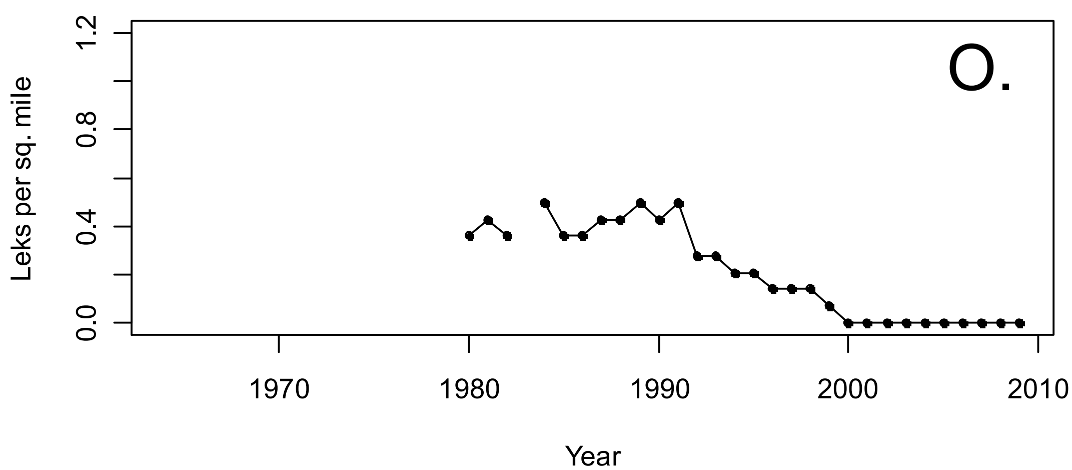
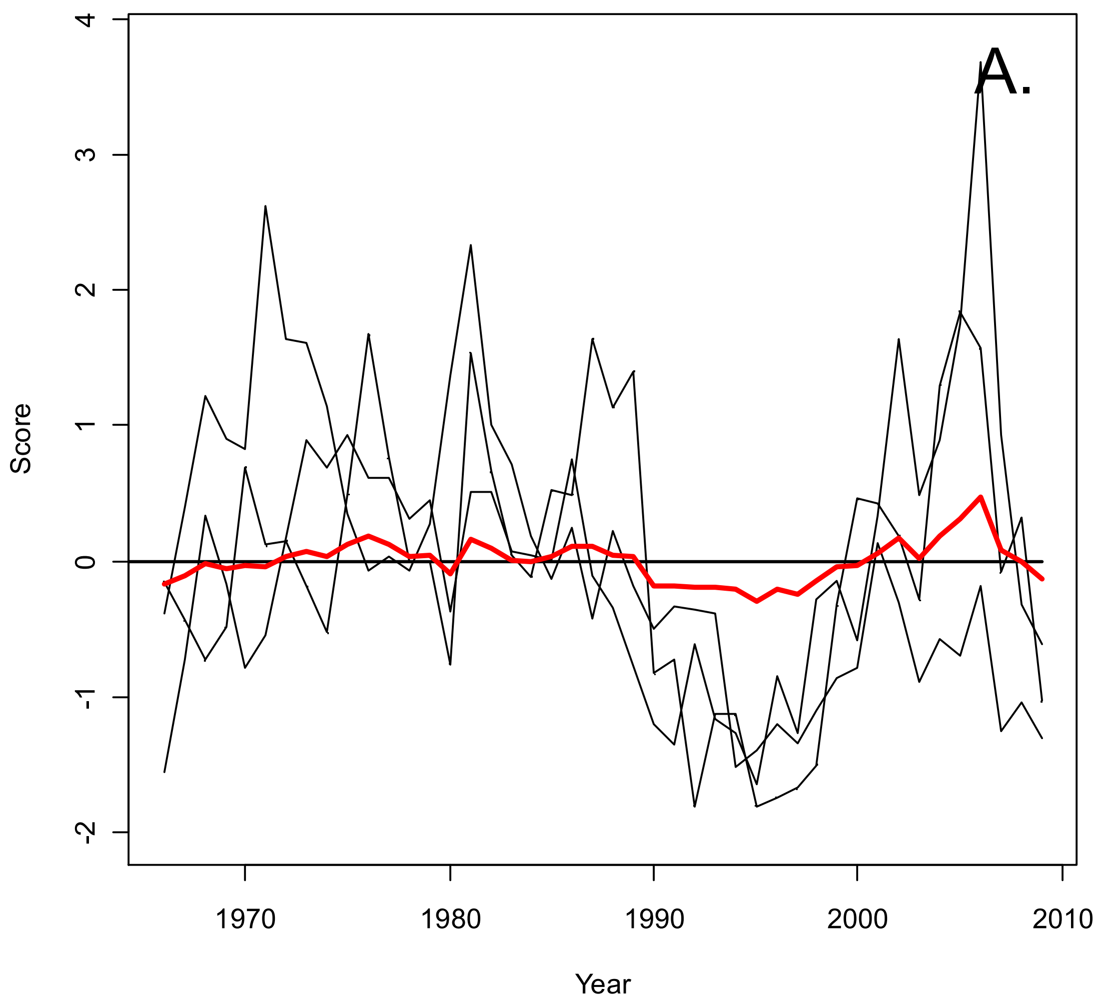
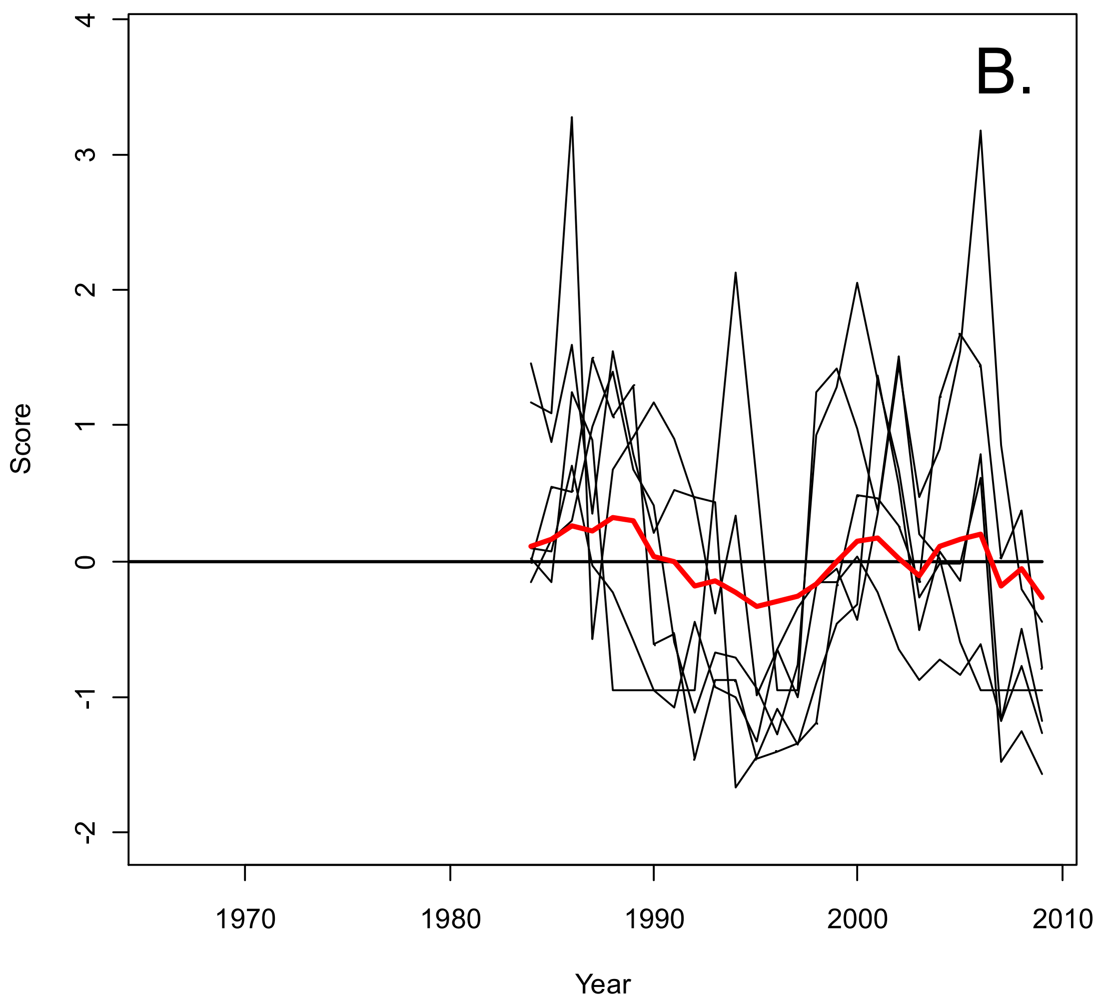
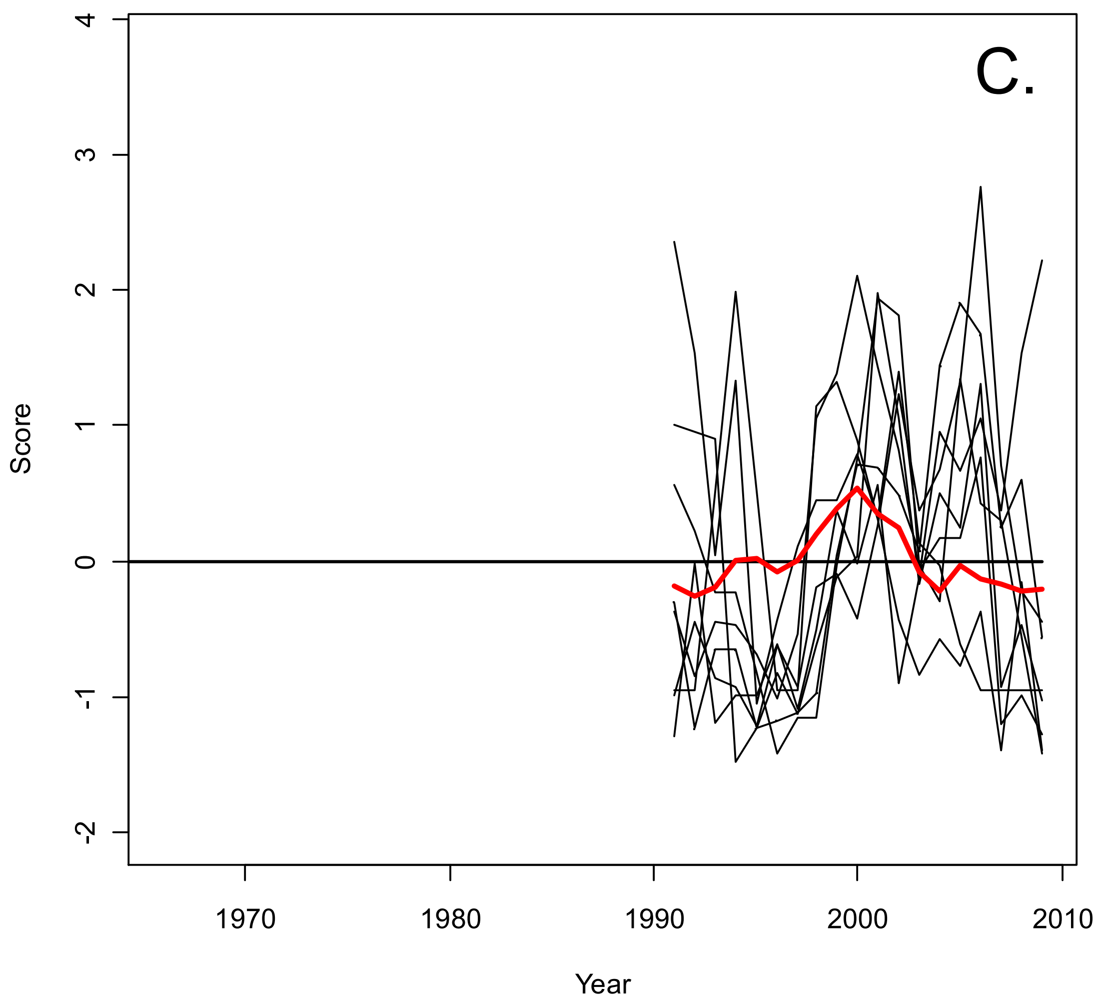

O.
Leks per sq. mile
0.0
0.4
0.8
1.2
1970
1980
1990
2000
2010
Year

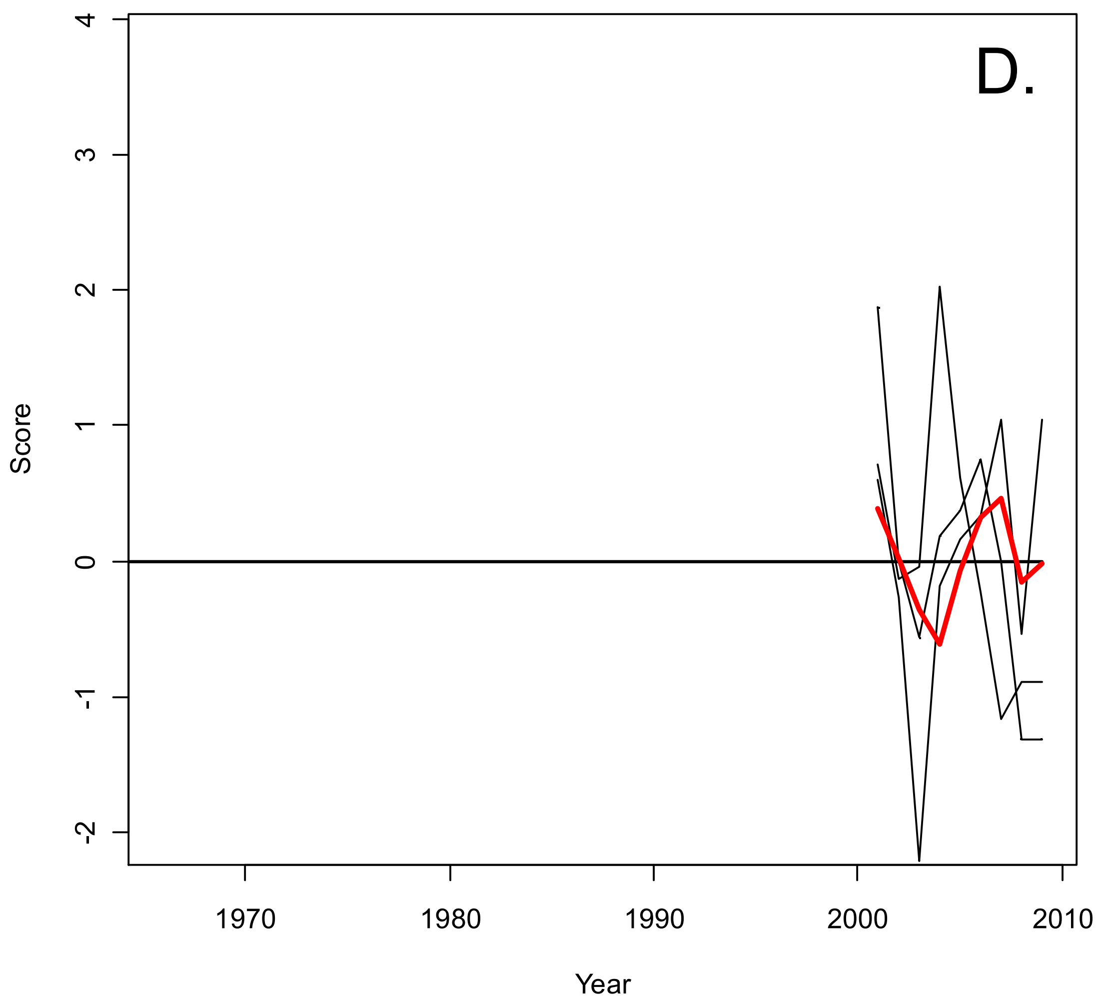
Figure 10. Trend analysis of lesser prairie-chicken density along survey routes in Kansas. The red line represents the generalized trend of density along the routes and times indicated. The thick black line represents the mean density over the time being analyzed. The standardized densities of the individual routes included in each analysis are shown as thin black lines to aid in comparison with the trend line.

A. 1966-2009 Clark, Meade, and Morton survey routes
B. 1984-2009 Clark, Finney, Hamilton, Kearny, Meade, and Morton survey routes
C. 1991-2009 Clark, Comanche, Finney, Ford, Hamilton, Kearny, Meade, and Morton survey routes
D. 2001-2009 Barber, Kiowa, and Hodgeman survey routes
E. 2006-2009 Gove and Ness survey routes

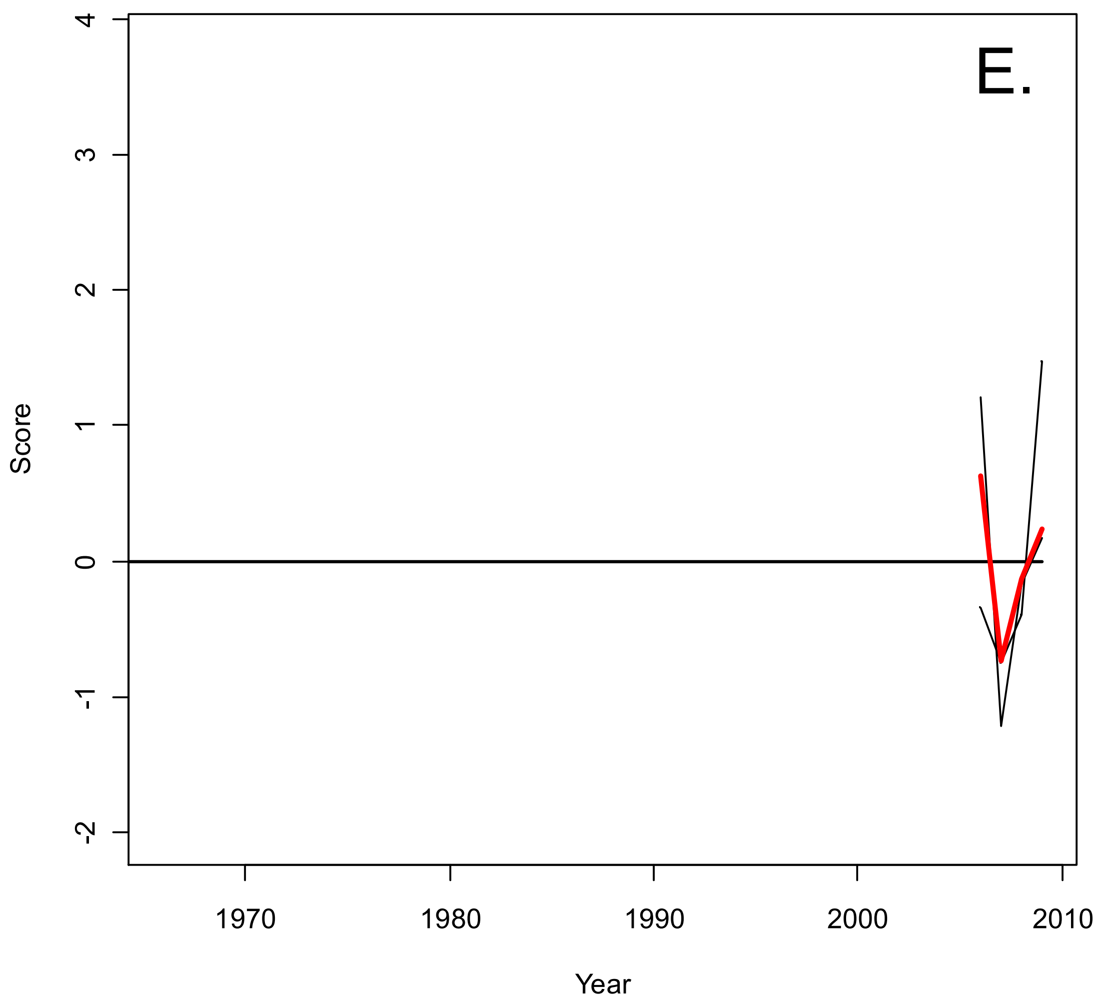

A.
Score
4
3
2
1
0
-1
-2
1970
1980
1990
2000
2010
Year


B.
Score
Year
4
3
2
1
0
-1
-2
1970
1980
1990
2000
2010


C.
Score
4
3
2
1
0
-1
-2
1970
1980
1990
2000
2010
Year



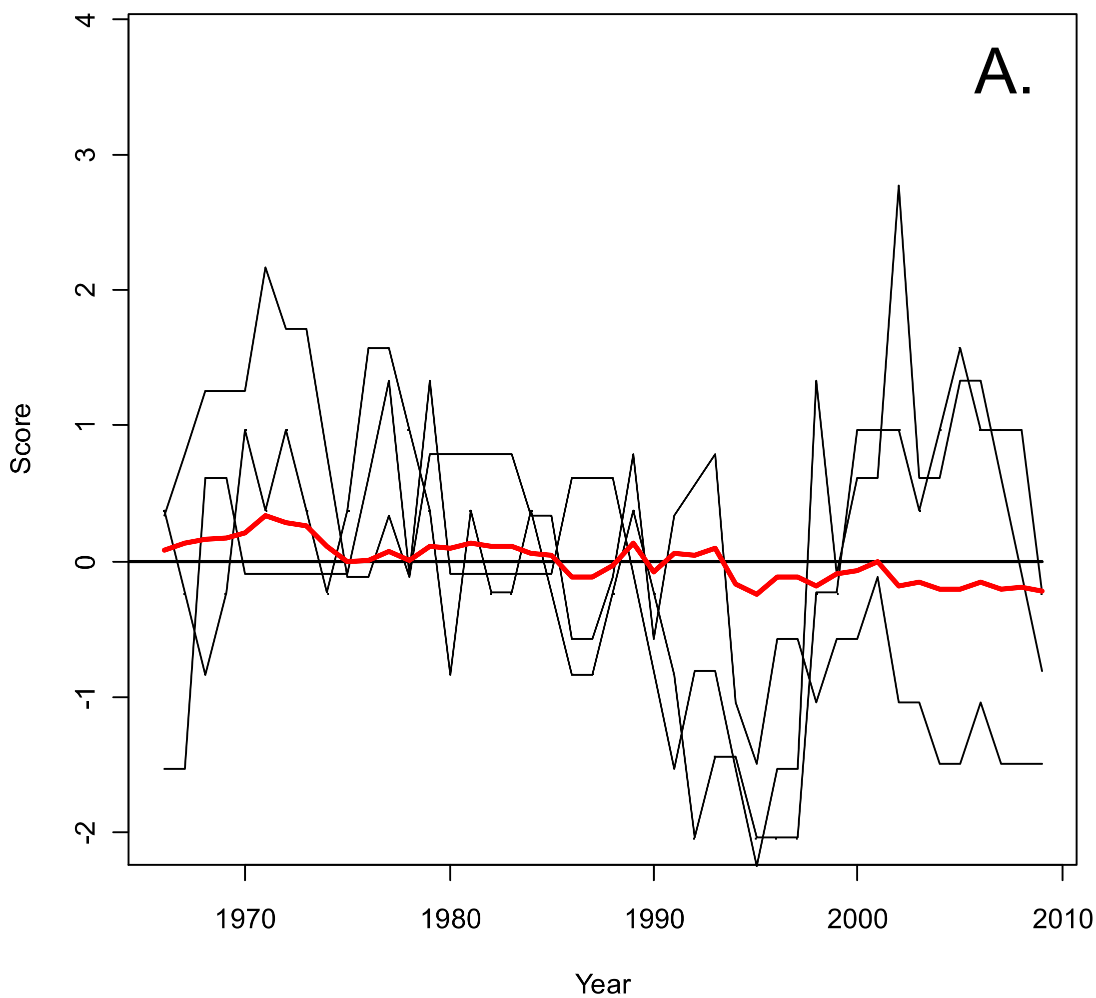
D.
Score
Year
4
3
2
1
0
-1
-2
1970
1980
1990
2000
2010

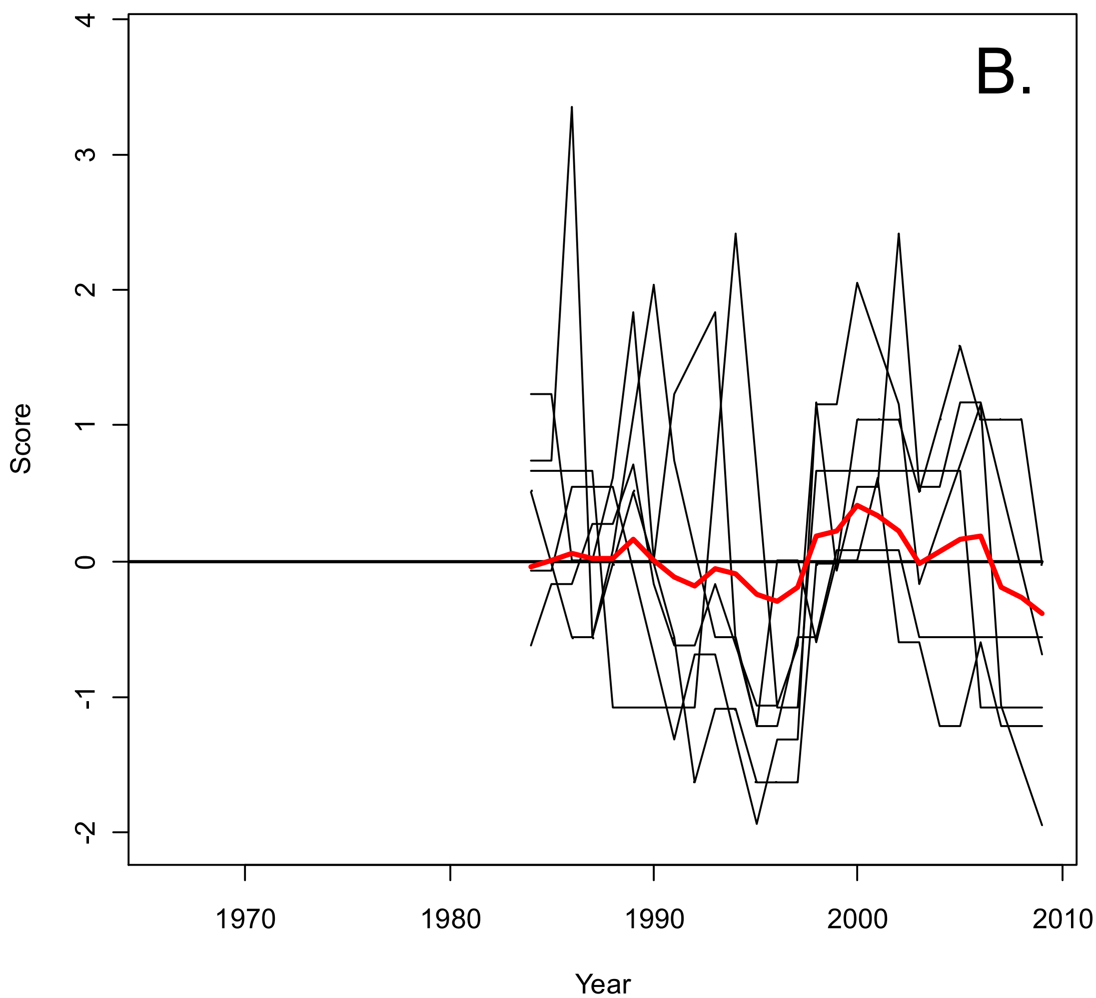


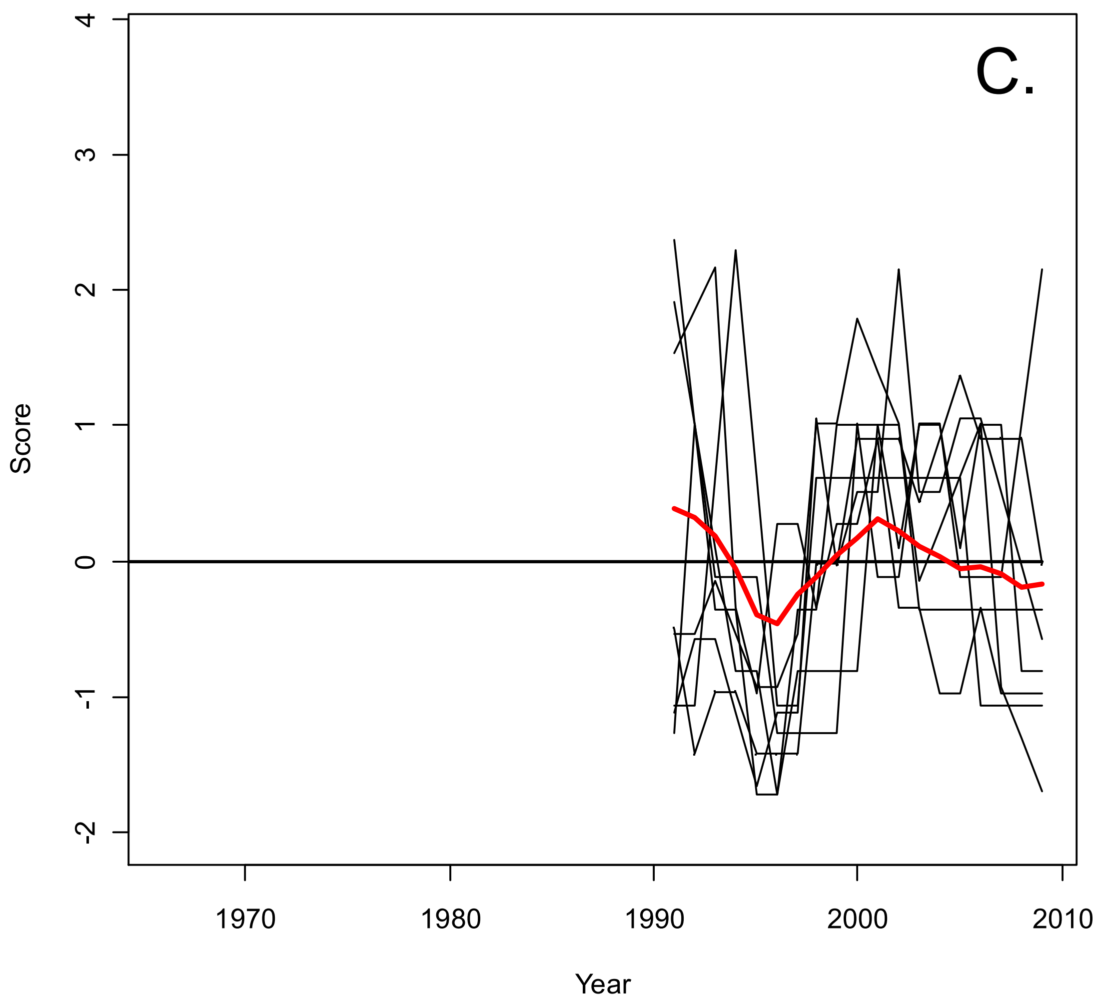
E.
Score
Year
4
3
2
1
0
-1
-2
1970
1980
1990
2000
2010

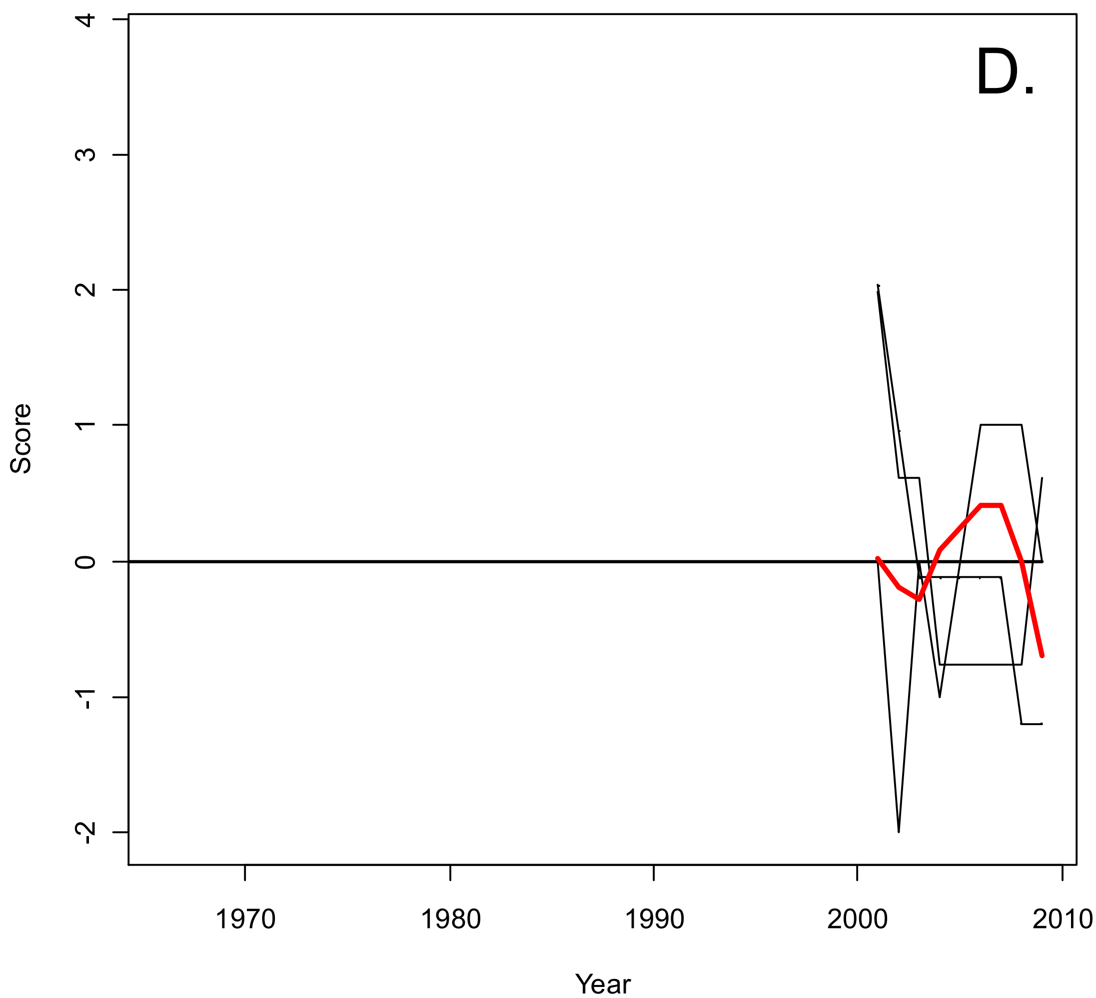
Figure 11. Trend analysis of lesser prairie-chicken lek density along survey routes in Kansas. The red line represents the generalized trend of lek density along the routes and times indicated. The thick black line represents the mean lek density over the time being analyzed. The standardized lek densities of the individual routes included in each analysis are shown as thin black lines to aid in comparison with the trend line.

A. 1966-2009 Clark, Meade, and Morton survey routes
B. 1984-2009 Clark, Finney, Hamilton, Kearny, Meade, and Morton survey routes
C. 1991-2009 Clark, Comanche, Finney, Ford, Hamilton, Kearny, Meade, and Morton survey routes
D. 2001-2009 Barber, Kiowa, and Hodgeman survey routes
E. 2006-2009 Gove and Ness survey routes


A.
Score
Year
4
3
2
1
0
-1
-2
1970
1980
1990
2000
2010


B.
Score
4
3
2
1
0
-1
-2
Year
1970
1980
1990
2000
2010


C.
Score
Year
4
3
2
1
0
-1
-2
1970
1980
1990
2000
2010



D.
Score
Year
4
3
2
1
0
-1
-2
1970
1980
1990
2000
2010

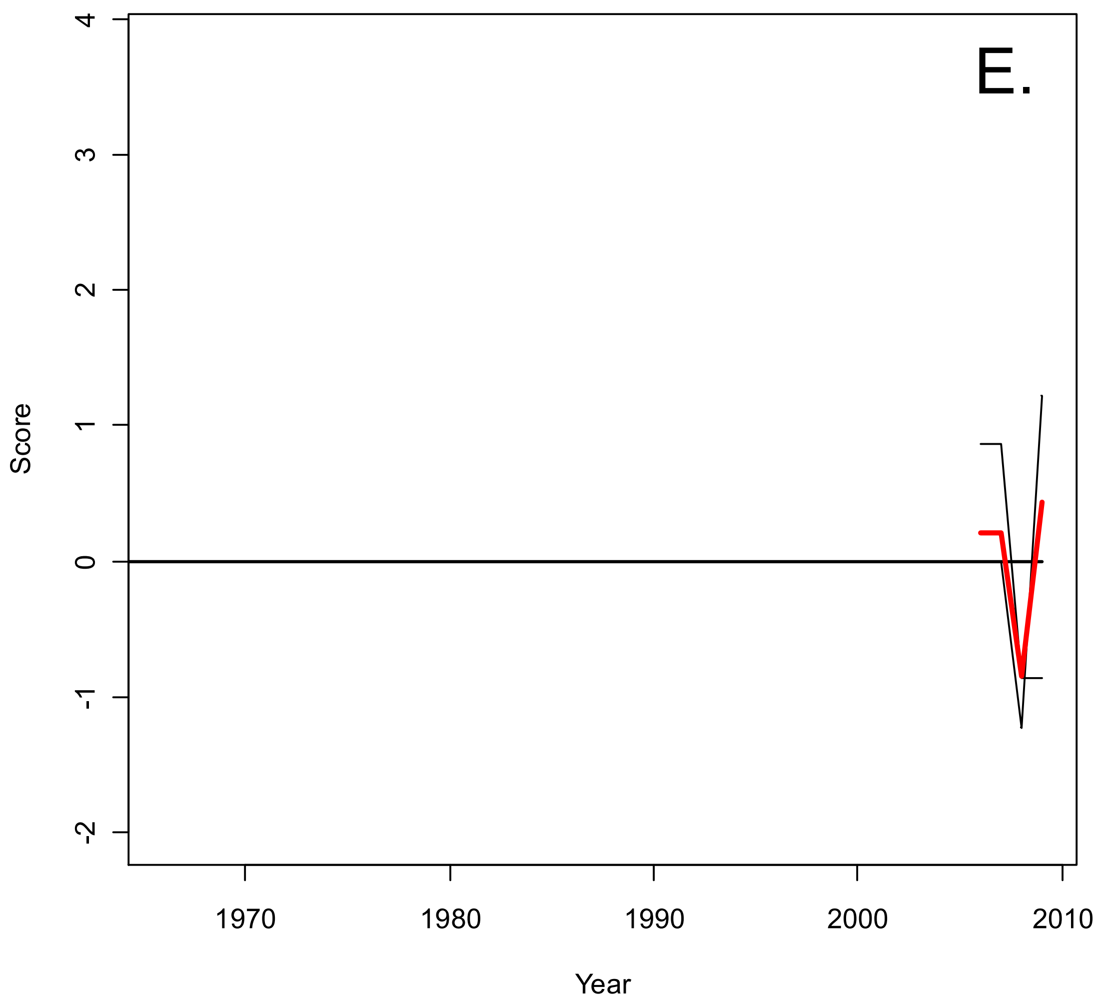
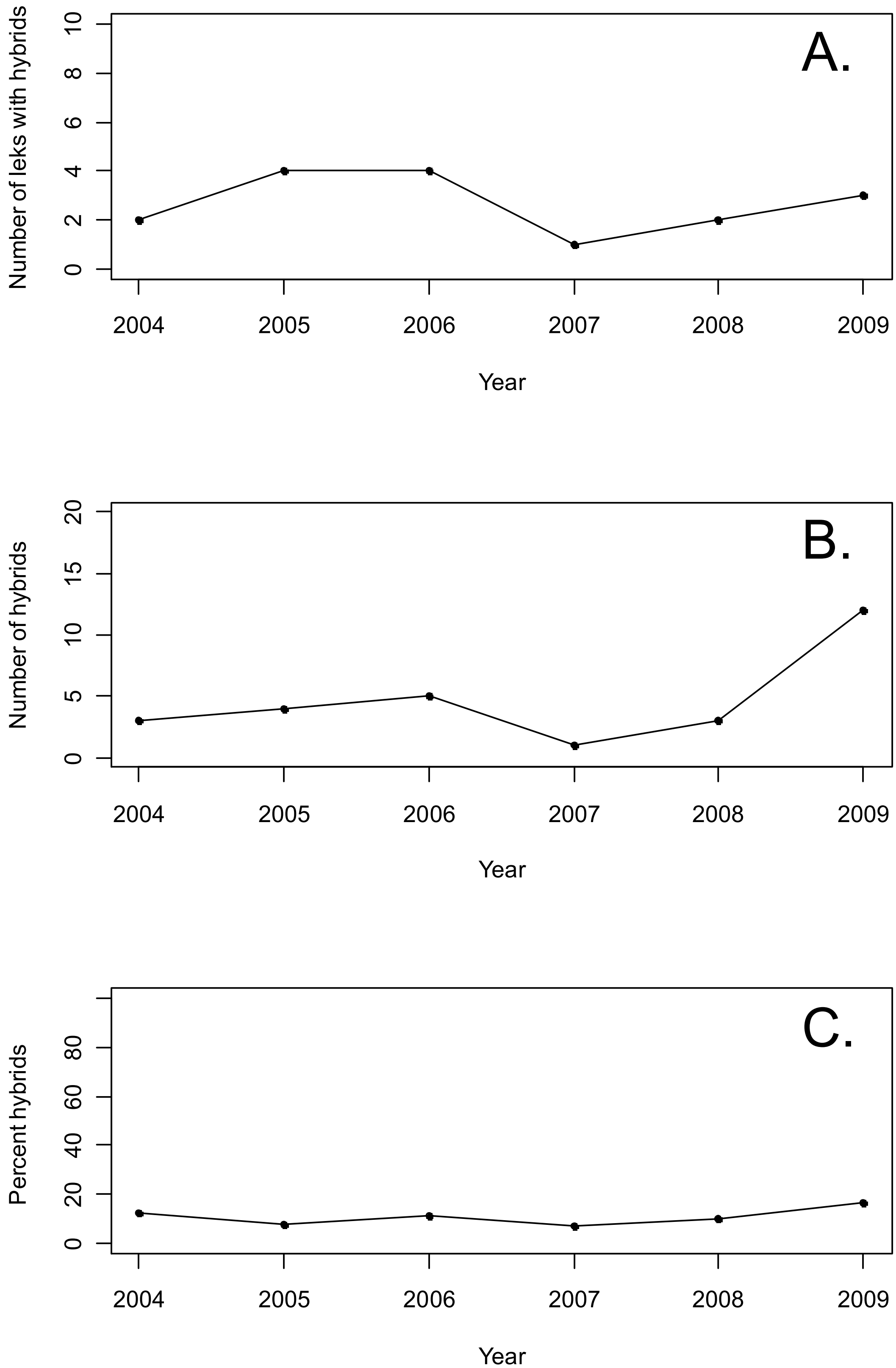

E.
Score
Year
4
3
2
1
0
-1
-2
1970
1980
1990
2000
2010

Figure 12. Data related to the hybridization of lesser and greater prairie-chickens in Kansas 2004-2009.

A. The number of leks with individuals identified as hybrids.
B. Total number of individuals identified as hybrids.
C. Percent of individuals on leks with hybrids identified as hybrids.


A.
Number of leks with hybrids
0
2
4
6
8
10
2004
2005
2006
2007
2008
2009
Year
B.
Number of hybrids
0
5
10
15
20
2004
2005
2006
2007
2008
2009
Year
C.
Percent hybrids
0
20
40
60
80
2004
2005
2006
2007
2008
2009
Year