A HISTORICAL RECORD OF LAND COVER CHANGE OF THE LESSER PRAIRIE-CHICKEN RANGE IN KANSAS

by

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Abstract

The Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*) is a prairie grouse of conservation concern in the Southern Great Plains. In response to declining population numbers and ongoing threats to its habitat, the Lesser Prairie-Chicken was listed as threatened under the Endangered Species Act in May 2014. In western Kansas, the Lesser Prairie-Chicken occupies the Sand Sagebrush Prairie, Mixed-grass Prairie, and Short-grass/CRP Mosaic Ecoregions. Since the beginning of the 20th century, the overall range and population has declined by 92% and 97% respectively. Much of this decline is attributed to the loss and fragmentation of native grasslands throughout the Lesser Prairie-Chicken range. Whereas much of the loss and degradation of native grassland have been attributed to anthropogenic activities such as conversion of grassland to cropland and energy exploration, federal legislation since the 1980s to convert cropland on highly erodible soils to perennial grasses through the U.S. Department of Agriculture (USDA) Conservation Reserve Program (CRP) may curtail or reverse these trends. My objective was to document changes in the areal extent and connectivity of grasslands in the identified Lesser Prairie-Chicken range in Kansas from the 1950s to 2013 using remotely sensed data. I hypothesized that the total amount of grassland decreased between the 1950's and 2013 because of an increase in agricultural practices, but predicted an increase of grassland between 1985 and 2013 in response to the CRP. To document changes in grassland, land cover maps were generated through spectral classification of LANDSAT images and visual analysis of aerial photographs from the Army Map Service and USDA Farm Service Agency. Landscape composition and configuration were assessed using FRAGSTATS to compute a variety of landscape metrics measuring changes in the amount of grassland present as well as changes in the size and configuration of grassland patches. Since 1985, the amount of grassland in the Lesser Prairie-Chicken range in Kansas has increased by 210,9963.3 ha, a rise of 11.9%, while the mean patch size and area-weighted mean patch size of grassland increased 18.2% and 23.0% respectively, indicating grassland has become more connected during this time in response to the CRP. Prior to the implementation of CRP, the amount of grassland had been decreasing since 1950, as 66,722.0 ha of grassland was converted to croplands. The loss of grassland had a considerable effect on the patch size of grasslands, as mean patch size and area-weighted mean patch size decreased by 8.8% and 11.1% respectively. The primary driver of grassland loss

between 1950 and 1985 was the emergence of center pivot irrigation, which had its greatest impact in western and southwestern parts of the range in Kansas. In particular, while the amount of grassland in Range 5, a region of the Lesser Prairie-Chicken range found in southwest Kansas, has increased overall since the 1950s by 4.7%, the area-weighted mean patch size has decreased by 53.0% in response to center pivot irrigation fragmenting the landscape. While the CRP has been successful in increasing and connecting grassland throughout the Lesser Prairie-Chicken range to offset the loss of grassland since the 1950s, continuation of the CRP faces an uncertain future in the face of rising commodity prices, energy development, and reduction in program scope leaving open the possibility that these areas that have created habitat for Lesser Prairie-Chickens could be lost. As time progresses, a reduction in the scope of the CRP would reduce the amount of habitat available to Lesser Prairie-Chickens, threatening the persistence of their population.

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Chapter 1 - Introduction

The Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*) is a prairie grouse species found in five states (Colorado, Kansas, New Mexico, Oklahoma, and Texas) across the Southern Great Plains. Prairies occupied by Lesser Prairie-Chickens are characterized by mid- and tall-grasses and typically include a shrub component. The type of vegetation Lesser Prairie-Chickens that rely upon varies from east to west, with shrub species becoming more important in western regions of the range, where the amount and frequency of precipitation is reduced compared to eastern portions (Haukos and Zavaleta 2015). Despite these differences, it appears that throughout its range, Lesser Prairie-Chickens select habitat based on vegetation structure, and to a lesser extent, vegetation composition (Hagen et al. 2013, Larrson et al. 2013). These choices are primarily influenced by the unique ecology of Lesser Prairie-Chickens, which requires combinations of space and habitat composition depending on the stage of their annual life cycle.

A distinguishing characteristic of Lesser Prairie-Chicken ecology is their mating system. Male Lesser Prairie-Chickens use communal display grounds, known as leks, to gather, display, and establish territories to attract females (Haukos and Zavaleta 2015). Leks are the focal point of Lesser Prairie-Chicken populations, as their daily and seasonal activities have been shown to occur within 4.8 km of leks, even during non-breeding periods (Riley et al. 1994, Woodward et al. 2001, Hagen and Giesen 2004, Kukal 2010). Leks are typically located at higher elevations within a landscape, such as the top of ridges or dunes, with vegetation height <10 cm, and exposed soil (Haukos and Zavaleta 2015). Perhaps the most influential variable in determining lek location/formation is the presence of quality nesting habitat. Generally, Lesser Prairie-Chicken females choose nest sites that provide visual obstruction, horizontal cover, residual vegetation cover, litter cover, and less bare ground compared to associated random points (Riley et al. 1992, Giesen 1994, Pitman et al. 2005, Hagen et al. 2013). The habitat in which Lesser Prairie-Chickens raise their brood requires its own unique vegetation composition. Compared to adult only and nest sites, brood habitat is usually characterized by shorter and less dense vegetation, allowing the smaller birds to move more easily and facilitate predator escape (Jones 1963, Riley and Davis 1993). The different habitat requirements of Lesser Prairie-Chickens at different stages of their life cycle highlight the need for a landscape in which a variety of vegetation cover is present.

Natural ecological processes such as drought, fire, and grazing shape the habitat structure and composition for Lesser Prairie-Chickens. Across the Lesser Prairie-Chicken range, drought is common and often severe, with the recent 2011 - 2013 drought being among the worst on record (Karl et al 2012). Not surprisingly, variation in precipitation has important consequences for vegetation dynamics (Augustine 2010), and drought events are known to impact short-term population trends of Lesser Prairie-Chickens, with populations decreasing during drought and increasing during periods of above-average precipitation (e.g, Henika 1940). In addition to drought, grazing patterns of endemic species such as black-tailed prairie dogs (*Cymomys ludovicianus*) and American bison (*Bison bison*) shaped the landscape. Bison are thought to restore prairie and prairie ecosystem functions by grazing in family groups, reducing vegetation in occupied areas while allowing unoccupied areas to regenerate and creating a more natural, heterogeneous landscape (Allred et al. 2011). These grazing patterns would act in conjunction with natural disturbance such as fire. In mixed-grass prairie, return intervals of fire events have been estimated to be between 5-10 years (Wright and Bailey 1982, Samson et al. 2004). These events would have swept across the landscape until meeting vegetation that was too sparse to fuel flames (e.g. grazed areas), or to wet to burn (riparian zones). These processes created a landscape with a variety of habitat in terms of composition and structure that support Lesser Prairie Chickens through different stages of their life cycle.

Lesser Prairie-Chickens require large patches of grassland to persist, with estimates of minimum patch sizes by some authors of ranging from 4,900 ha to 20,236 ha of contiguous native prairie for self-sustaining populations (Haukos and Zavaleta 2015). Within these patches, a variety of plant types and structures must exist to support Lesser Prairie-Chickens through breeding, nesting, brooding, and non-brooding seasons. Settlement of the Great Plains by Europeans changed the composition and configuration of the landscape. The Homestead Act of 1862 allowed settlers to claim 65 hectares (160 acres) of land to develop and support themselves, which resulted in the conversion of native prairie to row-crop agriculture. Over time, technological developments such as innovations in mechanical plowing and the ability to exploit aquifers for irrigation rapidly increased the rate of conversion from grassland to cropland across the range of the Lesser Prairie-Chicken. In particular, development of center-pivot irrigation in the 1960s allowed for areas historically unsuitable for agriculture because of sandy soils to be converted to croplands (Sexson 1980). As a result, Samson et al. (2004) estimated that <50% of the historic amount of mid- and tall-grass prairie remain as grassland.

The habitat and range of the Lesser Prairie-Chicken have undergone significant reduction since the beginning of the 20th century. During this time, the overall range and population has declined by 92% and 97% respectively (Taylor and Guthery 1980). The principal reason for this decline is the loss and fragmentation of habitat throughout the Lesser Prairie-Chicken range (Boal and Haukos 2015). Anthropogenic activities such as the conversion of native grassland to cropland, unmanaged grazing by livestock, urban development, fire suppression, invasion by exotic and woody plants, and energy exploration have all contributed to the degradation of Lesser Prairie-Chicken habitat. The population decline and anticipated continued loss of habitat resulted in the United States Fish and Wildlife Service (USFWS) listing the Lesser Prairie-Chicken as a threatened species in May 2014 (U.S. Fish and Wildlife Service 2014). While environmental conditions such as drought and available food sources will dictate Lesser Prairie-Chicken populations in the short-term, changes in the amount and quality of available habitat will influence the long-term success or failure of Lesser Prairie-Chicken populations. Given the dynamic nature of land use within their region, from increases in agriculture and energy development to the implementation of conservation practices, documenting changes in the areal extent and connectivity of Lesser Prairie-Chicken habitat over time allows for further analysis of the relationship between available habitat and population size of Lesser Prairie-Chickens. Recognizing the threats associated with soil erosion, there have been multiple government sponsored programs to slow and reverse the conversion of native grassland to cropland since the 1930s, the most contemporary and prevalent in the Great Plains being the Conservation Reserve Program (CRP), a cost-share payment program under the United States Department of Agriculture (USDA). The program's origins trace to the conservation branch of the Soil Bank Program in the 1950s, but the Food Security Act of 1985 (i.e., Farm Bill) established the CRP. The initial objectives of the CRP was to provide technical and financial assistance to landowners to establish perennial grass cover on former row-crop farm fields with highly erodible soils to reduce soil erosion and surplus commodity crops. Rental contracts are for a period of 10-15 years. Later authorizations of the CRP further addressed benefits of the program for water quality and natural resources.

While CRP was initially enacted to prevent soil erosion and reduce production of surplus crops, it has had considerable positive impacts on other ecological processes, such as water quality and wildlife habitat (White et al. 2010, Dahlgren et al. 2015, Rodgers 2015). This is especially true for grassland bird species, which have been experiencing population declines across North America (Brennan et al. 2005). A major benefit of CRP lands for grassland birds is that it provides additional habitat variety, which has shown to increase avian species density (Ribic et al. 2009). Additionally, CRP has been shown to increase the abundance of arthropod species, a significant food source for Lesser Prairie-Chicken, relative to neighboring croplands (McIntyre et al. 2003). With current management recommendations for grassland birds centered on maximizing patch size of grassland habitat (Winter et al. 2006), and two-thirds of the remaining Lesser Prairie-Chickens being in Kansas, a better understanding of how CRP has contributed to land cover within the Kansas range of the Lesser Prairie-Chicken will aid in management efforts focused on conservation of this threatened species.

The CRP has already been shown to increase the amount of habitat available to the Lesser Prairie-Chicken as well as the extent of its range (Dahlgren et al. 2015). Historically within Kansas, the Lesser Prairie-Chicken was predominately found in sand sagebrush (*Artemisia filifolia)* and mixed-grass prairies south of the Arkansas River, as the vegetation in this region provided the necessary visual obstruction for nesting cover. The short-grass prairie north of the Arkansas River in northwestern Kansas is not generally considered habitat for the Lesser Prairie-Chicken because of the lack of cover, but the conversion of croplands to perennial mid and tall grasses through CRP changed this distinction. The presence of mid and tall grasses present in CRP fields facilitated a northward expansion of the Lesser Prairie-Chicken range. A key difference between CRP lands in Kansas and other states is that in Kansas, CRP fields were required to be planted to a mix of native seeds that resembled mixed-grass and tall-grass communities; this increased the available habitat to Lesser Prairie-Chickens and reduced fragmentation of grasslands throughout the landscape, resulting in increased population abundance and occupancy in this region (Rodgers 1999, Fields 2004, Rodgers and Hoffman 2005, Fields et al. 2006). This region, commonly referred to as the Short-grass Prairie/CRP Mosaic Ecoregion (Van Pelt et al. 2013, McDonald et al. 2014), currently supports ~65% of range-wide Lesser Prairie-Chicken population (Dahlgren et al. 2015).

Classifying and mapping land cover is an important component of managing natural resources. While traditional methods of mapping land cover such as field surveys, literature reviews, map interpretation, and ancillary data analysis may be appropriate for local or small scale sites, they are not effective for range-wide or landscape land cover analysis because they are often time consuming, date lagged, and expensive (Yichun et al. 2008). Remote sensing offers a practical and economical alternative to study land cover and land cover change over large areas (Kusimi 2008). The ability to monitor the nature, frequency, and extent of land cover change allow researchers to assess the spatial impacts of landscape changes.

While much of the research on land cover change has focused on single, large scale events, land-use and the resultant vegetative cover undergo constant change (Watson et al. 2013). Often these changes are driven by changing technological, political, and socioeconomic conditions. Across the central United States, much of the land cover change is associated with agricultural commodities. In the Corn Belt region of the United States, Wright and Wimbley (2013) documented increased rates of conversion of grassland to corn between 2006 and 2011 in response to a doubling in the market value of these crops. Similarly, the amount of area converted to corn production in the United States increased by seven million hectares (ha) between 2006 and 2007 at the expense of other crops (Goldemberg and Guardabassi 2009). During the initial enrollment period for participation in the CRP from 1985 to 1994, 14.8 million ha (36.5 million acres) were converted from croplands to CRP fields (Margheim 1994). However the short-term contracts of CRP fields (10-15 years) does not ensure that the conversion of croplands to grasslands will last longer than the duration of the contract, leaving open the possibility of future land cover changes.

Remote sensing applications allow for continuous monitoring of the Earth’s land cover over large areas. Beginning in the 1950s, the USDA conducted aerial photography surveys over the United States to support federal farm programs. Other agencies and organizations, such as the Army Map Service and the U.S. Forest Service also used aerial photography to document land cover, creating a valuable historical database on vegetation cover and condition (Cohen et al. 1996). Unlike traditional methods of recording land cover such as field surveys, photography allows researchers to visually revisit field conditions at the time of collection (Sant et al. 2014). Aerial photographs have also played a pivotal role in supporting the management of ecological processes (Morgan et al. 2010, Strand et al. 2012), as well as modeling wildlife habitat (Grant et al. 2004, Lauver et al. 2002).

Perhaps the greatest advantage of using aerial photography to assess land cover change is that it is the longest available, temporally continuous record of landscape change (Morgan et al. 2010). While the proliferation of satellite imagery has rendered aerial photography a secondary source in many land cover maps, satellite imagery only began being collected in the early 1970s, limiting the temporal extent of any analysis. Another major advantage of using aerial photography to assess land cover change is the high spatial resolution of each image. Higher degrees of spatial resolution allow for landscape features to be delineated more easily in geographic information systems while being able to detect changes occurring at a smaller spatial scale (Strand et al. 2012).

Since its inception in 1972, the National Aeronautics and Space Administration's (NASA) Landsat program has been widely used in change detection analysis because of the high temporal frequency and systematic collection of images (Morgan et al. 2010). Landsat satellites follow 16-day return intervals, creating a series of images collected at a higher frequency than can be reasonably done with aerial photography. In addition to the high temporal frequency over which images are collected, the broad spatial coverage of each individual image (185 km x 172 km) make Landsat images ideal for mapping regional or national scale land cover. Landsat images have been the basis for many large-scale land cover maps, including the National Land Cover Data map series (Thogmartin et al. 2004).

Researchers studying grassland ecosystems similar to the Lesser Prairie-Chicken range have regularly used aerial photography and satellite imagery to classify land cover and document change (Booth et al. 2003, Sant et al. 2014, Egbert et al. 1998). Monitoring grasslands is complicated by the high degree of spatial and temporal variation in vegetation, with meaningful information requiring an evaluation across large landscapes and over extended periods of time (Booth et al. 2003, Sant et al. 2014). Drummond (2007) used Landsat imagery to classify land cover across the northwestern Great Plains and western High Plains from 1973 to 2000 to document the rate of change from grassland to cropland. Much of the change between those dates was attributed to CRP land. Egbert et al. (1998) used Landsat imagery to map CRP fields in Finney County, Kansas, with an accuracy of approximately 88%. Accurate digital land cover maps can aid in answering key ecological questions regarding natural resources such as water, soil, and wildlife (Egbert et al. 1998).

The Lesser Prairie-Chicken has suffered habitat loss and fragmentation within its range, first through agricultural conversion and then energy and other anthropogenic developments, threatening the existence of this species (Bartuszevige and Daniels 2015). While there has been extensive research assessing Lesser Prairie-Chicken habitat, it has been primarily limited to short term, patch-level studies without regard to long-term landscape-level population patterns and dynamics (Woodward et al. 2001). My objectives were to (1) classify the land cover within the Lesser Prairie-Chicken range in Kansas from the 1950s to 2013, (2) evaluate the influence of CRP on landscape change and configuration, and (3) document temporal patterns in landscape extent and connectivity.

Study Area

Land cover was classified based on the extent of Lesser Prairie-Chicken range in Kansas in 2012. The defined range in Kansas was determined by the Lesser Prairie-Chicken Interstate Working Group and included three distinct habitat regions: the Sand Sagebrush Prairie Region in southwestern Kansas, the Mixed-Grass Prairie Region in south-central Kansas, and the Short-grass Prairie/CRP Mosaic in northwestern Kansas (McDonald et al. 2014). The range covered 22,922 km^2 across the High Plains physiographic region of western Kansas and encompassed all or parts of 36 counties (Figure 1.1). The range was determined by Kansas Wildlife, Parks, and Tourism and other agency biologists who annually survey for active leks across the range. The range-wide landcover was a mosaic of native prairies, shrublands, and croplands. South of the Arkansas River, sand sagebrush (*Artemisia filifolia*) and mixed-grass communities are dominate native cover types, while mixed-grass intermixed with short-grass prairie communities are found north of the Arkansas River (Hagen et al. 2004). The area of the Lesser Prairie-Chicken found in south-central Kansas is comprised of mixed-grass prairie. Agriculture is a mixture of dryland and irrigated crops as well as cattle grazing and feedlot operations interspersed through the range. This semi-arid region receives <60 cm of precipitation annually and experiences periodic drought episodes (Hagen et al. 2004).

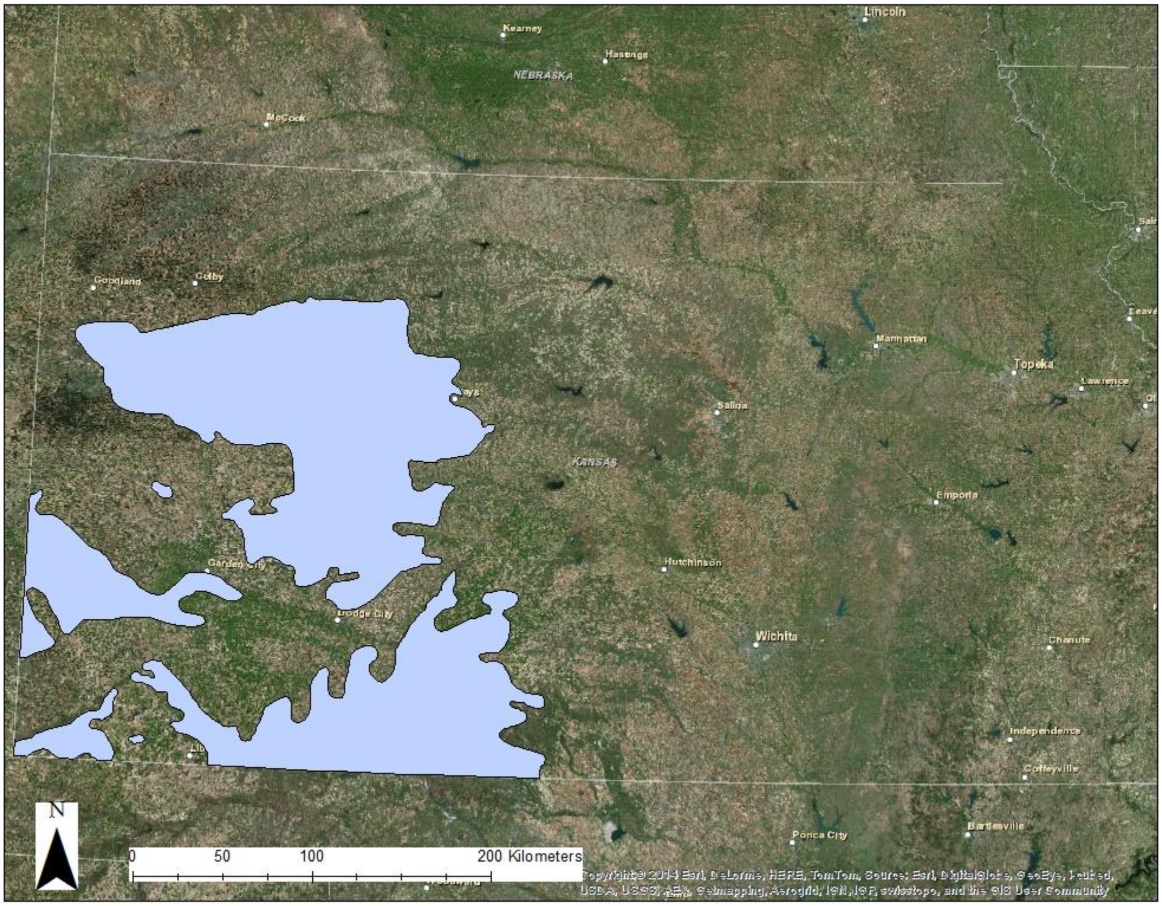

Figure 1.1 The Lesser Prairie-Chicken range in Kansas as of 2012 as defined by the Lesser Prairie-Chicken Interstate Working Group.

Chapter 2 - Methods

Data Acquisition

Images from each decade between the 1950s and 2013 were acquired to classify land cover during these time periods (Table 2.1). The 1950s was the earliest decade in which land cover was classified because it was the earliest decade in which aerial photographs were available for the entire region of interest. Aerial photographs and satellite images were acquired for a period in each decade following the 1950s the document changes in cover type. However for the 1980s, images were gathered for two years, 1985 and 1988, to document land cover conditions prior to and after the implementation of the CRP.

To create the 1950s land cover map of the Lesser Prairie-Chicken range in Kansas, aerial photographs taken by the U.S. Army Map Service were downloaded from the U.S. Geological Survey's (USGS) Earth Explorer website. The aerial photos were taken between 1955 and 1958. Any missing photos needed to complete the coverage of the Lesser Prairie-Chicken range were identified by county; in the event that coverage of the entire county was not needed, coordinates representing the shape of the desired coverage area were entered into the search toolbar. Only vertical cartographic photos were considered, as high or low oblique aerial photographs do not allow for accurate interpretation of land cover. The aerial photographs were then downloaded by county using the Bulk Downloading Application offered by the USGS website. I downloaded 550 aerial photographs at a scale of 1:56,000 to provide entire coverage.

The 1960s land cover map of the Lesser Prairie-Chicken range in Kansas was created by obtaining aerial photographs taken by the U.S. Department of Agriculture (USDA). These photos were originally taken in either 1963, 1965, or 1968. These photos were scanned at a 600 dots-per-inch (dpi) resolution to allow for accurate visual interpretation of land cover. Scanning initially took place at the Digital Collections Office of Hale Library at Kansas State University. Aerial photographs not stored at Hale Library were scanned at the Kansas Applied Remote Sensing (KARS) laboratory at the University of Kansas. Photographs that were neither available at Kansas State University or the University of Kansas were purchased from the USDA Aerial Photography Field Office in Salt Lake City, Utah. The photos needed for complete coverage of the Lesser Prairie-Chicken range were identified by using maps of the flight lines taken for each county when photography took place. Flight line maps show each individual photograph's index

Year	Source	Type	Cartographic Scale	Number of Images
1950	Army Map Service	Aerial Photography	1:56,000	550
1960	U.S. Department of Agriculture	Aerial Photography	1:20,000	5,183
1978	Landsat 2	Satellite Imagery	1:100,000	5
1985	Landsat 5	Satellite Imagery	1:100,000	10
1988	Landsat 5	Satellite Imagery	1:100,000	10
1994	Landsat 5	Satellite Imagery	1:100,000	10
2003	Landsat 5	Satellite Imagery	1:100,000	10
2013	Landsat 8	Satellite Imagery	1:100,000	10

Table 2.1 Images used to classify land cover within the Lesser Prairie-Chicken range in Kansas for each decade of analysis. Image source denotes the organization or satellite that gathered images.

number, allowing the user to identify the location of where an individual photograph was taken. 5,183 photos at a scale of 1:20,000 were scanned to complete coverage for the entire Lesser Prairie-Chicken range in Kansas.

Landsat satellite images were used to classify land cover for the periods of interest between 1978 and 2013. Landsat images were downloaded from the USGS Earth Explorer website and selected by identifying the path and row number of the desired photo as well as the desired dates. Only images with <10% cloud cover were considered for analysis to minimize atmospheric obstruction. Landsat 1 images were downloaded for 1978 classification. Landsat 5 images were downloaded for 1985, 1988, 1994, and 2003 classifications. Landsat 8 images were used for 2013 classification. Individual Landsat images are identified by their path and row number according to the World Referencing System (WRS). Landsat 1 subscribes to WRS-1 while Landsat 5 and Landsat 8 use WRS-2 to index images. The path and row number of the Landsat 1 images used for classification were 31:34, 32:34, 33:34, 32:33, and 33:33. The path and row number of the Landsat 5 and Landsat 8 images used for classification were 29:34, 30:33, 30:34, 31:33, and 31:34 (Figure 2.1).

Two images from different dates for each year were obtained for each path and row for a total of ten images per period of interest. The two images selected represented one image from the peak growing season (Jun/July/August) and one from a winter month (December/January/February). Using images from multiple dates maximizes the spectral differences of cover types over the course of a growing season. Within the Lesser Prairie-Chicken range, wheat and grassland are often spectrally confused during spring and summer months as both are in the midst of growing (Egbert et al. 1998). Combining images from different dates of the year capitalizes on phenologic differences and improves classification accuracy.

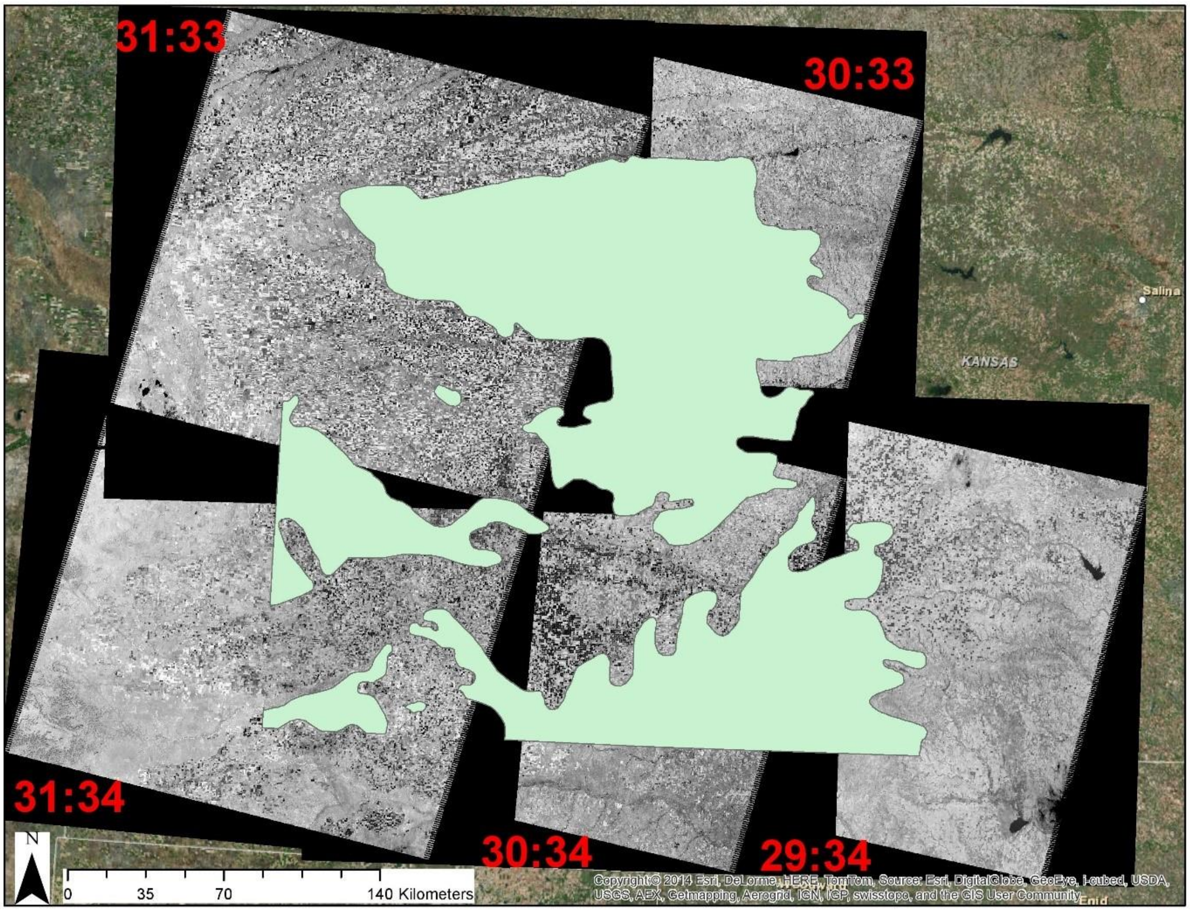

Figure 2.1 Landsat images used for spectral classification with their WRS-2 path and row identification for assessing changes in grassland cover from the 1950s – 2013 for Lesser Prairie-Chicken habitat in Kansas.

Pre-Classification Processing

Aerial photographs were georeferenced in ArcMap 10.2 using a satellite imagery base map as a template for reference. The North American Datum of 1983 (NAD83) was used as the projection to assign coordinate points in each image. All images were assigned a minimum of five control points in the georeferencing process that amounted to a root-mean-squared error no greater than 15, indicating each image was georeferenced to within 15 m of where the image was taken.

Pre-processing of Landsat images included stacking the bands from each image of the same path/row and year into one image. The six reflective bands from each image were included in the stacking process, including the visible bands (blue/green/red), the near infrared band, and both short-wave infrared bands. The output image was assigned to NAD83 projection to match the coordinates of the georeferenced aerial photographs. Stacked images were subset by the portion of the Lesser Prairie-Chicken range that fell within the extent of each image. The Lesser Prairie-Chicken range was delineated as six separate polygons (see Results); however, the majority of these polygons did not fall entirely within a single Landsat image. Polygons were divided along the edges of Landsat images so the area being classified fell entirely within an image. This resulted in 11 separate polygons used to subset Landsat images prior to land cover classification.

Classification

An ISODATA unsupervised classification was used to classify each image using the Classification Workflow tool in the image analysis program ENVI (Exelis Visual Information Solutions). Unsupervised classification was chosen over supervised classification after multiple trials with each method demonstrated unsupervised classification a better ability to differentiate between cover types. After testing multiple parameters, the pixels in each image were grouped into 40 spectral clusters at a convergence threshold of 95%. These parameters were repeated for every unsupervised classification. A visual overlay technique, in which each of the 40 clusters was overlaid on multispectral imagery was used to define each cluster to either grassland or cropland. Because of the limited spatial resolution of Landsat images (30 m^2), and the large spatial and temporal scale being classified, classification was limited to differentiating between grassland and cropland to allow for a more accurate, albeit coarser, level of classification among dates. The grassland class therefore included short-, mixed-, and tall-grass prairie; sand sagebrush prairie; and CRP fields. Croplands refer to both dryland (i.e., wheat) and irrigated crops such as corn, sorghum, and alfalfa among others. Other reference data, such as high resolution Google Earth imagery and ESRI's satellite imagery base maps in ArcMap 10.2 were used to assist in the interpretation of the land cover represented by each spectral class.

For each image, the majority of the 40 spectral clusters would accurately represent either grassland or cropland, yet approximately five to six spectral clusters would not be able to differentiate between grassland and cropland; these clusters contained an equal proportion of pixels representing grassland or cropland. These areas of confusion were often associated with areas of bare ground in grassland and fallow crop fields, as well as riparian vegetation areas and heavily irrigated cropland (Egbert et al. 1998). To address confused classes, a "cluster-busting" approach was initially employed (Egbert et al. 1998). An image consisting of only the pixels from the confused class was created and ran through the Classification Workflow tool to separate pixels into an additional six spectral clusters. These new clusters were defined as either grassland or cropland using the same visual overlay technique and then merged back into the initial land cover map. This process had varying degrees of success in separating confused classes depending on the image and class. In the event cluster busting was unsuccessful, a vector shapefile was created by heads-up digitizing polygons in ArcMap 10.2 over areas that were classified incorrectly. These polygons were assigned a value representing the correct land cover class, then merged into the raster, effectively changing incorrectly classified pixels to their correct class.

As previously mentioned, the Lesser Prairie-Chicken range was subdivided into 11 polygons so the extent of each polygon would fit entirely within the bounds of a Landsat image. After each region had been classified, the 11 regions were rejoined to the original six polygons. This was accomplished by adding the adjacent polygons into ArcMap 10.2 and digitizing along the border to create a file representing the land cover on either side of the border. This file was used to join adjacent regions with the Append Tool in ArcMap 10.2.

The six rasters representing the Lesser Prairie-Chicken range in Kansas were converted into a single raster by loading them into a raster catalog and then converting the raster catalog to a raster dataset. Two layers from the Kansas Land Cover Mapping Project (Egbert et al. 1998), representing water bodies and other urban areas, were masked into the raster with the Append tool, creating separate urban and water land cover classes. These layers were added from a separate source rather than spectrally classified because of the spectral confusion associated with these classes, and given the small proportion of the landscape they represent, a more accurate representation of these classes was achieved by importing them from another source.

While unsupervised classification was the technique used to create land cover maps from 1985-2013, land cover maps for 1978, 1960s and 1950s were created by overlaying the subsequent decade's land cover map and visually detecting change. Despite having Landsat 1 images for 1978, the significant errors associated with many of the images bands, along with many of the bands not being accurately georeferenced made spectral classification challenging. The infrared band from each 1978 Landsat 1 image was georeferenced to an RMS error no greater than 15 m, and then the 1985 map was overlain on the original bands. A vector shapefile was created to edit areas where land cover had changed. When a patch of land was observed to have changed from the subsequent decade, a polygon was digitized over the area to reflect the nature of this change. After visually inspecting the entire range and digitizing change in a shapefile, the vector shapefile was converted to a raster and masked into a copy of the 1985 image, resulting in a land cover map for 1978. This process was repeated for the aerial photography of the 1960s and 1950s to create land cover maps for those decades.

Classification Accuracy

An accuracy assessment was conducted for the 2013 land cover map using a combination of field-gathered ground truth points and randomly generated points in ArcMap 10.2. In August of 2013, 35 points were collected throughout the Lesser Prairie-Chicken range. Each location was chosen to represent a different type of land cover within the range to encompass all the potentially different cover types that could fall under the categories of grassland or cropland. Locations were considered viable if they were large expanses of a particular cover type; any patch smaller than the 30 m^2 of a single Landsat pixel were not considered. At each location, Universal Transverse Mercator (UTM) coordinates were recorded using a handheld global positioning system (GPS) device (Garmin Etrex Vista), the cardinal direction the data recorder was facing towards the land cover patch, a written description of the plant species present as well as the proportional abundance of plants types (recorded as a percentage), and multiple photos of the scene were taken.

In addition to these point locations, 50 points describing local vegetative cover gathered by wildlife biologists as part of concurrent research efforts were included to determine the classification accuracy. These points, defined by UTM coordinates, were gathered between June and August of 2013 at Lesser Prairie-Chicken nest and used-point locations and included a description of the dominant cover types present. To create a more robust sample to test classification accuracy, an additional 420 points were randomly generated within the Lesser Prairie-Chicken range using ArcMap 10.2. The cover type at each point was determined by loading the point data into Google Earth and interpreting the high resolution imagery (Kuemmerle et al. 2006). Values representing the cover type at each of the 505 sample points was recorded in an Excel spreadsheet.

Sample points were overlain on the 2013 land cover map and land cover values were extracted and recorded in the Excel spreadsheet. Using the statistical program R (R Development Core Team 2012), accuracy was determined by cross-tabulating the values extracted from the land-cover map with the ground-truth values to produce an error matrix.

Post Classification Analysis

Land-cover maps were subsequently analyzed using the software program FRAGSTATS (McGarigal et al. 2012) to compute a variety of landscape metrics for each date and observe changes between dates. In addition to analyzing the entire Lesser Prairie-Chicken range in Kansas, landscape metrics were computed for each of the four largest regions of the range for each decade to allow for a comparison among regions and across time. The metrics that were used are described below:

Total Area: A measure of how much of the landscape was comprised of grassland. Measured in hectares (ha). Total area is a measure of landscape composition and used in the computation of many of the other landscape metrics.

Patch Area: The area of each individual patch of grassland measured in hectares (ha). Patches were delineated using an eight-neighbor cell rule; patches are defined by the four orthogonally and four diagonally adjacent cells.

Percentage of Landscape: The proportional abundance of grassland in the landscape. A relative measure of landscape composition, it can be used for comparing the composition of landscapes of varying sizes.

Largest Patch Index: Quantifies the percentage of the total landscape that was comprised by the largest patch of grassland.

Mean Patch Size: The total area of grassland within the landscape divided by the number of grassland patches. Mean patch size represents an average of patch sizes but does not represent the conditions an individual dropped at random on the landscape would experience, as it does not account for the proportional abundance of patch sizes. It is a patch-centric metric.

Area-Weighted Mean Patch Size: The total area of grassland divided by the number of grassland patches while accounting for the proportional abundance of each patch. Area-weighted mean patch size provides a landscape-centric perspective of the landscape, as it reflects the conditions that an individual would experience if dropped at random onto the landscape.

Effective Mesh Size: Denotes the size of patches when grassland within the landscape was divided into N areas of equal size with the same degree of landscape division as obtained for the observed cumulative area distribution.

Total Edge: A measure of the total edge length of grassland patches, measured in meters (m). The boundary interface of the landscape was not included in the calculation of total edge. This measurement was most appropriately used when comparing landscapes of identical sizes.

Edge Density: Measures the total length of grassland patch edges in the landscape, divided by the total landscape area, measured in meters (m) per hectare (ha). The boundary interface of the landscape was not included in the calculation of edge density. Edge density facilitates the comparison of edge length between landscapes of varying size by reporting edge length as a per unit area metric. When comparing landscapes of identical size, total edge and edge density are redundant.

Chapter 3 - Results

Classification Accuracy

Of the 505 measured points, 454 were accurately classified in the 2013 land-cover map (Figure 3.1) for an overall accuracy of 89.9% with a Kappa value of 80.9%. The Kappa statistic reflects the difference between actual agreement between the land cover map and ground control points and agreement expected by chance. The 80.9% Kappa value indicates that there is 80.9% better agreement in the land cover map then by chance alone. User accuracy for both cropland and grassland were 94.9% and 94.3%, respectively, while the producer accuracy for cropland was 92.3% and 89.8% for grassland. The 22,922 km^2 Lesser Prairie-Chicken range in Kansas was depicted as six separate polygons, yet the largest four accounted for >99% of the range in Kansas (Figure 3.2). These four are profiled below as each is individually analyzed with the same metrics as the entire range.

Range 1

Range 1 was the northern most extent of the Lesser Prairie-Chicken range and represented the Short-grass/CRP Mosaic Ecoregion as defined by Van Pelt et al. (2013) and McDonald et al. (2014). The ecoregion is comprised of grasses such as buffalograss (*Buchloe dactyloides*) and blue grama, as well as mid-grass species such as sideoats grama (*Bouteloua curtipendula*), little bluestem (*Schizachyrium scoparium*), sand dropseed (*Sporobolus cryptandrus*) and western wheatgrass (*Pascopyrum smithii*). Lying entirely north of the Arkansas River, this region of the Lesser Prairie-Chicken range is a mosaic of short-grass, mixed-grass, CRP fields, along with dryland crops, and expands 20,763 km^2 across western Kansas, covering 19 counties. Average annual precipitation in this region ranges from 54 cm to 59 cm (National Oceanic and Atmospheric Administration, http://reseach.noaa.gov).

Range 2

Bordering Oklahoma to the south, Range 2 represented the southern bound of the Lesser Prairie-Chicken range in Kansas. Range 2 was the second largest region of the Lesser Prairie-Chicken range in Kansas, extending 11,206 km^2. The majority of this range was within the Mixed-Grass Prairie Ecoregion as defined by Van Pelt et al. (2013) and McDonald et al. (2014), with some of

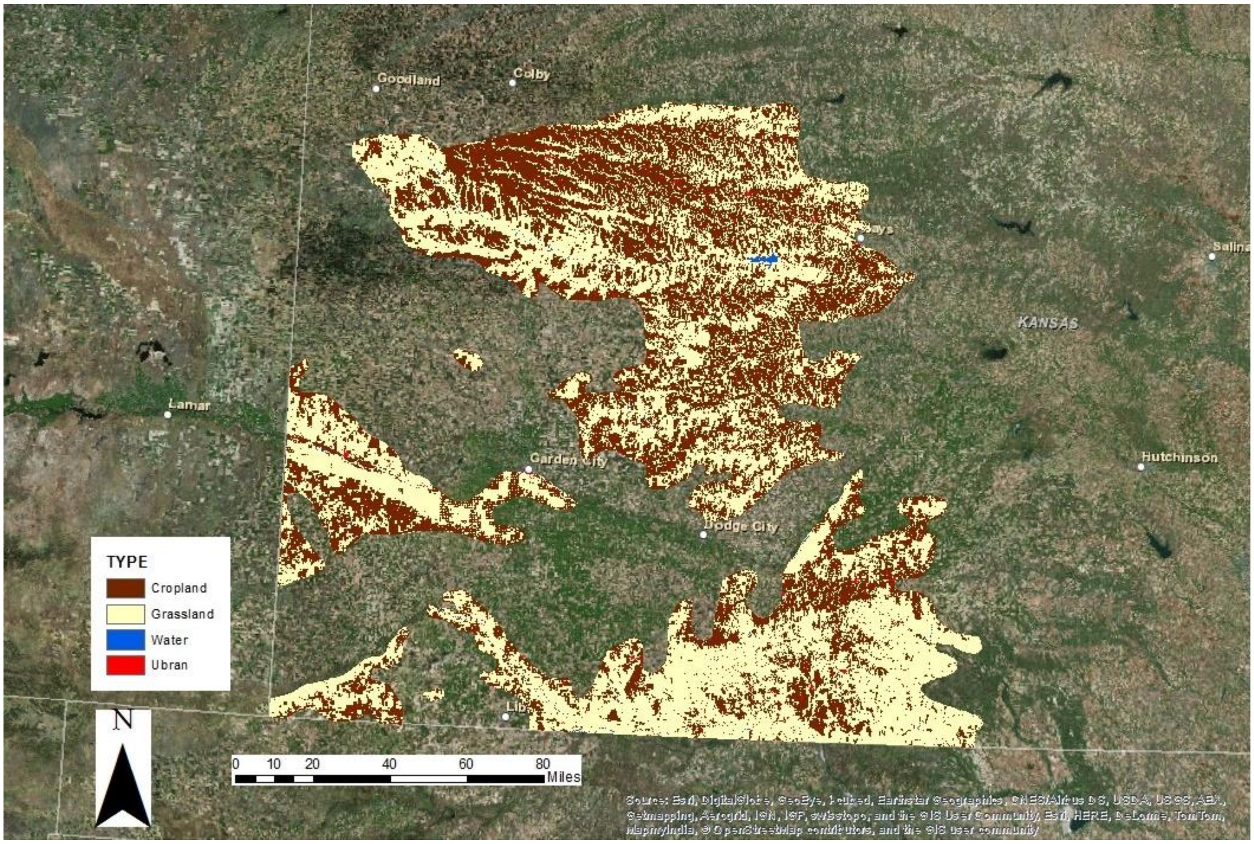

Figure 3.1 Land cover (grassland, cropland, water, and urban) extent of Lesser Prairie Prairie-Chicken range in Kansas in 2013.

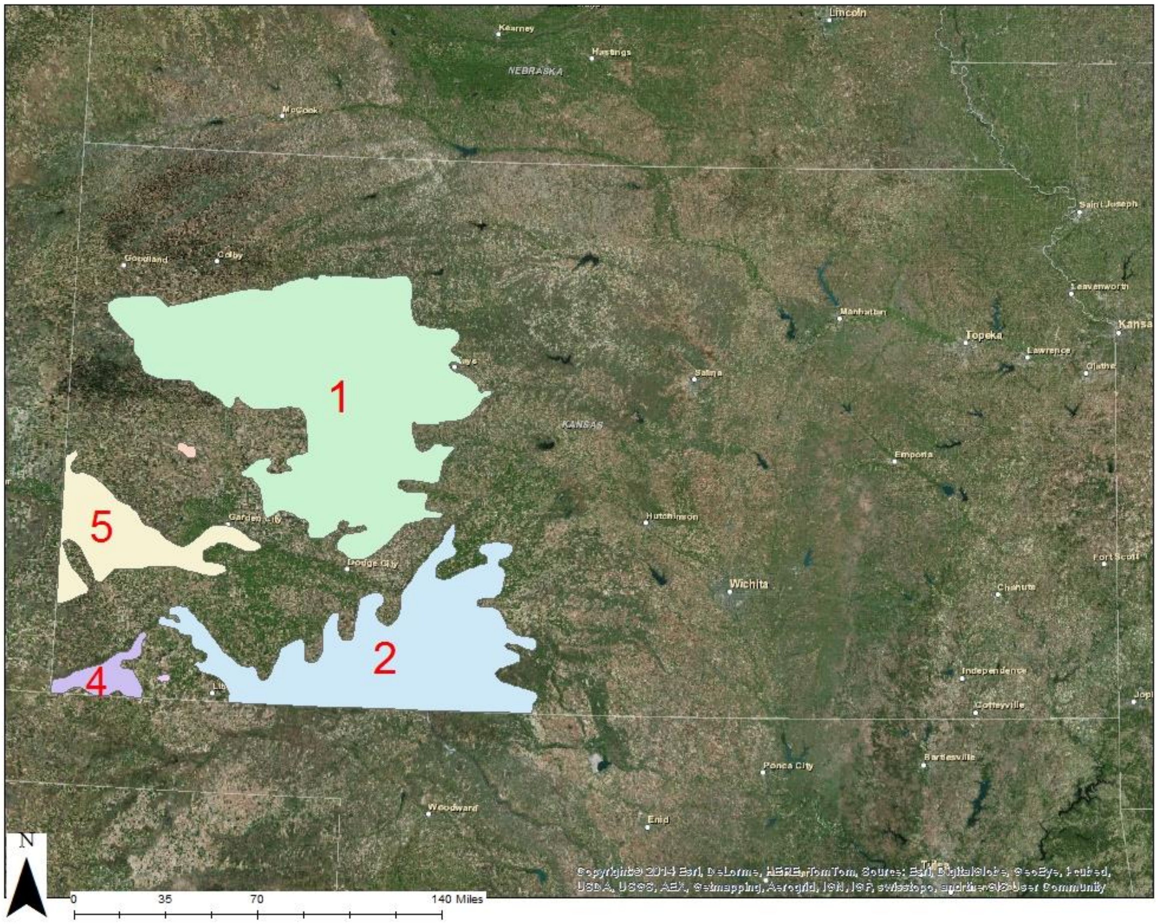

Figure 3.2 The four major regions of the Lesser-Prairie Chicken range in Kansas. These regions account for >99% of the entire range in Kansas.

the western portion of this range occupying the Sand Sagebrush Prairie Ecoregion. Crop production in this region included both dryland and irrigated crops. Average annual precipitation ranges from 50 cm to 63 cm (National Oceanic and Atmospheric Administration, http://reseach.noaa.gov).

Range 4

Range 4 was found in the southwest corner of Kansas, bordering both Colorado and Oklahoma and falling entirely within the Sand Sagebrush Prairie Ecoregion as defined by Van Pelt (2013) and McDonald et al. (2014). At 940 km^2, it was the fourth largest region of the Lesser Prairie-Chicken range in Kansas and covered parts of Morton and Stevens County. A mixture of mid- and tall grasses are associated with sand sagebrush prairie, such as sand bluestem (*Andropogon* hallii), little bluestem, switchgrass, prairie sandreed (*Calamovilfa longifolia*), and sand dropseed. Range 4 contained large expanses of sand sagebrush prairie as well as mixed-grass prairie, along with dryland and irrigated crops. The annual average precipitation in Range 4 is approximately 46 cm (National Oceanic and Atmospheric Administration, http://reseach.noaa.gov)..

Range 5

Range 5 was located in western Kansas in the Sand Sagebrush Prairie Ecoregion as defined by Van Pelt et al. (2013) and McDonald et al. (2014), and covered 3,854 km^2 across eight counties. Within Range 5, mid- and tall-grasses such as little bluestem, sand bluestem, switchgrass, prairie sandreed, and sand dropseed make up much of the native prairie. This region was divided by the Arkansas River with the northern extent consisting of mixed-grass prairie and dryland crops and the southern extent a mosaic of sand sandbrush prairie, mixed-grass prairie, and irrigated crops. This region of the Lesser Prairie-Chicken range has an annual average of approximately 40 cm of precipitation (National Oceanic and Atmospheric Administration, http://reseach.noaa.gov).

Total Area

The total area of grassland in the Lesser Prairie-Chicken range increased from 1,845,535.3 ha during the 1950s to 1,989,776.6 ha in 2013, an increase of 144,241.3 ha, or 7.8% (Table 3.1). From the 1950s to 1985, the total area of grassland decreased by 66,722 ha or 3.6% (1,845,535.3 to 1,778,813.3), followed by an increase of 237,288.3 ha or 13.3% between 1985 and 2003 (1,778,813.3 ha to 2,016,101.6 ha). Between 2003 and 2013, the total area of grassland in the Lesser Prairie-Chicken range decreased by 26,325 ha or 1.3% (2,016,101.6 ha to 1,989,776.6 ha). These results indicate that for the entire range, grassland experienced a small decrease between the 1950s and 1985, followed by a large increase between 1985 and 2003. In the last decade, there has been a slight reduction in the amount of grassland within the Lesser Prairie-Chicken range in Kansas.

Within Range 1, the total area of grassland increased from 902,098.3 ha during the 1950s to 967,970.3 ha in 2013, an increase of 65,872 ha or 7.3% (Table 3.1). From the 1950s to 1985, total area of grassland in Range 1 decreased by 13,927.1 ha or 1.5% (902,098.3 ha to 888,171.2 ha), followed by an increase of 95,611.6 ha, or 10.8%, between 1985 and 1994 (888,171.2 ha to 983,782.8 ha). From 1994 to 2013, the total area of grassland in Range 1 decreased by 15,812.5 ha, or 1.6% (983,782.8 ha to 967,970.3 ha).

The total area of grassland in Range 2 increased from 698,824.4 ha during the 1950s to 753,985.4 ha in 2013, an increase of 55,161 ha or 7.9% (Table 3.1). Between the 1950s and 1985, the total area of grassland decreased by 14,614.1 ha or 2.1% (698,824.4 ha to 684,210.3 ha), followed by an increase of 86,149 ha, or 12.6%, between 1985 and 2013 (684,210.3 ha to 770,359.3 ha). From 2003 to 2013, the total area of grassland in Range 2 decreased by 16,373.9 ha, or 2.1% (770,359.3 ha to 753,985.4 ha).

Within Range 4, the total area of grassland increased from 43,979.6 ha during the 1950s to 56,235.9 ha in 2013, an increase of 12,256.3 ha or 27.9% (Table 3.1). From the 1950s to 1985, the total area of grassland in Range 4 decreased by 402.5 ha or 0.009% (43,979.6 ha to 43,577.1 ha), followed by an increase of 13,404.4 ha, or 30.8%, between 1985 and 2003 (43,577.1 ha to 56,981.5 ha). Between 2003 and 2013, the total area of grassland in Range 4 decreased by 745.6 ha or 1.3% (56,981.5 ha to 56,235.9 ha).

The total area of grassland in Range 5 increased from 195,805.6 ha during the 1950s to 205,039.4 ha in 2013, an increase of 9,233.8 ha or 4.7% (Table 3.1). Between the 1950s and 1985, the total area of grassland decreased by 38,309.6 ha or 19.6% (195,805.6 ha to 157,496 ha), followed by an increase of 58,238 ha, or 37%, between 1985 and 2003 (157,496 ha to 215,734 ha). From 2003 to 2013, the total area of grassland in Range 5 decreased by 10,694.6 ha or 4.9% (215,734 ha to 205,039.4 ha)

YEAR	LEPC Range	RANGE_1	RANGE_2	RANGE_4	RANGE_5
1950	1,845,535.32	902,098.26	698,824.35	43,979.58	195,805.62
1960	1,845,377.91	902,098.26	698,824.35	43,979.58	195,648.21
1978	1,785,218.67	888,262.56	684,007.20	43,696.35	164,424.24
1985	1,778,813.28	888,171.21	684,210.33	43,577.10	157,495.95
1988	1,935,928.89	953,383.59	759,231.99	47,493.36	170,320.05
1994	2,037,070.08	983,782.80	771,892.38	57,997.71	216,026.91
2003	2,016,101.61	965,952.45	770,359.32	56,981.52	215,733.96
2013	1,989,776.61	967,970.25	753,985.35	56,235.96	205,039.44

Table 3.1 Total area of grassland (ha) within the Lesser Prairie-Chicken (LEPC) range in Kansas and the four major regions comprising the range from the 1950s to 2013.

Percentage of Landscape

From the 1950s to 2013, the percentage of grassland in the Lesser Prairie-Chicken range increased from 50.0% during the 1950s to 53.9% in 2013 (Table 3.2). Within that time period, grassland experienced a decrease between the 1950s and 1985 (50.0% to 48.2%), followed by an increase between 1985 and 2003 (48.2% to 54.6%). In the last decade, the percentage of landscape that was grassland has decreased from 54.6% in 2003 to 53.9% in 2013. These statistics reflect similar changes observed in the total area; that the amount of grassland decreased between the 1950s and 1985, followed by a large increase between 1985 and 2003, and then a small decrease between 2003 and 2013.

The percentage of grassland in Range 1 increased between the 1950s and 2013 from 43.4% to 46.6% (Table 3.2). From the 1950s to 1985, the percentage of grassland decreased from 43.4% to 42.7%.. Between 1985 and 1994, the percentage of grassland in Range 1 increased from 42.7% to 47.4%, followed by decrease from 47.4% in 1994 to 46.6% in 2013.
From the 1950s to 2013, the percentage of grassland in Range 2 increased from 62.3% during the 1950s to 67.2% in 2013 (Figure 6). Between the 1950s and 1985, the percentage of grassland decreased by from 62.3% to 61.0% (62.3% to 61.0%), followed by an increase between 1985 and 2003 (61.0% to 68.7%). From 2003 to 2013, the percentage of landscape that was grassland decreased from 68.7% to 67.2%

The percentage of grassland in Range 4 increased between the 1950s and 2013 from 46.7% to 59.8% (Table 3.2). Within that time period, grassland experienced a decrease between the 1950s and 1985 (46.7% to 46.3%). Between 1985 and 2003, the percentage of grassland in Range 4 increased from 46.3% to 60.6%.From 2003 to 2013, the percentage of grassland decreased from 60.6% to 59.8%..

From the 1950s to 2013, the percentage of grassland in Range 5 increased by from 50.8% to 53.1% (Table 3.2). Between the 1950s and 1985, grassland decreased from 50.8% to 40.8%, followed by an increase between 1985 and 2003 (40.8% to 55.9%). Between 2003 and 2013, the percentage of grassland in Range 5 decreased from 55.9% to 53.1%.

YEAR	LEPC RANGE	RANGE_1	RANGE_2	RANGE_4	RANGE_5
1950	50.0293	43.4461	62.3617	46.7917	50.8019
1960	50.0251	43.4461	62.3617	46.7917	50.761
1978	48.3942	42.7798	61.0395	46.4904	42.6599
1985	48.2206	42.7754	61.0576	46.3635	40.8624
1988	52.4797	45.9161	67.7524	50.5301	44.1896
1994	55.2215	47.3801	68.8822	61.7062	56.0483
2003	54.6531	46.5214	68.7454	60.625	55.9723
2013	53.9395	46.6186	67.2842	59.8318	53.1976

Table 3.2 Percentage of grassland in the Lesser Prairie-Chicken (LEPC) range in Kansas and in each of the four major regions from the 1950s to 2013.

Patch Area

The area of individual grassland patches was calculated to assess changes in the distribution of patch sizes from the 1950s to 2013. Range-wide, the distribution of grassland patches has remained relatively constant, as 95.32% of grassland patches were <10 ha during the 1950s, and 95.44%, <10 ha in 2013, representing a slight in the amount of small grassland patches (Figure 3.3). From the 1950s to 2013, the amount of grassland patches that were >10,000 ha and <100,000 ha increased from 25 patches to 29. In both 1950 and 2013, there existed four patches that were >100,000 ha.

Within Range 1, there has been a slight increase in the amount of grassland patches that are <10 ha, as 95.74% of grassland patches were <10 ha during the 1950s and 95.91% <10 ha in 2013 (Figure 3.4). The amount of grassland patches that are >1,000 ha and <10,000 ha decreased from 85 during the 1950s to 68 during 2013, yet the amount of grassland patches >10,000 ha increased from 15 during the 1950s to 18 in 2013.

The amount of small grassland patches in Range 2 increased from the 1950s to 2013, as 93.24% of grassland patches during the 1950s were <10 ha, while 94.42% were <10 ha in 2013 (Figure 3.5). The amount of grassland patches that were >1,000 ha in Range 2 increased from 38 patches in the 1950's to 40 patches in 2013.

Within Range 4, there was a slight decrease in the amount of grassland patches that were <10 ha, as 94.29% of patches were <10 ha during the 1950s and 93.77% were <10 ha in 2013 (Figure 3.6). The amount of grassland patches that were >1,000 ha decreased in Region 4 from 7 during the 1950's to 4 in 2013.

The amount of small grassland patches in Range 5 decreased between the 1950s and 2013, as 94.53% of grassland patches were <10 ha during the 1950s whereas 91.71% were <10 ha in 2013 (Figure 3.7). The amount of large grassland patches remained relatively constant, as there were 13 grassland patches >1,000 ha during the 1950s and 16 grassland patches >1,000 ha in 2013.

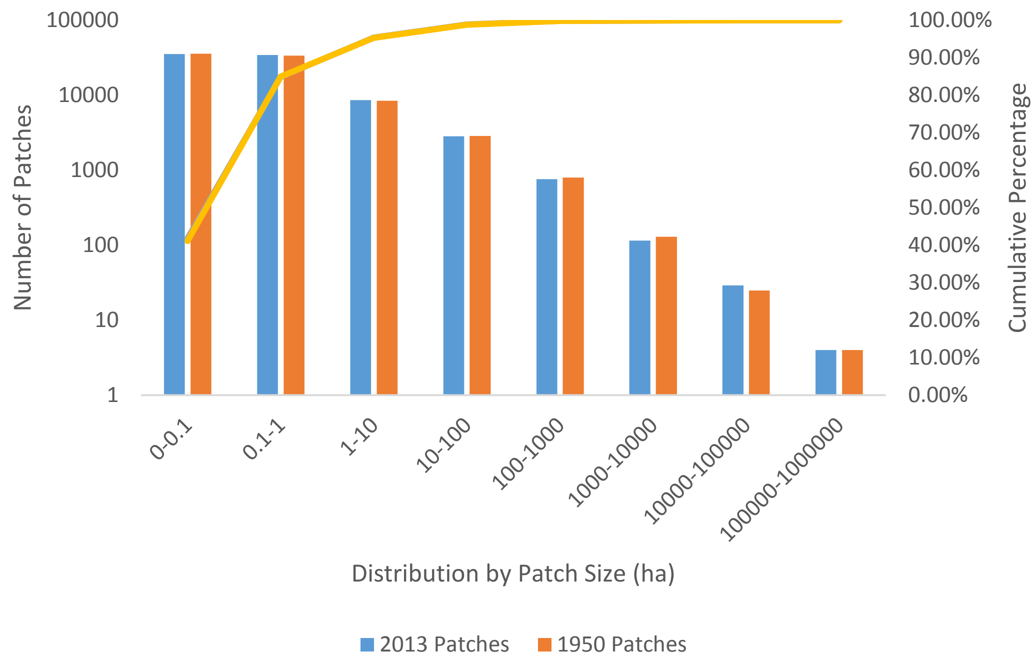

Figure 3.3 Distribution of grassland patch size (ha) across the Lesser Prairie-Chicken range in Kansas during the 1950s and in 2013.

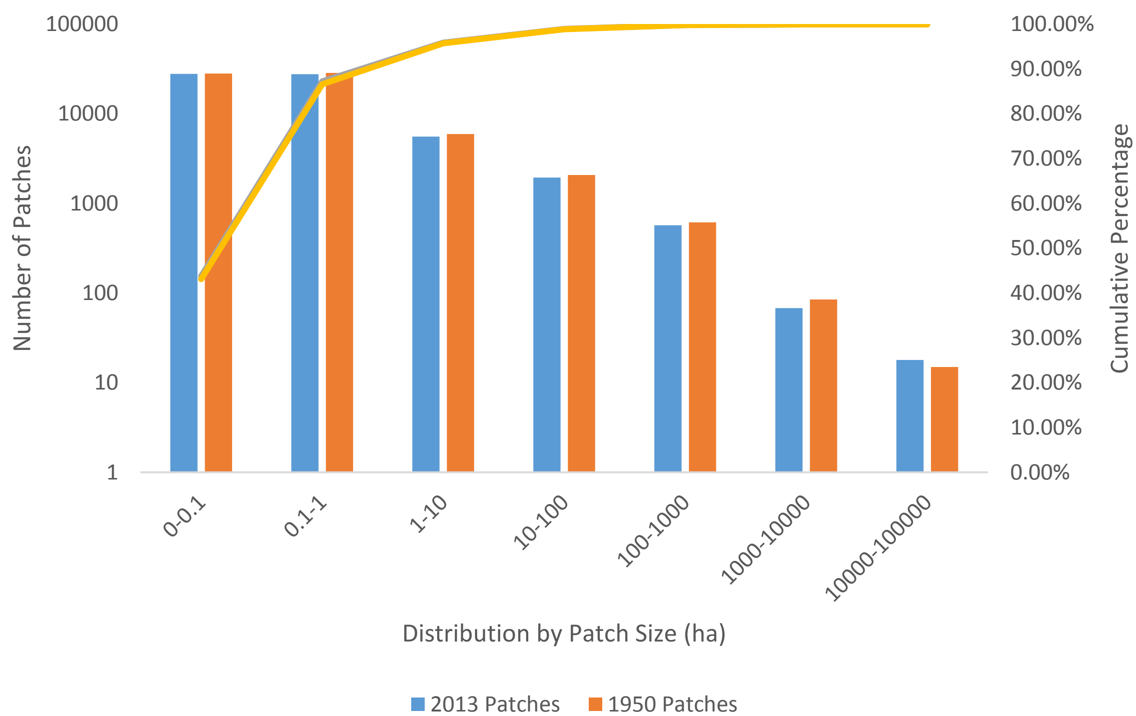

Figure 3.4 Distribution of grassland patch sizes (ha) across Range 1 of the Lesser Prairie-Chicken range in Kansas during the 1950s and in 2013.

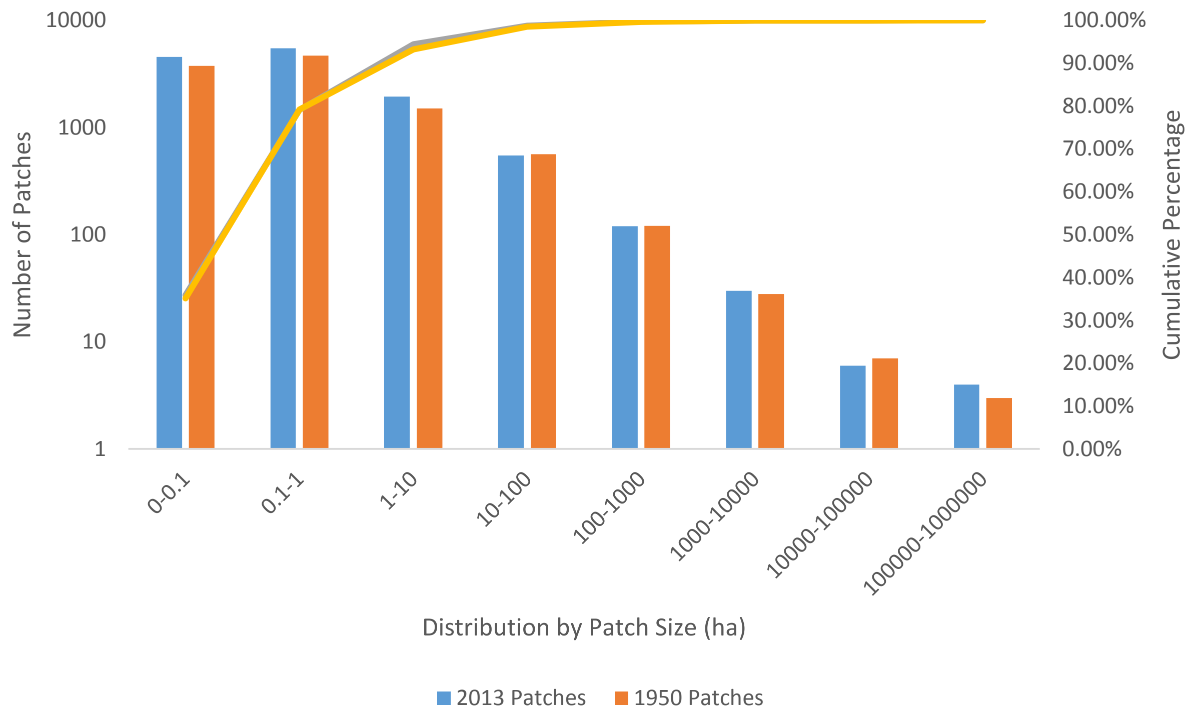

Figure 3.5 Distribution of grassland patch size (ha) across Range 2 of the Lesser Prairie-Chicken range in Kansas during the 1950s and in 2013.

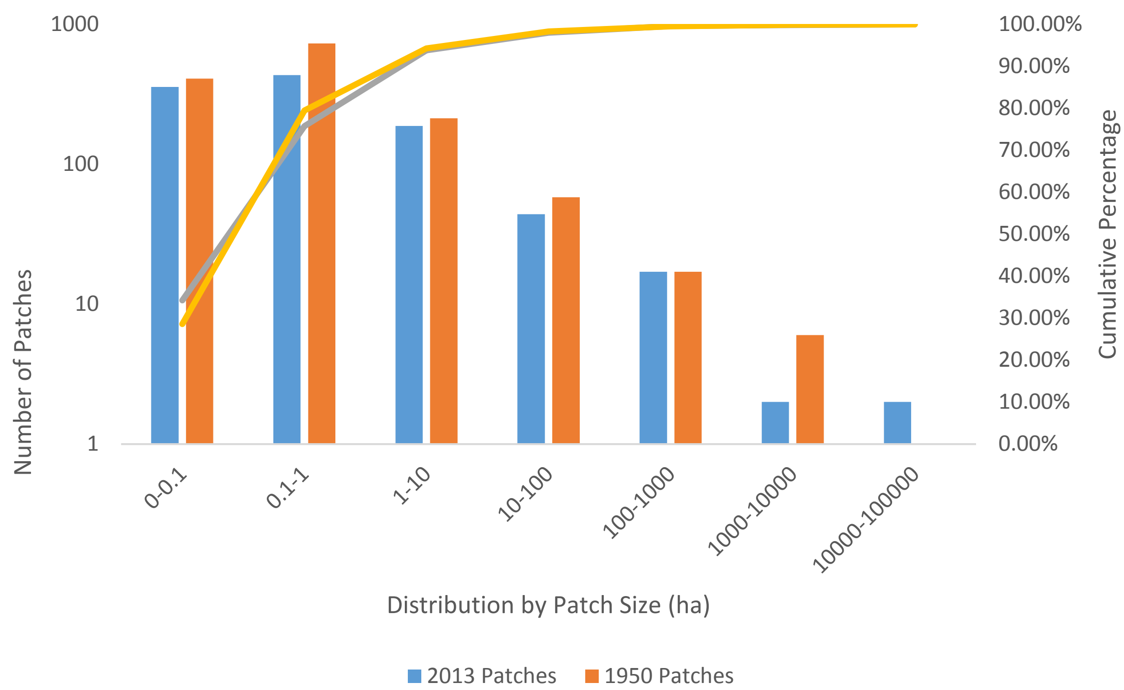

Figure 3.6 Distribution of grassland patch sizes (ha) across Range 4 of the Lesser Prairie-Chicken range in Kansas during the 1950s and in 2013.

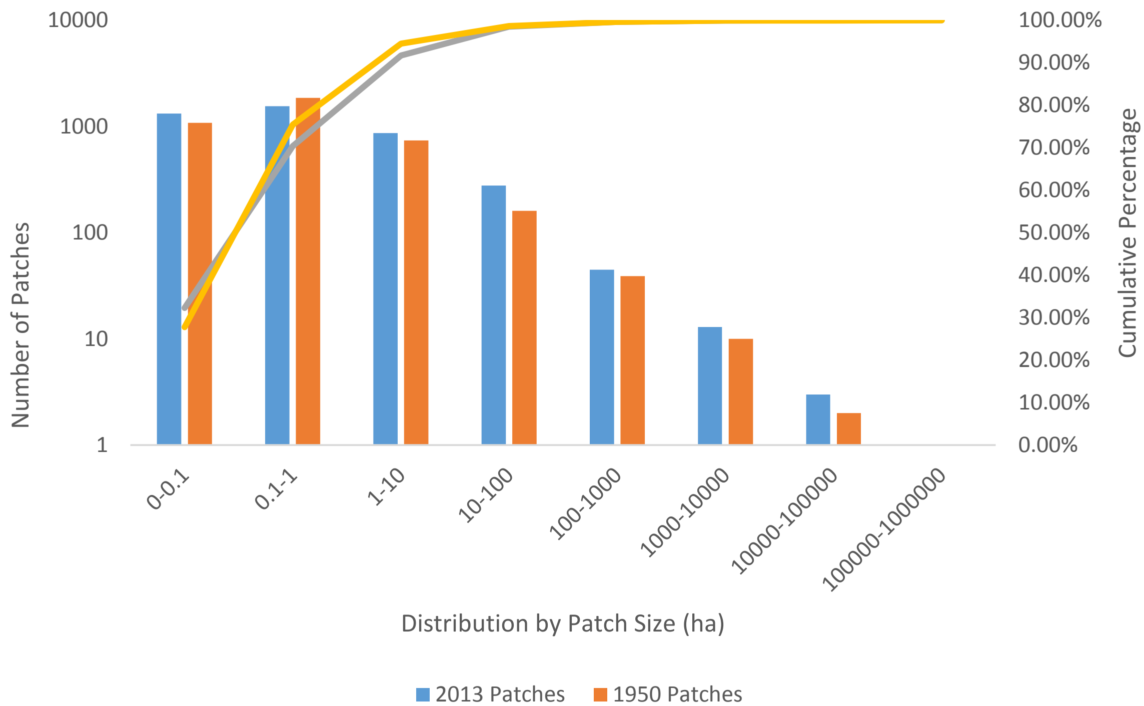

Figure 3.7 Distribution of grassland patch sizes (ha) across Range 5 of the Lesser Prairie-Chicken range in Kansas during the 1950s and in 2013.

Mean Patch Size

The mean patch size of grassland in the Lesser Prairie-Chicken range increased from 22.5 (SE = 3.5) ha in 1950 to 24.2 (SE = 3.8) ha in 2013, an increase of 1.7 ha (Table 3.3). Within this time period, the mean patch size of grassland decreased by 2 ha between the 1950s and 1985 (22.5 [SE = 3.5] ha to 20.5 [SE = 3.1] ha). From 1985 to 2003, grassland mean patch size increased by 5.7 ha (20.5 [SE = 3.1] ha to 26.2 [SE = 4.2] ha), followed by a decrease of 2 ha between 2003 and 2013 (26.2 [SE =4.2] ha to 24.2 [SE = 3.8] ha).

Grassland mean patch size in Range 1 increased from 13.7 (SE = 1.8) ha during the 1950s to 15.1 (SE = 2.3) ha in 2013, an increase of 1.4 ha (Table 3.3). From the 1950s to 1985, grassland mean patch size decreased by 0.4 ha (13.7 (SE = 1.8) ha to 13.3 (SE = 1.8) ha), followed by an increase of 3.2 ha between 1985 and 2003 (13.3 (SE = 1.8) ha to 16.5 (SE = 2.5) ha). From 2003 to 2013, grassland mean patch size decreased by 1.4 ha (16.5 (SE = 2.5) ha to 15.1 (SE = 2.3) ha).

Mean patch size of grassland in Range 2 decreased from 65.4 (SE = 21.2) ha during the 1950s to 59.4 (SE = 20.5) ha in 2013, a decrease of 6.0 ha (Table 3.3). Between the 1950s and 1985, grassland mean patch size decreased by 10.6 ha (65.4 (SE = 21.2) ha to 54.8 (SE = 18.1) ha). From 1985 to 2013, grassland mean patch size increased by 4.6 ha (54.8 (SE = 18.1) ha to 59.4 (SE = 20.5) ha).

The mean patch size of grassland in Range 4 increased by 23.3 ha between the 1950s and 2013 from 30.6(SE = 17.0) ha to 53.9 (SE = 31.4) ha (Table 3.3). From the 1950s to 1985, grassland mean patch size decreased by 4.5 ha (30.6 (SE = 17.0) ha to 26.1 (SE = 14.0) ha), followed by an increase of 30 ha between 1985 and 2003 (26.1 (SE = 14.0) ha to 56.1 (SE = 32.7) ha). Grassland mean patch size decreased by 2.2 ha from 2003 to 2013 (56.1 (SE = 32.7) ha to 53.9 (SE = 31.4) ha).

Grassland mean patch size in Range 5 decreased by 0.1 ha between 1950 and 2013 from 50.2 (SE = 32.5) ha to 50.1 (SE = 21.7) ha (Table 3.3). Between the 1950s and 1985, grassland mean patch size decreased by 21.7 ha (50.2 (SE = 32.5) ha to 28.5 (SE = 12.9) ha), followed by an increase of 27.2 ha between 1985 and 2003 (28.5 (SE = 12.9) ha to 55.7 (SE = 23.6) ha). From 2003 to 2013, the mean patch size of grasslands decreased by 5.6 ha from 55.7 (SE = 23.6) ha in 2003 to 50.1 (SE = 21.7) ha in 2013.

YEAR	LEPC Range	RANGE_1	RANGE_2	RANGE_4	RANGE_5
1950	22.5164 (SE= 3.5)	13.7287 (SE= 1.8)	65.4575 (SE= 21.2)	30.6478 (SE= 17.0)	50.2968 (SE= 32.5)
1960	22.5139 (SE= 3.5)	13.7287 (SE= 1.8)	65.4575 (SE= 21.2)	30.6478 (SE= 17.0)	50.2306 (SE= 32.5)
1978	20.708 (SE= 3.2)	13.3361 (SE= 1.8)	55.0642 (SE= 18.2)	26.4186 (SE= 14.1)	31.141 (SE= 18.7)
1985	20.5268 (SE= 3.1)	13.3077 (SE= 1.8)	54.807 (SE= 18.2)	26.141 (SE= 14.0)	28.5629 (SE= 12.9)
1988	23.2933 (SE= 3.8)	14.9485 (SE= 2.3)	60.4821 (SE= 21.1)	32.9586 (SE= 17.1)	33.2526 (SE= 14.2)
1994	25.2491 (SE= 4.0)	15.6771 (SE= 2.5)	59.5458 (SE= 20.7)	59.7299 (SE= 34.7)	56.0526 (SE= 23.7)
2003	26.2849 (SE= 4.2)	16.5664 (SE= 2.5)	57.6616 (SE= 20.0)	56.1394 (SE= 32.7)	55.774 (SE= 23.6)
2013	24.2531 (SE = 3.8)	15.1099 (SE= 2.3)	59.486 (SE= 20.5)	53.9175 (SE= 31.4)	50.1442 (SE= 21.7)

Table 3.3 Mean patch size (ha) of grassland for the Lesser Prairie-Chicken (LEPC) range and the four major regions comprising the range in Kansas from the 1950s to 2013.

Area-Weighted Mean Patch Size

Area-weighted mean patch size of grassland in the Lesser Prairie-Chicken range increased by 4,226.9 ha from 1950s to 2013 from 44,918.9 ha to 49,145.8 ha (Table 3.4). Within that time period, the area-weighted mean patch size of grassland decreased by 4,979 ha between the 1950s and 1985 (44,918.9 ha to 39,939.9 ha), followed by an increase of 10,446.2 ha between 1985 and 2003 (39,939.9 ha to 50,386.1 ha). From 2003 to 2013, area-weighted mean patch size of grassland decreased by 1,240.3 ha (50,386.1 ha to 49,145.8).

The area-weighted mean patch size of grassland in Range 1 increased from 16,333.2 ha during the 1950s to 21,700.3 in 2013, an increase of 5,367.1 ha (Table 3.4). Between the 1950s and 1985, area-weighted mean patch size of grassland decreased by 498.8 ha (16,333.2 ha to 15,834.4 ha), followed by an increase of 5,865.9 ha between 1985 and 2013 (15,834.4 ha to 21,700.3 ha).

Grassland area-weighted mean patch size in Range 2 increased from 73,639.2 ha during the 1950s to 89,869.5 in 2013, an increase of 16,230.3 ha (Table 3.4). From the 1950s to 1994, the area-weighted mean patch size increased by 19,272.3 ha (73,639.2 ha to 92,911.5 ha). From 2003 to 2013, area-weighted mean patch size decreased by 2,708 ha (92,577.5 ha to 89,869.5 ha).

Area-weighted mean patch size of grassland in Range 4 increased from 13,559.8 ha during the 1950s to 19,108.7 ha in 2013, an increase of 5,548.9 ha (Table 3.4). From the 1950s to 1985, area-weighted mean patch size of grassland decreased by 1,030.6 ha (13,559.8 ha to 12,529.2 ha), followed by an increase of 6,876.7 ha between 1985 and 2003 (12,529.2 ha to 19,405.9 ha).

The area-weighted mean patch size of grassland in Range 5 decreased from 82,030.6 ha during the 1950s to 38,487.5 ha in 2013, a decrease of 43,453.1 ha (Table 3.4). Between 1988 and 2013, area-weighted mean patch size of grassland in Range 5 increased by 7,397.2 ha (31,090.3 ha to 38,487.5 ha).

YEAR	LEPC Range	RANGE_1	RANGE_2	RANGE_4	RANGE_5
1950	44,918.9071	16,333.2589	73,639.244	13,559.7673	82,030.5815
1960	44,901.1013	16,333.2589	73,639.244	13,559.7673	81,892.5427
1978	42,384.7534	15,887.8322	74,887.958	12,511.3828	59,235.2948
1985	39,939.91	15,834.4084	74,987.8791	12,529.1797	32,308.8323
1988	50,817.6731	23,047.3044	92,794.4656	12,842.8245	31,090.3217
1994	51,916.5219	24,861.2124	92,911.483	19,674.4461	38,773.7469
2003	50,386.1664	21,482.184	92,577.5096	19,405.9231	38,687.8713
2013	49,145.8071	21,700.308	89,869.5496	19,108.6521	38,487.4843

Table 3.4 Area-weighted mean patch size (ha) of grassland in the Lesser Prairie-Chicken (LEPC) range and the four major regions of the range in Kansas from the 1950s to 2013.

Largest Patch Index

The Largest Patch Index (LPI), which measures the percentage of landscape dominated by the single largest patch of a cover type, was 3.4% for grassland during the 1950s and 4.1% in 2013, an increase of 20.6% (Figure 3.5). For the entire Lesser Prairie-Chicken range, LPI was greatest in 1994 at 4.2%. Within Range 1, LPI was 2.4% in 1950 and 3.2% in 2013, an increase of 33.3%. LPI reached its maximum for Range 1 in 1994 at 3.3%. Range 2 LPI was 11.3% during the 1950s and 13.3% in 2013, a 17.7% increase, while reaching its maximum value in 2003 at 14.0%. Range 4 LPI was 24.8% during the 1950s and 30.9% in 2013, an increase of 24.6%. In Range 4, LPI reached its maximum value in 1994 at 31.5%. The LPI for Range 5 was 32.4% during the 1950s and 18.4% in 2013, a decrease of 43.2%. The 32.4% observed during the 1950s was the maximum LPI value for Range 5.

YEAR	LEPC Range	RANGE_1	RANGE_2	RANGE_4	RANGE_5
1950	3.4204	2.4403	11.2597	24.8478	32.4192
1960	3.4204	2.4403	11.2597	24.8478	32.3777
1978	3.3816	2.366	11.1318	23.8833	25.2102
1985	3.3779	2.3623	11.1196	23.8833	17.024
1988	4.187	3.1355	13.7762	24.6749	17.2631
1994	4.2205	3.2012	13.8863	31.5061	18.5354
2003	4.2497	3.1894	13.9825	31.2509	18.488
2013	4.051	3.1771	13.3283	30.9229	18.3883

Table 3.5 The Largest Patch Index (%) of grassland in the Lesser Prairie-Chicken (LEPC) range and the four major regions comprising the range in Kansas from the 1950s to 2013.

Mesh Size

The effective mesh size of grassland patches in the Lesser Prairie-Chicken range increased from 22,472.6 ha during the 1950s to 26,508.9 in 2013, an increase of 4,036.3 ha (Table 3.6). From the 1950s to 1985, effective mesh size of grassland patches decreased by 3,213.4 ha (22,472.6 ha to 19,259.2 ha), followed by an increase of 9,409.9 ha between 1985 and 1994 (19,259.2 ha to 28,669.1 ha). Between 1994 and 2013, effective mesh size of grassland patches decreased by 2,160.2 ha (28,669.1 ha to 16,508.9 ha)

In Range 1, the effective mesh size of grassland patches increased from 7,096.2 ha during the 1950s to 10,116.4 ha in 2013, an increase of 3,020.2 ha (Table 3.6). Between the 1950s and 1985, effective mesh size decreased by 323 ha (7,096.2 ha to 6,773.2 ha), followed by an increase of 5,006.1 ha between 1985 and 1994 (6,773.2 ha to 11,779.3 ha). From 1994 to 2013, effective mesh size of grassland patches decreased by 1,662.9 ha (11,779.3 ha to 10,116.4 ha).

The effective mesh size of grassland patches in Range 2 increased from 45,922.7 ha during the 1950s to 60,467.9 ha in 2013, an increase of 14,545.2 ha (Table 3.6). From the 1950s to 1985, effective mesh size of grassland patches in Range 2 decreased by 136.9 ha (45,922.7 ha to 45,785.8 ha), followed by an increase of 18,213.6 ha between 1985 and 1994 (45,785.8 ha to 63,999.4 ha). The effective mesh size of grassland patches in Range 2 between 1994 and 2013 decreased by 3,531.5 ha (63,999.4 ha to 60,467.9 ha)

In Range 4, the effective mesh size of grassland patches increased from 6,344.8 ha during the 1950s to 11,433 ha in 2013, an increase of 5,088.2 ha (Table 3.6). Between the 1950s and 1985, the effective mesh size decreased by 535.9 ha (6,344.8 ha to 5,808.9 ha), followed by an increase of 6,331.4 ha between 1985 and 1994 (5,808.9 ha to 12,140.3). Effective mesh size of grassland patches in Range 4 decreased by 707.3 ha between 1994 and 2013 (12,140.3 ha to 11,433 ha).

The effective mesh size of grassland patches in Range 5 decreased from 41,673.1 ha during the 1950s to 20,474.4 ha in 2013, a decrease of 21,198.7 ha (Table 3.6). Between 1950 and 1985, effective mesh size decreased by 28,470.9 ha (41,673.1 ha to 13,202.2 ha), followed by an increase of 8,452.3 ha between 1985 and 1994 (13,202.2 ha to 21,654.5 ha). In Range 5, the effective mesh size decreased by 1,257.6 ha between 1994 and 2013 (21,732 ha to 20,474.4 ha).

YEAR	LEPC_RANGE	RANGE_1	RANGE_2	RANGE_4	RANGE_5
1950	22,472.6247	7,096.1666	45,922.6984	6,344.8443	41,673.0592
1960	22,461.8006	7,096.1666	45,922.6984	6,344.8443	41,569.4879
1978	20,511.7794	6,796.7785	45,711.2092	5,816.5857	25,269.7437
1985	19,259.2647	6,773.2272	45,785.7935	5,808.9631	13,202.1631
1988	26,668.9817	10,582.4183	62,870.4577	6,489.498	13,738.6934
1994	28,669.084	11,779.2772	63,999.443	12,140.3447	21,732.0184
2003	27,537.5938	9,993.8147	63,642.7421	11,764.8391	21,654.4815
2013	26,508.982	10,116.3774	60,467.9884	11,433.0427	20,474.4089

Table 3.6 The effective mesh size (ha) of grassland in the Lesser Prairie-Chicken (LEPC) range and the four major regions comprising the range in Kansas from the 1950s to 2013.

Total Edge

The total edge of grassland patches within the Lesser Prairie-Chicken range increased from 111,949,140 m in 1950 to 119,592,150 m in 2013, an increase of 7,643,010 m (Table 3.7). Total edge reached its maximum value within the Lesser Prairie-Chicken range in 1994 at 120,149,040 m. The total edge of grassland patches in Range 1 increased from 74,442,720 m during the 1950s to 75,199,470 m in 2013, an increase of 75,750 m. Within Range 2, the total edge of grassland patches increased from 27,854,070 m during the 1950s to 31,475,430 m in 2013, an increase of 3,621,360 m. Total edge reached its maximum value within Range 2 in 2003 at 32,740,380 m. The total edge of grassland patches within Range 4 increased from 1,760,130 m during the 1950s to 2,126,160 m in 2013, an increase of 366,030 m. Within Range 5, the total edge of grassland patches increased from 7,557,690 m during the 1950s to 10,462,140 m in 2013. Total edge reached its maximum value in Range 5 in 2003 at 10,736,880 m.

Edge Density

Edge density of the Lesser Prairie-Chicken range increased from 30.3 m/ha in 1950 to 32.4 m/ha in 2013, an increase of 2.1 m/ha, reaching its maximum value in 1994 at 32.6 m/ha (Table 3.8). Within Range 1, edge density increased from 35.8 m/ha in 1950 to 36.2 m/ha in 2013, an increase of 0.4 m/ha. Edge density of grassland patches in Range 2 increased from 24.8 m/ha during the 1950s to 28.1 m/ha in 2013, an increase of 3.1 m/ha, reaching its maximum value in 2003 at 29.2 m/ha. In Range 4, edge density of grassland patches increased from 18.7 m/ha during the 1950s to 22.6 m/ha in 2013, an increase of 3.9 m/ha. Edge density of Range 5 increased from 19.6 m/ha during the 1950s to 27.1 m/ha in 2013, an increase of 7.5 m/ha, reaching its peak value in 2003 at 27.9 m/ha.

YEAR	LEPC_RANGE	RANGE_1	RANGE_2	RANGE_4	RANGE_5
1950	111,949,140	74,442,720	27,854,070	1,760,130	7,557,690
1960	111,953,880	74,442,720	27,854,070	1,760,130	7,562,430
1978	115,615,170	74,857,620	29,394,420	1,945,830	9,089,670
1985	116,095,260	74,961,660	29,466,420	1,963,110	9,354,750
1988	119,166,600	75,020,970	31,910,490	2,043,420	9,845,940
1994	120,149,040	74,669,160	32,393,190	2,063,460	10,700,190
2003	117,929,520	72,009,780	32,740,380	2,119,260	10,736,880
2013	119,592,150	75,199,470	31,475,430	2,126,160	10,462,140

Table 3.7 The total combined edge (m) of grassland patches in the Lesser Prairie-Chicken (LEPC) range and in each of the four major regions comprising the range in Kansas from the 1950s to 2013..

YEAR	LEPC_RANGE	RANGE_1	RANGE_2	RANGE_4	RANGE_5
1950	30.3475	35.8525	24.8564	18.7267	19.6085
1960	30.3488	35.8525	24.8564	18.7267	19.6208
1978	31.3413	36.0523	26.231	20.7025	23.5832
1985	31.4714	36.1024	26.2953	20.8863	24.2709
1988	32.304	36.131	28.4763	21.7408	25.5453
1994	32.5704	35.9615	28.907	21.954	27.7617
2003	31.9687	34.6808	29.2169	22.5477	27.8569
2013	32.4194	36.217	28.0881	22.6211	27.1441

Table 3.8 The edge density (m/ha) of grassland patches in the Lesser Prairie-Chicken (LEPC) range and the four major regions comprising the range in Kansas from the 1950s to 2013.

Chapter 4 - Discussion

Since the 1950s, the amount of grassland has increased within the Lesser Prairie-Chicken range in response to the implementation of the CRP in 1986. Across the species range, grassland decreased slightly between 1950 and 1985, but only by 3.6% over the 35-year period. This indicates that the majority of cropland throughout the range was converted from grassland prior to the 1950s. Across the range, the major change in the amount of grassland occurred between 1985 and 1988, the time period in which CRP was implemented, with an increase of 8.8% in these three years. The results indicate that the effects of CRP were fully realized in 1994, as the amount of grassland between 1988 and 1994 rose an additional 5.2%. Since 1994, the amount of grassland has slightly reduced as a result of the continuing expansion of agriculture, as well as a decline in CRP enrollment, particularly between 2003 and 2013 when the amount of grassland decreased by 1.3%. While changes in the amount of grassland were not dramatic, CRP was able to add more grassland than was lost to agriculture, resulting in a net grassland increase of 7.8% since the 1950s in Kansas.

Several statistics measuring grassland patch size suggest that the greatest benefit of CRP was increasing connectivity among grasslands. The progressive reduction of habitat patches is a key component of fragmentation (McGarigal et al. 2012). Thus, an increase or decrease in mean patch size, area-weighted mean patch size, and effective mesh size can indicate a cover type that is either fragmenting or becoming more connected. The mean patch size, area-weighted mean patch size, and effective mesh size increased by 7.7%, 9.4%, and 18% respectively between the 1950s and 2013. While each statistic can be interpreted to represent a more connected landscape, the implications of each are slightly different. Mean patch size is a *patch-centric* view of the landscape, in that each individual patch contributes equally to the calculation of the mean, regardless of patch area. Because such a large proportion of the grassland patches are small (84% of grassland patches ≤1 ha; 95% ≤10 ha), mean patch size does not reflect the most likely grassland patch size Lesser Prairie-Chicken are found in, despite being an adequate measure of fragmentation. These measures of mean patch size are substantially lower than estimates of minimum habitat patch size needed for a self-sustaining Lesser Prairie-Chicken population, which range from 4,900 ha to 20,236 ha (Haukos and Zavaleta 2015). In 2013, there were 33 grassland patches that were greater than >10,000 ha throughout the Lesser Prairie-Chicken range in Kansas, and four of these were >100,000 ha. Area-weighted mean patch size remedies this issue by giving patches that are larger more influence (i.e. weight) on the calculated mean. Area-weighted mean patch size provides a *landscape-centric* perspective of the landscape in that it represents that average condition an animal dropped at random on the landscape would encounter (McGarigal et al. 2012)**.** Given the large quantity of small grassland patches throughout the Lesser Prairie-Chicken range, area-weighted mean patch size is more effective in estimating the size of patches Lesser Prairie-Chickens likely occupy and should be the focus of determining whether large enough patches of grassland exist for populations. The area-weighted mean patch size calculated for the Lesser Praire-Chicken range in Kansas in 2013 (49,145.8 ha) greatly exceeds the 4,900 ha to 20,236 ha range of habitat patch sizes estimated to support a Lesser Prairie-Chicken population. Effective mesh size, a statistic developed to measure subdivision, denotes the size of the patches when the landscape is divided into N areas of the same size and of the same division as obtained from the cumulative patch distribution (Jaeger 2000). The advantage to using effective mesh size is that it is insensitive to the omission or addition of very small patches, which comprise much of the range of the Lesser Prairie-Chicken. Jaeger (2000) described the effective mesh size as 'area-proportionately additive"; it characterizes the subdivision of a landscape independent of the landscape size. While maintaining different interpretations of patch size, the increase in mean patch size, area-weighted mean patch size, and effective mesh size from the 1950s to 2013 indicate that grassland within the Lesser Prairie-Chicken range has become less fragmented in response to implementation of CRP. Considering that loss and fragmentation of habitat (i.e. grassland) are primary threats to the long-term persistence of Lesser Prairie-Chicken populations, these results indicate that CRP is an effective tool to conserving and improving the quality of Lesser Prairie-Chicken habitat.

While statistics measuring patch size indicate grasslands have become more connected since the implementation of CRP, measures of total edge and edge density of grassland patches slightly contradict this trend. Since the 1950s, both total edge and edge density have increased by 6.8%. In the past, wildlife management intended to maximize edge habitat with the belief that the juxtaposition of different habitats would increase species diversity (Leopold 1933). More recently, studies have suggested that edge effects such as changes in microclimate, vegetation, and predation along edges can have negative effects on groups of native species (McGarigal et al. 2012). This has resulted in total class edge being considered a key piece of information in habitat fragmentation. However, many of the studies measuring habitat edge and its effects on wildlife have focused on grassland-forest edges (Renfrew et al. 2005) rather than the grassland-cropland edges observed in the Lesser Prairie-Chicken range. It is more likely that the increase in grassland edge reflect a landscape transitioning from large expanses of grassland to a more complex, yet connected, network of grassland, thereby increasing the amount of edge. In the majority of cases, entire cropland fields were converted to CRP, maintaining the geometric character of the formerly farmed landscape (Egbert et al. 1998). These geometric shapes, while increasing the amount of grassland and potentially connecting grassland patches, also create more complex boundaries between patches, resulting in an increase in the amount of grassland edge. Furthermore, pivot irrigation plots often have small corner patches of grassland, which also contributed to the increase in the amount of grassland edge. An increase in the amount of grassland edge in conjunction with an increase in the total amount of grassland creates a complicated scenario for Lesser Prairie-Chickens. While an increase in grassland provides additional habitat for Lesser Prairie-Chickens, an increase in edge may result in more fences being erected to separate different land uses, such as CRP and croplands, or different land ownership. Fences pose a threat to Lesser Prairie-Chickens, as collisions with fences during flight have shown to be a considerable cause of mortality. In the southern mixed-grass prairie of Oklahoma, collisions, primarily with fences but also with powerlines and vehicles, accounted for >40% of documented Lesser Prairie-Chicken deaths (Patten et al 2005, Wolfe et al. 2007). It is recommended that unnecessary fences, such as those surrounding CRP fields, be removed, or alternative fencing practices, such as the electric fences that are lower in height (50-60 cm) be used to reduce the occurrence of collision (Wolfe et al. 2015).

Largest Patch Index, a measurement of dominance of the largest grassland patch within a landscape, has been found to be important for Lesser Prairie-Chickens (Bartuszevige and Daniels 2015). They employed a geographic information system to evaluate whether Lesser Prairie-Chicken lek locations were negatively associated with anthropogenic structures. Their results indicated that lek presence was related to the percent of landscape that was unimpacted by anthropogenic features and, of the variables they measured, only Largest Patch Index was related to the presence of leks. Since the 1950s, the Largest Patch Index for the Lesser Prairie-Chicken range has increased by 18.4%, indicating that CRP has contributed to increasing the size of larger, contiguous patches.

Although the Kansas range of the Lesser Prairie-Chicken has experienced increases in the total amount of grassland, grassland patch sizes, and the total edge of grassland, separate regions of the range have been evolving in various manners since the 1950s. Many of these differences can be attributed to the agricultural practices in each region, which are a function of soil type, native vegetation, and climate within each region. These differences are best illustrated by analyzing the percent change between decades for each region.

Range 1

The amount of grassland in Range 1 has remained relatively stable compared to the other four regions, as the amount of grassland has increased by only 7.3% since the 1950s. The largest change between measured years in the amount of grassland occurred between 1985 and 1988 (7.3% increase), and over the first 30+ years the 1950s and 1985, grassland only decreased by 1.5%. The digital maps, as well as these metrics, indicate that Range 1 did not experience much agricultural expansion in response to advances irrigation technology during the 1960s despite agriculture having a considerable presence in the region. These findings suggest that much of the grassland conversion to cropland occurred prior to the 1950s, and given the small amount of conversion between the 1950s and 1985 (1.6% decrease in grassland), that much of the suitable land for farming had already been converted. Within Range 1, the percentage of landscape attributed to grassland has not exceeded 48% since 1950, and only grew by 3.3 percentage points, from 43.3% to 46.6%, between the 1950s and 2013.

The major effect the implementation of CRP had on Range 1 was increasing the size of grassland patches. Of the 4 major regions, Range 1 was historically the most fragmented based on measures of patch size; the associated mean patch size, area-weighted mean patch size, and effective mesh size were lower than the range-wide average for every decade. The positive gains in mean patch size (10.1% increase since 1950), area-weighted mean patch size (32.9%) and effective mesh size (42.6%) all indicate that grasslands have become increasingly connected throughout Range 1 as the result of CRP. This increase in connectivity was also reflected in the decrease in the number of patches (from 65,709 during the 1950s to 64,062 in 2013) and a 33.3% increase in the Largest Patch Index, from 2.4% in the 1950s to 3.2% in 2013. In addition to increasing the size of grassland patches, the CRP created habitat structure within Range 1 that was more suitable to the Lesser Prairie-Chicken. Range 1 falls within the Short-grass

Prairie/CRP Mosaic Ecoregion, and as the name suggests, short-grass prairie has a considerable presence in this region. Because the Lesser Prairie-Chicken relies upon vegetation for concealment and thermoregulation, the short stature of short-grass prairie plants were not viable habitat. In Kansas, CRP land was required to be comprised of a mixture of native plants resembling mixed-grass and tall-grass prairies. Most biologists believe the change in vegetative community structure, along with favorable environmental conditions compared to other regions the Lesser Prairie-Chicken inhabit, made the Short-grass Prairie/CRP Mosaic Ecoregion an ideal habitat for Lesser Prairie-Chickens (Dahlgren et al. 2015). While not conveyed in these digital land cover maps, it should be noted that not only the change to grassland, but the change in grassland structure, has benefited the Lesser Prairie-Chicken.

Range 2

Range 2 of the Lesser Prairie-Chicken range was the most grassland-dominated region in Kansas. Since the 1950s, grassland never accounted for <61% of the landscape in this region, with the total area of grassland increasing by 7.9% since the 1950s. Historically, the lack of a consistent water source, along with sandy soils limited farming activity in this area. While center pivot irrigation technology increased agricultural development in this region, (particularly Grant, Edwards, and Kiowa County), it has mostly occurred in isolated areas rather than range-wide, allowing for large, continuous patches of grassland to persist. This fact was evident when the mean-patch size, area-weighted mean patch size, and effective mesh size for Range 2 were analyzed and compared to the other regions and the range as a whole. For each year and period measured in this study, Range 2 had the largest mean patch size; twice as large as the mean patch size for the entire range. Despite maintaining the largest mean patch size, Range 2 experienced a 9.1% reduction in mean patch size since 1950, as the number of grassland patches increased (from 10,676 during the 1950s to 12,675 in 2013). Utilizing metrics that were not as sensitive to the number of small patches further illustrates that Range 2 was comprised of larger patches of grassland compared to the remainder of the Lesser Prairie-Chicken range. From the 1950s to 2013, Range 2 consistently had a larger area-weighted mean patch size and effective mesh size than the other regions of the Lesser Prairie-Chicken range. In 2013, Range 2 had the single largest patch of grassland of any region at 149,356.7 ha. These results indicate that of the four ranges, Range 2 best meets the area requirements of the Lesser Prairie-Chicken, and that CRP has contributed to expanding grassland area. However, other activities threaten to undermine the expanses of grassland that exist in this region. Range 2 falls primarily within the Mixed-grass Prairie Ecoregion, with a portion of the western region occupying the Sand Sagebrush Prairie Ecoregion. Within this region, there is a concern that despite large grassland patches, metapopulations of Lesser Prairie-Chickens are becoming increasingly isolated, increasing the risk of inbreeding depression and a loss of genetic diversity (Wolfe et al. 2015). The emergence of oil and gas development as well as wind energy in this region contribute as barriers to Lesser Prairie-Chicken mobility, hindering the ability of individuals to travel among. Understanding how these activities affect the distribution of Lesser Prairie-Chickens within the available habitat in Range 2 will aid in more effective conservation.

Range 4

Range 4 was the only region within the Lesser Prairie-Chicken range in which the dominant cover type changed from cropland to grassland between 1950 and 2013. Between 1950 and 1985, the percentage of the landscape in Range 4 attributed to grassland never exceeded 47% and was rather constant, as the amount of grassland decreased by only 0.9%. However, following the implementation of the CRP, the amount of grassland in Range 4 dramatically increased and grassland became the proportionately dominate cover type, increasing from 46.4% of the landscape in 1985 to 61.7% of the landscape in 1994. Not surprisingly, the addition of grassland through the CRP had considerable effects on grassland patch sizes. Of the four regions individually examined, Range 4 had the largest increase in mean patch size between 1950 and 2013, growing by 75.9% during this time period (from 30.6 ha to 53.9 ha). Similar rises in area-weighted mean patch size (41.0%) and effective mesh size (80.2%) further illustrate that grassland became more connected within Range 4 as the result of CRP. While CRP has been able to reclaim areas that were formerly croplands and increase grassland patch sizes, there is limited knowledge of sand sagebrush ecology, making restoration of this area difficult. Range 4 lies within the Sand Sagebrush Prairie Ecoregion, where the Lesser Prairie-Chicken Range-wide Conservation Plan restoration goal is >176,000 ha, greater than all other ecoregions (Van Pelt et al. 2013). Further research in restoration strategies would assist in ensuring these efforts are able to increase sand sagebrush prairie for Lesser Prairie-Chickens.

Range 5

At a glance it appears that little has changed within Range 5 of the Lesser Prairie-Chicken range. Since the 1950s, the amount of grassland has only risen by 4.7%. However unlike Ranges 1, 2, and 4, which have seen a steady increase in the amount of grassland between 1950 and 2013, Range 5 experienced a significant decrease in the amount of grassland between 1950 and 1985. As previously mentioned, advances in irrigation technology allowed for areas previously unsuitable for crop production to successfully produce a variety of crops. With the Arkansas River and Ogallala Aquifer as water resources, much of the eastern portion of Range 5 was converted to center-pivot irrigation during this time period. From 1950 to 1985, the amount of grassland in Range 5 decreased by 19.6%, with much of this loss in grassland occurring between the 1960s and 1978 (16.0% decrease) (Figure 4.1 and 4.2).

Despite the total amount of grassland in Range 5 having been restored to levels exceeding those in the 1950s due to the CRP, the new configuration of grassland is of a more fragmented nature. While the mean patch size for Range 5 in 2013 was nearly identical to its value in 1950 (50.1 ha to 50.3 ha), these were influenced by an increase in the amount of grassland as well as an increase in the number of grassland patches during this time. Area-weighted mean patch size, which more accurately represents conditions a Lesser Prairie-Chicken would experience, decreased by 53% since the 1950s. During the 1950s, prior to center-pivot irrigation appearing in the eastern half of Range 5, the largest area-weighted mean patch size as well as the highest largest patch index value at 82,030.6 ha and 32.4%, respectively, were found in Range 5. These metrics experienced marked reductions between 1960 and 1985 when the majority of pivot irrigation was implemented. While the CRP has provided additional grassland area over the last 30 years, the majority of this occurred in the western portion of Range 5, which already existed as cropland during the 1950s, rather than reclaiming the area lost to center-pivot irrigation. The addition of center-pivot irrigation, as well as the addition of CRP in the western half of Range 5, greatly increased the amount of edge within Range 5 by creating smaller patches of grassland.

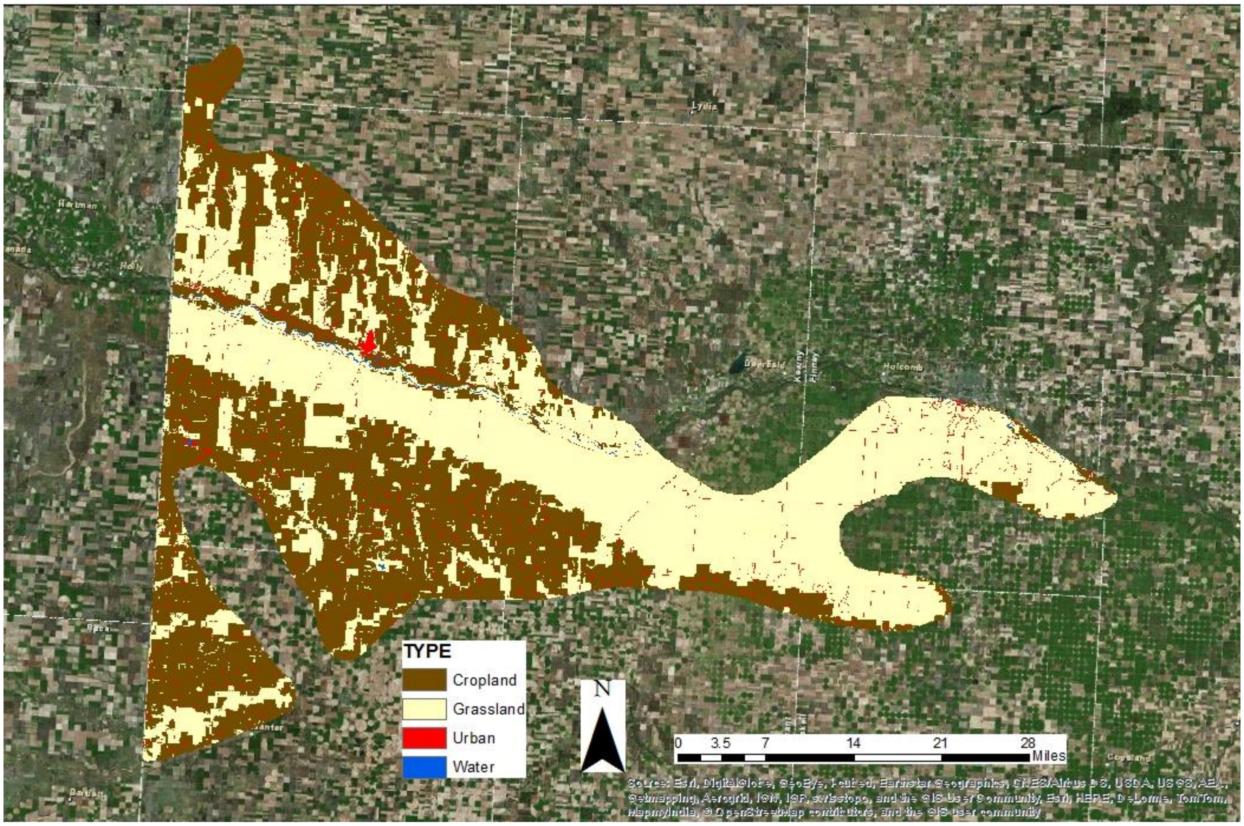

Figure 4.1 Land cover map of Range 5 in the Lesser Prairie-Chicken range during the 1960s. Much of the eastern portion of this range was continuous grassland during this time period.

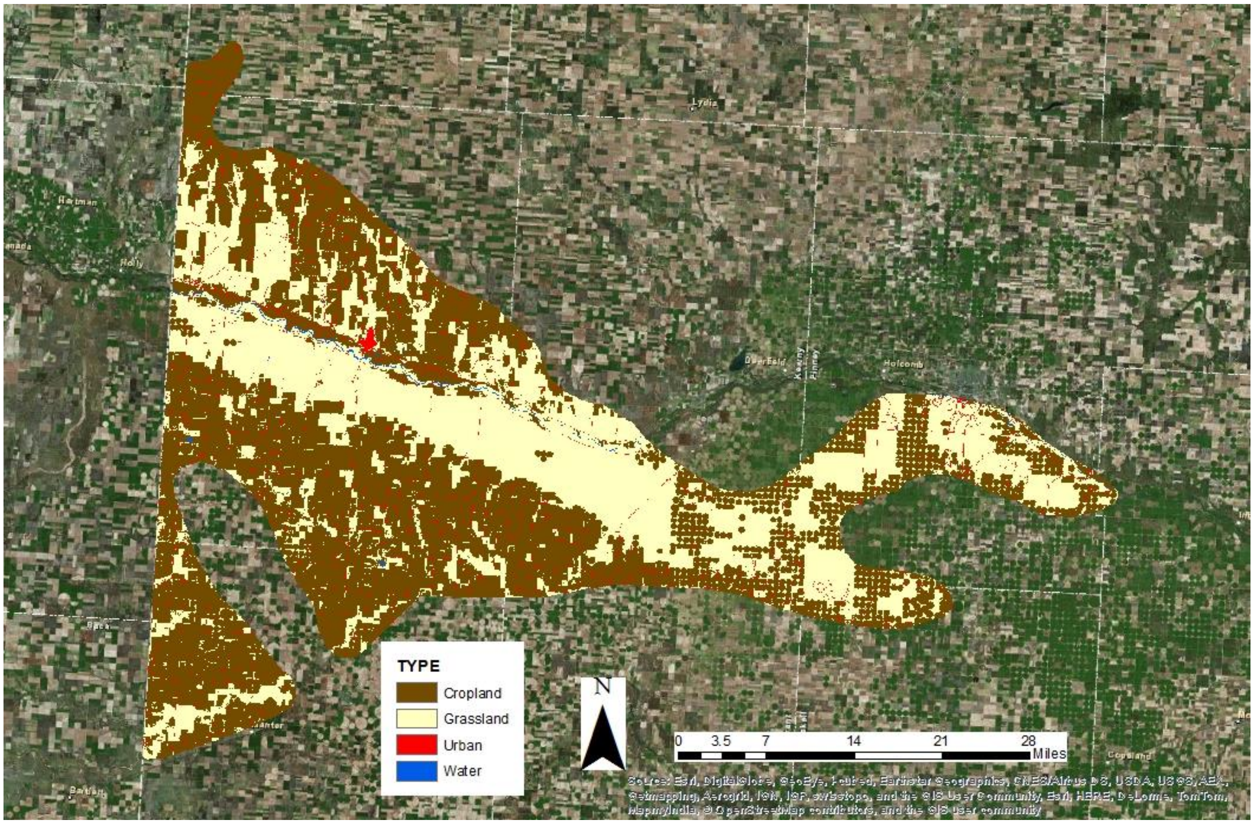

Figure 4.2 Land cover map of Range 5 in the Lesser Prairie-Chicken range in 1985. Center-Pivot irrigation established between 1960 and 1985, fragmenting an area of historically continuous grassland

Quantifying the Impact of CRP

The passage of the 1985 Food Security Act and subsequent implementation of the CRP has had a great effect on the composition and configuration of land cover within the Lesser Prairie-Chicken range of Kansas over the last 60 years. The results of this research indicate that the increased amount of grassland within the Lesser Prairie-Chicken range can be directly attributed to the CRP, as grassland was declining from 1950 to 1985 before this trend was reversed following implementation of the CRP. However, these digital maps only estimated the amount of grassland added as a result of CRP. The earliest available map that illustrates fields enrolled in CRP, provided by the Playa Lakes Joints Venture (PLJV) via the U.S. Department of Agriculture Farm Services Agency (FSA), was from 2007. Additional CRP maps from 2009, 2011, 2012, and 2014 were also acquired from the PLJV and FSA. After-the land cover maps from 1988, 1994, 2003, and 2013 were classified, two copies of each map were produced. With one of the copies, CRP was added to the map as its own land cover class so the amount of CRP could be calculated. With the other copy, CRP was added as part of the grassland class to determine the maximum amount of grassland available, through both natural patches and CRP. The 2007 CRP layer was added in to the 1988, 1994, and 2003 layer because it was the earliest available map, and after conversing with officials aware of re-enrollment rates, it was determined it offered a reasonable expectation of the amount of CRP during those years. The 2012 CRP layer was added to the 2013 map.

There were 394,515 ha of CRP land within the Lesser Prairie-Chicken range during 2007. Between 2007 and 2014, the amount of CRP land in the Lesser Prairie-Chicken range declined to 288,314.7 ha, a decrease of 106,200 ha (26.9%). When comparing the unaltered land cover maps with the maps in which CRP was added as grassland, the percentage of grassland was less in the unaltered land cover maps, suggesting that some CRP fields may have gone undetected in spectral classification. However, a few things must be considered. First, does the CRP layer used for 1988, 1994, and 2003 represents CRP as of 2007?. Despite the high re-enrollment of CRP fields between 1985 and 2007, it is likely that additional fields were enrolled in CRP between 2003 and 2007; thus, the 2007 layer may overestimate the amount of CRP present during 1988, 1994, and 2003. Another important factor to consider is the time it takes for CRP to establish as grassland and appear spectrally similar to areas of native cover. When comparing the original land cover maps to the maps where CRP was added as grassland, the difference in the percentage of the landscape attributed to grassland was 2.9% in 1994, 2.3% in 2003, and 2.2% in 2013, yet for 1988 the percentage was considerably larger at 5.5%. This could be the result of CRP grasses having not yet established, given it had been only two years since implementation of the CRP. Conversely, it could be because using the 2007 CRP layer was an overestimation of the amount of CRP grasses present in 1988. This appears reasonable, as the amount of grassland in the original maps became closer to the amount of grassland in the maps with CRP added as the dates approach the source year of CRP.

Spatial Resolution

Using Landsat satellite imagery offers several advantages and disadvantages that affect the potential level of classification and the subsequent calculation of statistics. The 30 m^2 spatial resolution of each land cover map was the same resolution as Landsat images. While this level of resolution is commendable given the broad spatial coverage of a single image (185 km x 172 km), it does pose limitations to what land cover can be detected. Different types of vegetative land cover reflect different proportions of energy throughout the electromagnetic spectrum, which is the basis of spectral classification (Jensen 1996). While this allows for large expanses of homogeneous cover to be accurately detected, smaller features, such as stands of trees and patches of shrubs can go undetected if their extent is less than the 30-m^2 extent of an individual pixel. As a result, Landsat products are normally used to map vegetation at the community level rather than vegetative assemblages that exist as patches in an otherwise homogenous landscape (Xie et al. 2008). Using satellite images with higher spatial resolution, such as SPOT satellite images (2.5 m^2 to 20 m^2) or Quickbird (2.44 m^2) would increase the ability to detect small features, but come with their own inherent limitations (limited spatial coverage, cost of image acquisition).

Patch definition is critical to the construction and analysis of wildlife habitat because it will determine patch size and connectivity; however, the way in which patches are defined is often arbitrary. The most common method for defining patches involves identifying contiguous areas of habitat (Cavanaugh 2014).The land-cover maps produced in this research only differentiated between four cover types (cropland, grassland, urban, water) because of the resolution of the satellite images used for classification. As a result, FRAGSTATS analysis conveyed the existence of extremely large patches, in some instances >100,000 ha. Higher levels of classification in which different types of croplands (corn, soybean, wheat), grasslands (tall-grass, shrublands), and other landscape features (fences, dirt roads) are mapped would impact, and likely reduce, the measured patch sizes. Researchers should take note of this when using these maps in population analyses, as patch size effects are important determinants of population density (Bender et al. 1998).

The potential to assess wildlife habitat using remote sensing technology extends beyond land cover classification. Lesser Prairie-Chickens rely upon a variety of cover types in different phases of their life cycle. Research has shown that Lesser Prairie-Chicken have greater nesting success in areas with taller cover of grasses and shrubs because they serve as visual obstructers to potential predators (Riley et al. 1992). Additionally, vegetation at nest site has been found to be taller than adjacent grassland sites (Haukos et al. 1989). Culbert et al. (2012) used 114 Landsat images to derive texture measures to model avian-species richness across the Midwest, and found their ability to explain variability in species richness similar to models that used landscape composition metrics. Furthermore, the emergence of airborne light detection and ranging (LIDAR) technology has increased the capability to model and characterize wildlife habitat at a high resolution (Garcia-Feced et al. 2011, Sankey et al. 2011). Unmanned Aircraft Systems (UAS) also have the ability to monitor and assess wildlife habitat by providing low-altitude, high-resolution aerial imagery that alleviate some of the risks associated with using manned aerial vehicles (Jones et al. 2006, Laliberte 2011). UAS technology has the ability to aid in assessing Lesser Prairie-Chicken habitat, particularly in the monitoring and counting leks, which is often conducted using aerial line-transect surveys (Timmer et al. 2014).

Chapter 5 - Conclusion

The range of the Lesser Prairie-Chicken in Kansas has experienced changes to the composition and continuity of its vegetative land cover, first through natural disturbances such as fire and drought, and more recently through human activity such as agriculture and energy development The amount of grassland within the Lesser Prairie-Chicken range in Kansas has increased since the 1950s, increasing from 50.0% during the 1950s to 53.9% in 2013. This is in direct response to government sponsored programs such as the CRP, which has returned some of the natural cover that was lost through intensive farming practices while providing habitat for the Lesser Prairie-Chicken (Dahlgren et al. 2015). The CRP has also affected the size and shape of grassland patches during this time period. During the 1950s, mean patch size and area-weighted mean patch size of grassland patches were 22.5 ha and 44,918.9 ha respectively. These measures of patch size increased to 24.3 ha and 49,145.8 ha in 2013, indicating that grassland has become a more connected cover type within this region. Despite an increase in patch size, the total amount of edge and edge density have increased between the 1950s and 2013, from 111,949,140 m and 30.3 m/ha to 119,592,150 m and 32.4 m/ha respectively. While the total amount of grassland and the size of grassland patches have increased, these patches seemingly exist as more convoluted shapes than in the past, increasing the edge-to-interior ratio of patches, and possibly reducing the amount of usable habitat within each patch in response to edge effects. Remotely sensed data such as aerial photography and satellite imagery are effective means of monitoring and measuring changes in the extent and configuration of land cover in response to anthropogenic activities. As land cover is constantly changing in response to political, social, and economic activity, the ability to monitor and measure these changes will play a key role in the management of threatened species such as the Lesser Prairie-Chicken. With commodity prices continuing to rise and land owners having other options for land management such as wind energy or oil and gas development, future of the CRP is uncertain, highlighted by its reduction between 2007 and 2014. The loss of CRP would have a considerable negative impact on the Lesser Prairie-Chicken. The Short-grass Prairie/CRP Mosaic Ecoregion, which currently supports ~65% of rangewide Lesser Prairie-Chicken population, is largely only viable because of the presence of CRP. Given the reliance of Lesser Prairie-Chickens on the CRP, along with declining numbers of CRP enrollment, focal areas should continue to be assessed and identified to ensure the CRP is being implemented in areas where they are most effective. Primary focus should include the continued support of CRP in the Short-grass Prairie/CRP Mosaic Ecoregion, which supports the largest amount of Lesser Prairie-Chickens, and strategic implementation of CRP between metapopulations in the Mixed-grass Prairie and Sand Sagebrush Prairie Ecoregion to prevent population isolation. Continuing to make the CRP a viable option for land owners in Kansas will create critical habitat for the Lesser Prairie-Chickens and contribute to the long term success of Lesser Prairie-Chicken populations.

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