

Statistical analysis of grassland trends and phenology using satellite time series imagery of the Flint Hills ecoregion

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Abstract

The Flint Hills ecoregion, spanning from eastern Kansas to north-central Oklahoma, is subject to a wide range of climate variation. This research study focuses on the counties of Elk and Pottawatomie due to their locations within the Flint Hills and explores a method for analyzing vegetation condition and trends as an indicator of grassland health throughout the ecoregion. By utilizing remotely sensed time series imagery collected from 16-day MODIS NDVI satellite composites over a timespan of 15 years and Breaks For Additive Seasonal and Trend (BFAST) analysis methods we were able to analyze trends in overall grassland health and number breaks for this time period. In addition to trends and breaks, various phenometric parameters were extracted using TIMESAT. They included: start of season, end of season, season length, maximum NDVI, and small season integral. These phenometric parameters were analyzed for three years that had varying climatic conditions and fell within the 15 year time series. The years examined exhibited conditions that were summarized as cool-wet (2008), hot-dry (2012), and normal (2005). These provided us with differing precipitation and temperature data so we could understand how phenological changes are affected by varying climate conditions. The phenometric values assigned to each pixel were compared between the two counties using a Kolmogorov-Smirnov (KS) test to obtain statistical D- and P-values. The D-values obtained from the tests revealed the maximum phenological data differences between the counties during a particular year. The P-values calculated were used to determine if the model probability was significant. Any P-value less than .050 was considered significant with a majority of our P-value results being less than 2.2×10^{-16} . KS tests revealed the phenological patterns of the two counties were significantly different. Overall analysis of the time series revealed that a majority of the grassland pixels in the two study areas were subject to negative grassland greenness trends. Both counties showed less than 25 percent increase in greenness over the 15 year period.

Introduction

Background

The Flint Hills is a 1.6 million hectare (ha) expanse of land in eastern Kansas and north-central Oklahoma that is representative of the tallgrass prairie with dominant grasses consisting of little and big bluestem, indiangrass, and switchgrass. The Tallgrass Prairie National Preserve is within the ecoregion and is the largest remaining tract of tallgrass prairie in North America. On average, April to October, are frost-free with a majority of annual precipitation being intense bursts of rainfall, 75 percent of which occurs during the growing season from May to October (Steward et al. 2011). This extreme variability in climate, as well as variable land management practices throughout the region could lead to interesting trends in vegetation throughout the region.

Our study seeks to investigate vegetative trends throughout the Flint Hills region using satellite imagery from a span of 15 years. Near real-time monitoring of ecosystem disturbances is critical for rapidly assessing and addressing impacts on carbon dynamics, biodiversity, and socio-ecological processes. Satellite remote sensing enables cost effective and accurate monitoring at frequent time steps over large areas (Verbesselt et al., 2012). We wanted to determine trends in vegetative health by analyzing NDVI values of grass in two counties in Kansas: Pottawatomie and Elk. These counties were chosen based on their locations within the Flint Hills region. Pottawatomie and Elk counties are respectively located along the northern and southern edge of the ecoregion. The climate classification lists Pottawatomie county as warm continental and Elk county as a humid subtropical climate (Larson and Lohrengel, 2011). The population of Elk county has been steadily decreasing from 3,157 people in 2001 to 2,655 people in 2013 whereas the Pottawatomie population has been increasing drastically from 18,273 people in 2001 to 22,691 people in 2013, according to the U.S. Census Bureau (Census.gov, 2016). These changes in population could affect the Flint Hills as human interaction becomes less or more of a factor for the two counties. The changes in population and the climate shifts could be reasoning for changes in NDVI measurements over time.

Purpose

There have been several studies conducted within the Flint Hills that examined the differences in grassland health between military training land and native grassland (Pockrandt, 2012 and Hutchinson et al., 2014) but few that dealt with long term trends solely in native grassland health within the Flint Hills ecoregion. This type of study is important because we can get an unobstructed glimpse into how factors such as climate and seasonal variation affect grassland health and drive trends in grassland productivity. Our study seeks to answer how grassland dynamics within the Flint Hills ecoregion have changed over the past 15 years.

Natural resource managers, policy makers and researchers demand knowledge of land cover changes over increasingly large spatial and temporal extents for addressing many pressing issues such as global climate change, carbon budgets, and biodiversity (Verbesselt et al., 2010). Detecting and characterizing change over time is the natural first step toward identifying the driver of the change and understanding the change mechanism. Satellite sensors are well-suited to this task because they provide consistent and repeatable measurements at a spatial scale which is appropriate for capturing the effects of many processes that cause change, including natural (e.g. fires, insect attacks) and anthropogenic (e.g. deforestation, urbanization, farming) disturbances (Verbesselt et al., 2010). Deviations from average season-trend vegetation dynamics over multiple years can indicate the effects of many processes that cause disturbances, including physical (e.g., droughts, fires, floods), biogenic, and anthropogenic factors. According to Verbesselt et al., 2010, ecosystem changes commonly observed with remote sensing approaches can be divided into three categories: (1) seasonal or cyclic change, for example driven by annual temperature and rainfall interactions impacting plant phenology resulting in distinct intra-annual patterns for different vegetation types; (2) gradual trend change such as trends in mean annual rainfall or gradual change in land management (e.g., long-term drought, forest regrowth after fire) that result in changes over several years; and (3) abrupt trend change, caused by events from human activities (e.g., deforestation) or natural causes (e.g., wind throw, or drought event) that change land surface over short time frames (Verbesselt et al., 2010). The detection of short-term abrupt changes (e.g., light frost, rainfall events) depends on the magnitude of change versus the signal-to-noise ratio often determined by the spectral, spatial and temporal characteristics of the remotely sensed data (Verbesselt et al., 2012).

We hypothesized that long-term trends in grassland greenness, which is a proxy for grassland health and condition, has been stable throughout the ecoregion. We also expected to find that the frequency of significant disturbances to grasslands is similar throughout the Flint Hills ecoregion, not varying with location, topography, climate, or other variables. We also hypothesized that phenometrics, or key measures of vegetation development, occur at relatively similar times and see similar growth throughout the ecoregion. These phenometrics included start of season, or when grass first showed signs of green-up; end of season, when grass showed signs of senescence; season length, or the difference between start and end of season dates; maximum NDVI, when grass was showed maximum greenness; and small season integral, which is the area under the growth curve extending from the start of season to the end of season. We narrowed our length of our phenometric study by dividing the 15 year study period into three “seasons” based on their measured temperature and precipitation characteristics. The seasons selected are 2012, 2008, and 2005 representative of a hot and dry season, a cool and wet season, and a normal season, respectively.

Material and Methods

Study Areas

Both of the counties used in this study, Elk and Pottawatomie, are located in the Flint Hills ecoregion of Kansas. The Flint Hills comprises 80 percent of the world's remaining tallgrass prairie (Hutchinson et al. 2014). While both counties are located in the same ecoregion, they represent northernmost and southernmost portions of the region and will likely display differences in vegetation dynamics. Pottawatomie county, is located northeastern Kansas and has a land area of approximately 217,800 ha. Elk county, is located in southeastern Kansas and has a land area of approximately 166,900 ha. Figure 1 shows the location of these counties within the Flint Hills ecoregion and the state of Kansas based on the Environmental Protection Agency's boundary definitions.

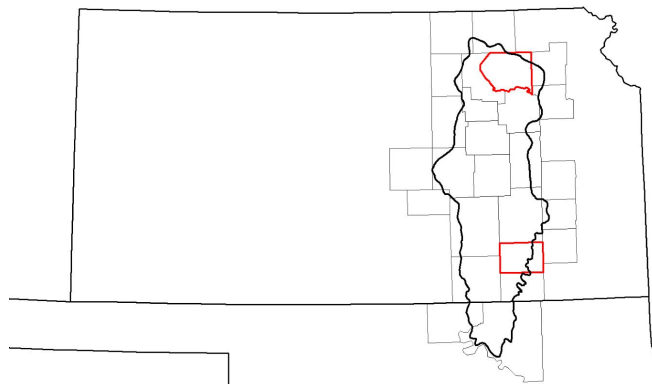


Fig. 1. Pottawatomie (northernmost) and Elk (southernmost) counties and their location within the Flint Hills ecoregion and the state of Kansas.

Image Data

Imagery data used for analysis were Moderate Resolution Imaging Spectrometer (MODIS) Normalized Difference Vegetation Index (NDVI) composites. NDVI is the normalized reflectance difference between near infrared and visible red bands in the electromagnetic spectrum. It measures the reflective and absorptive changes in chlorophyll content and in spongy mesophyll within the vegetation, or greenness characteristic of health and condition. The composites used were the maximum NDVI value collected within a 16-day temporal scale. This technique helps eliminate atmospheric and cloud effects that could distort NDVI measurements. The challenge of long-term analysis is to deal with the non-stationarity of the NDVI time series (Guyet and Nicholas, 2016). A 16-day temporal scale means 23 images were taken each year. This study focused on a time period from January 1, 2001 to December 31, 2015 resulting in a total of 345 images of each pixel within the study area. The spatial resolution of each composite were 231 x 231-meters pixels. The scope of our analysis was also refined by the selection of

three years to determine phenometric parameters for various climatic conditions. The years selected for phenometric analysis were 2005, 2008, and 2012.

The focus of this study was primarily on grasslands within each of these two counties. To determine land cover classifications, data was obtained from the National Land Cover Database 2011 (NLCD 2011) (MRLC, 2016). It was determined that only pixels (231 x 231-meters) consisting of more than 80 percent grassland according to NLCD 2011 would be used. Using ArcMap Geographic Information Systems (GIS) software we created a raster grid of each county comprised of individual rectangular polygons that coincided with image pixels. To simplify analysis, land-cover changes were not monitored during the 15 year period. It was assumed that the pixels identified as greater than 80 percent grassland in 2011, were greater than 80 percent grassland for the entirety of the time series.

Phenometrics

Pockrandt, 2014, stated that raw data NDVI data must be filtered, composited, and/or screened to extract desired phenometric data. The program TIMESAT was used in our study to filter raw NDVI data and extract phenometrics of interest. Similar to what was done in Pockrandt, 2014, our study utilized the Savitzky-Golay TIMESAT filter in addition to parameters found optimal for our Flint Hills study area. The phenometrics that were extracted included: start of season, end of season, small seasonal integral, maximum NDVI, and season length. The Kolmogorov-Smirnov (KS) Test was used in the R statistical program to determine if phenometric results were significantly different between the two counties and across the three years. The KS test also determined the maximum magnitude of those differences.

Vegetation Dynamics

Time series analysis is done by collecting remotely sensed data from satellite imagery over a given period of time and extracting and analyzing the data using a variety of modeling techniques. We used the Breaks For Additive Seasonal and Trend (BFAST) method to extract components of time series NDVI from MODIS imagery. The BFAST method enables the extraction of seasonal, trend, and noise components of NDVI grassland imagery for each pixel (Hutchinson et al. 2014). The method is globally applicable since it analyzes each pixel individually without the setting of thresholds to detect change within a time series (Verbesselt et al., 2010). In addition to modeling trends, BFAST can also detect breakpoints including when they occur and the magnitude of the break (Hutchinson et al. 2014). According to Hutchinson et al., 2014, “BFAST is a parametric method that uses an additive model to decompose each pixel of a time series dataset into the three components: seasonal (S_t), trend (C_t), and residuals (ϵ_t).” This model is described by Equation (1) from Hutchinson et al., 2014.

$$Y_t = S_t + C_t + \varepsilon_t \quad (1)$$

Figure 2 shows raw 16-day MODIS NDVI for two pixels located within Pottawatomie county broken down into the three components.

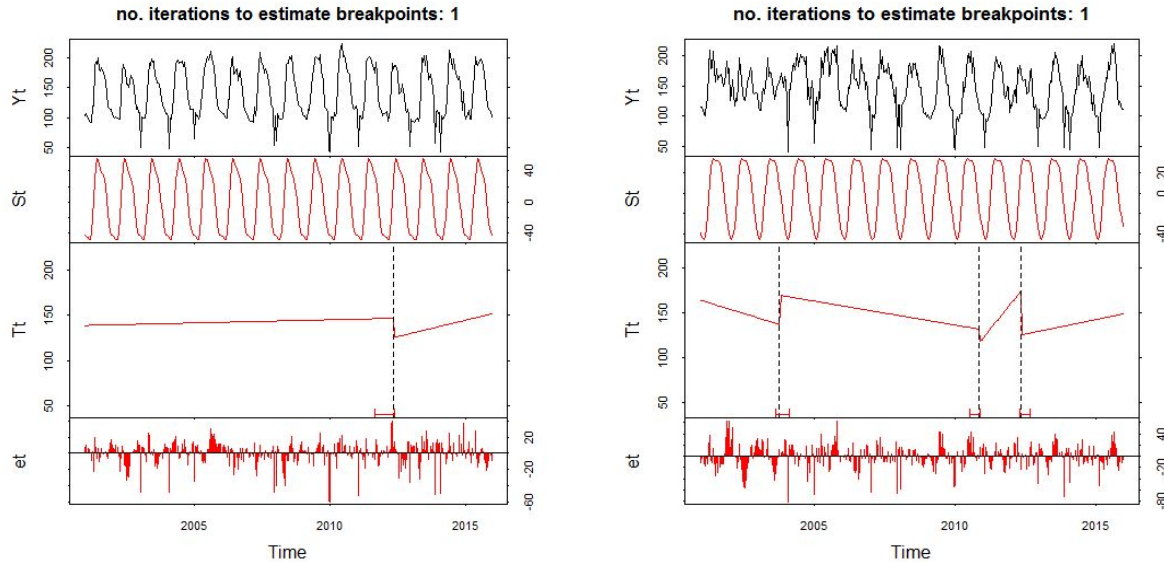


Fig. 2. Raw 16-day MODIS NDVI time series between 2001 and 2015 (black) and components resulting from BFAST (red) for two grassland pixels located in Pottawatomie County, Ks. The graph on the left represents pixel 10 and the graph on the right represents pixel 64 of the Pottawatomie mapping area.

The Student's T-Test to determine significance of time series trends. A Chi-squared analysis was conducted to determine site differences (Elk vs Pottawatomie) for breaks during the time series. The null hypothesis of the Chi-squared test was that values observed were independent of the study site. If the p-value was less than the desired significance, the null hypothesis was rejected, meaning that the values observed are dependent on the study site.

Results and Discussion

For phenometric analysis the 15 year study was subdivided into three differing seasons based on their measured temperature and precipitation characteristics: normal, hot-dry, and cool-wet. 2008 was set aside as our cool-wet season, 2012 was designated as our hot-dry season, and 2005 was deemed our normal season. Using the KS test it was determined that all the phenometric comparisons between the two counties were significant.

For vegetation dynamics analysis, the entire time series was used to determine trends and breaks for the two counties.

Start of Season

The SOS is a measure of initial greenup in vegetation. Figures 3 through 5 show the proportion of grassland pixels within the county that had reached the start of season thresholds by specific times in spring season. Each unit of the X-axis coincides with the 16-day temporal scale. For example, 167 on the X-axis of figure 4 corresponds to April 6, 2008, and 168 corresponds to April 22, 2008, and so on.

From our Cumulative Distribution Function (CDF) plots, during a normal year (*Figure 3*) the start of season takes place over a period of approximately 24 days for Elk County and approximately 28 days for Pottawatomie County. Elk County began its start of season cycle later, but was the first to see all pixels finish their transition. During a cool,wet year, Pottawatomie was first to show change in the start of season data, but last to complete the change. For both counties, the abrupt change in the start of season data occurred over a period of about two weeks. The largest calculated D-value difference among all the seasons occurs during the 2008 start of season phenometric (*Figure 4 and Table 1*).

The CDF plots show that Elk county saw 100 percent of its grassland pixels reach start of season thresholds before grasslands in Pottawatomie county in all three years that were examined. In both the cool-wet, 2008, and the hot-dry, 2012, grassland greenup on a significant portion of pixels occurred earlier in Elk county. For our normal year, 2005, greenup occurred at a similar pace for both Elk and Pottawatomie counties.

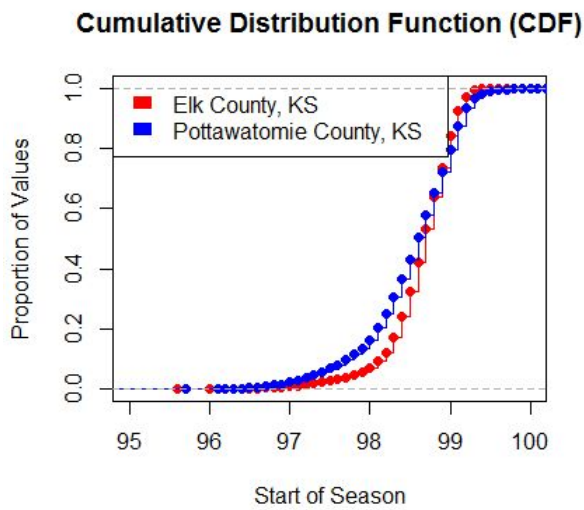


Fig. 3. Start of season phenometrics (2005)

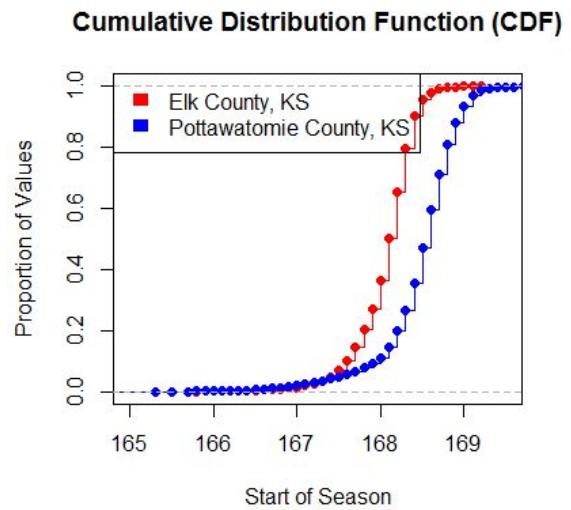


Fig. 4. Start of season phenometrics (2008)

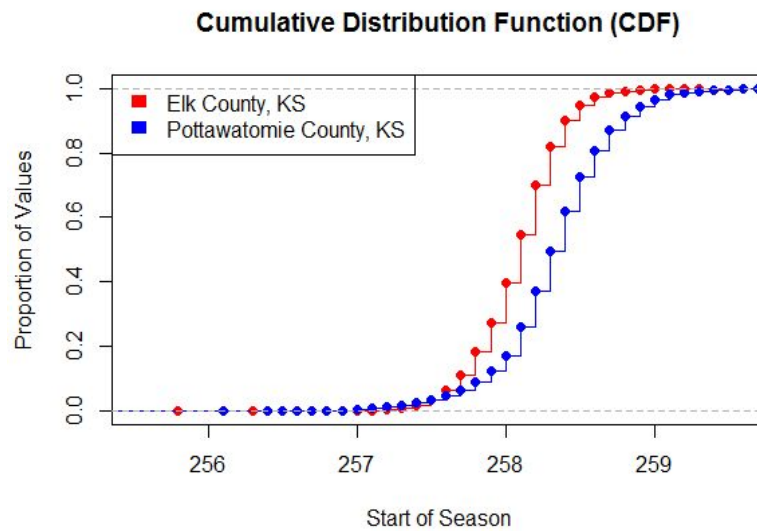


Fig. 5. Start of season phenometrics (2012)

Season (Year)	Phenometrics of Interest	D-Value	P-Value
2005	Small Seasonal Integral	0.30536	< 2.2E-16
2005	Start of Season	0.13248	< 2.2E-16
2005	End of Season	0.17163	< 2.2E-16
2005	Season Length	0.07054	< 2.2E-16
2005	Maximum NDVI	0.19652	< 2.2E-16
2008	Small Seasonal Integral	0.24107	< 2.2E-16
2008	Start of Season	0.5473	< 2.2E-16
2008	End of Season	0.02673	3.01E-05
2008	Season Length	0.07054	< 2.2E-16
2008	Maximum NDVI	0.21291	< 2.2E-16
2012	Small Seasonal Integral	0.23888	< 2.2E-16
2012	Start of Season	0.329	< 2.2E-16
2012	End of Season	0.11146	< 2.2E-16
2012	Season Length	0.10784	< 2.2E-16
2012	Maximum NDVI	0.25661	< 2.2E-16
*D-Value is the statistic representing the maximum distance between the CDFs of the two samples			
*Any P-Value less than .050 is significant			

Table 1: Kolmogorov-Smirnov (KS) test results

End of Season

The end of season is a measure of senescence or browning in vegetation. It marks the end of the growing season and the onset of vegetation dormancy. During a normal year (*Figure 6*) it is seen that the end of season started earlier in Elk county and ended earlier in Pottawatomie county. The total span of the end of season is about 48 days for Elk county and 24 days for Pottawatomie county. During a wet, cool year (*Figure 7*) it is seen that the end of season started earlier in Pottawatomie County and slightly later in Elk county with the end of season spanning about 24 days in Pottawatomie county and 12 days in Elk county. Finally, during a dry year (*Figure 8*) Elk county experienced an earlier end of season than did Pottawatomie county, yet both counties saw all pixels ended at about the same time. The duration of the end of season was about 128 days for Elk county and 32 days for Pottawatomie county. Overall, it is seen that Elk county entered the end of season earlier than Pottawatomie county for two of the three years analyzed (2005 and 2012).

It would be expected that end of season may occur earlier in Pottawatomie county due to its northern location, and likely, earlier freeze dates. The 2012 growing season was remarkably hot and dry, Elk county saw a significant portion (~10 percent) of pixels enter dormancy in mid-August. This could have been a result of browning due to drought or significant grass fires that were likely aided by drought conditions.

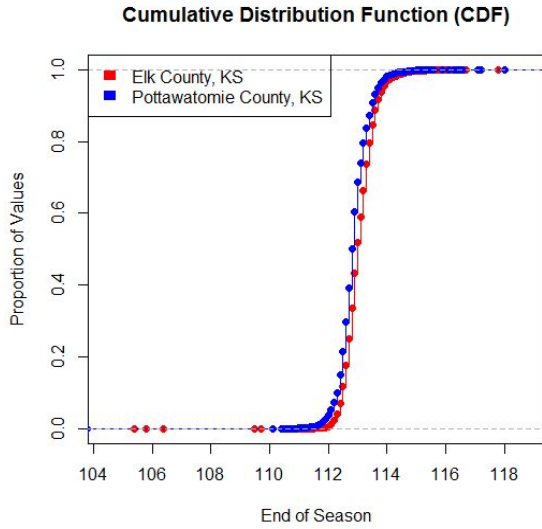


Fig. 6. End of season phenometrics (2005)

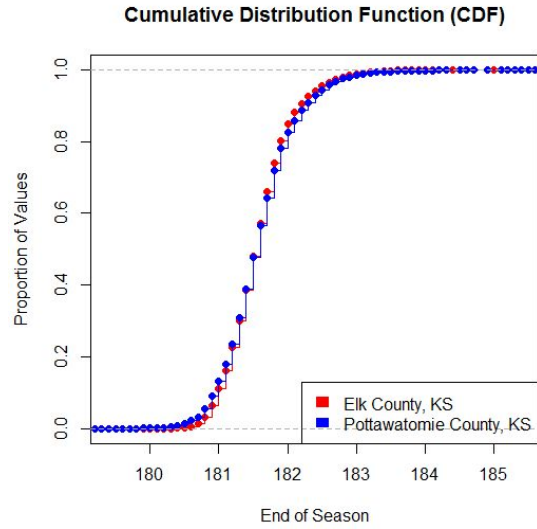


Fig. 7. End of season phenometrics (2008)

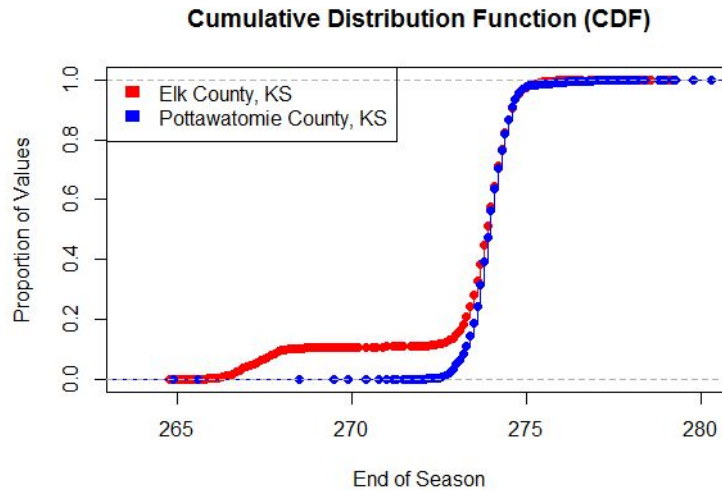


Fig.8. End of season phenometrics (2012)

Season Length

Season length is the difference between the start and end of season. Due to geographical location it would be expected that Elk county would generally see a longer season length. This was generally the case in 2005 and 2008 but in 2012 approximately 10 percent of Elk county pixels saw a shortened season length. This pattern is consistent with what was observed in the 2012 end of season CDF plot. *See Appendix for figures.*

Maximum NDVI

Maximum NDVI is a phenometric measure of the point where vegetative greenness and therefore vegetative biomass is at its relative maximum. NDVI is measured on a scale from 0 to 255, with 255 coinciding with maximum possible greenness. It is seen from Figure 9 that in a normal year Pottawatomie county generally had a maximum NDVI slightly larger than that of Elk county. The same is true for 2008, our cold, wet year (*Figure 10*). Both 2005 and 2008, show a visually similar trend in the data for maximum NDVI. However, in 2012 which was our hot and dry year, Elk county had a maximum NDVI value higher than Pottawatomie county (*Figure 11*). The lowest maximum NDVI values among our three seasons occurred during the 2012 hot, dry year. This is most likely related to the drought that took place that year.

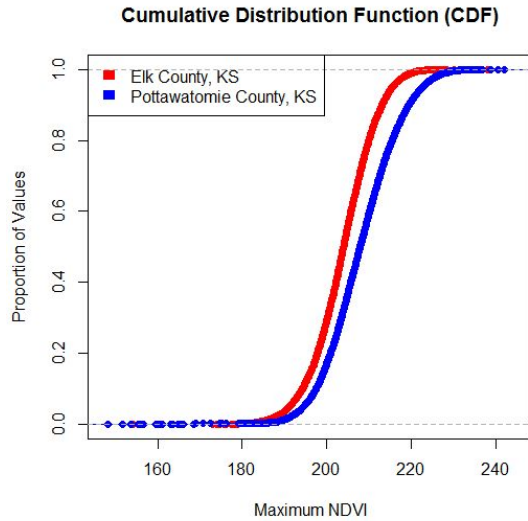


Fig. 9. Maximum NDVI values (2005)

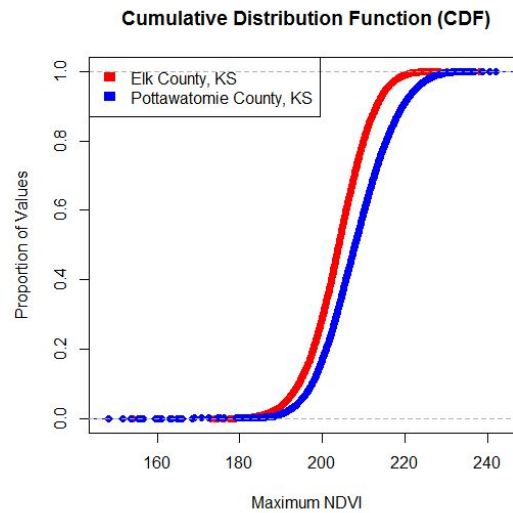


Fig. 10. Maximum NDVI values (2008)

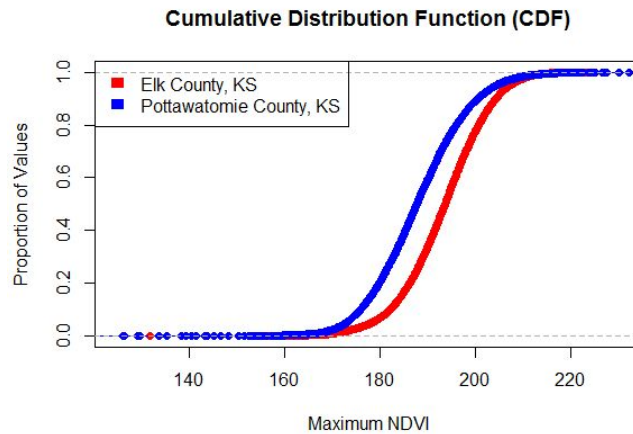


Fig. 11. Maximum NDVI values (2012)

Small Season Integral

The small season integral is a measure of total grassland production for the growing season. A larger small season integral means more grassland production. It combines three phenometric parameters: start of season, end of season, and maximum NDVI. It is the area under the curve created by these three parameters. A large small season integral results from large maximum NDVI values or a long growing season, or a combination of the two.

Figures in the Appendix show that Elk county reached a larger small season integral than Pottawatomie county in 2005 and 2008 but not in 2012 which was a hot and dry year. Interestingly, Elk county reached a higher maximum NDVI in 2012, meaning the smaller small season integral is likely affected by a shortened season length. In 2005 and 2008, the growing season extended into late fall for Elk county but in 2012, approximately 10 percent pixels reached the end of season in mid-August. This shortened season likely resulted in reduced productivity.

Trends and Breaks

We can see from Figure 12, the overall trends of both study areas were overwhelmingly negative. Of the 16,415 pixels in Pottawatomie containing more than 80 percent grassland, 68.9 percent exhibited a browning trend over the 15 year study period. Less than 25 percent of the pixels comprising Pottawatomie county showed a positive increase in vegetation greenness. As seen in the Pottawatomie county raster grid (*Figure 22*) a majority of the positive trend pixels occurred in the western portion of the county. This could be contributed to the drainage watershed that flows into Tuttle Creek Reservoir bounding Pottawatomie County on its western border. Landsat imagery also shows an abundance of trees, primarily invasive Eastern Red Cedars, within the area. The saturation of coniferous evergreens in the western portion of the

county could lead to a false-positive indication of greenness within the NDVI satellite time series analysis. Elk county was composed of 14,255 grassland pixels encompassing 760 km². Of those pixels, 16.4 percent showed a positive increase in greenness over the study period (*Figure 13*). Approximately 25 percent of the pixels studied displayed little to no change in their average NDVI values throughout the years. Over 59 percent of the Elk county study area maintained a negative trend over the study period. There are little differences in the overall trend between the two counties. The differences in percentages could be contributed to 2,200 less grassland pixels within the Elk mapping area. The biggest differences between the trends in each county was the amount of pixels that remained stable. The larger percentage of stable pixels combined with the lower percentage of negative trend pixels leads us to believe that Elk county may be less susceptible to climatic changes than Pottawatomie county.

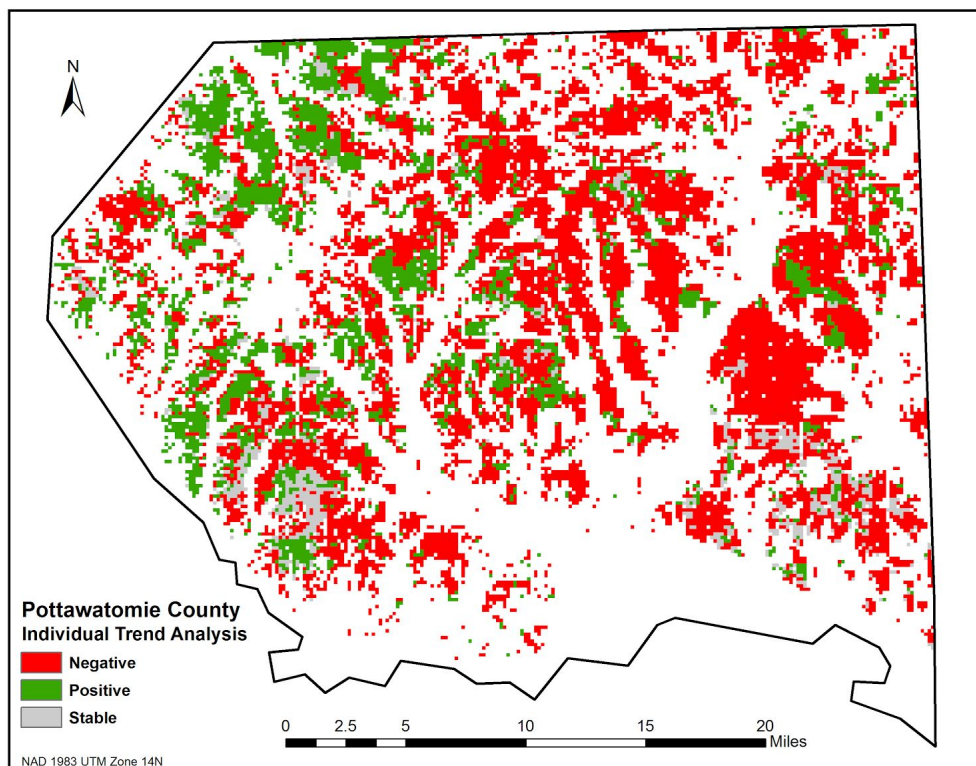


Fig. 12. Individual Pixel Trend Analysis. Only pixels that were comprised of at least 80% were taken into account. The white space within the Pottawatomie study area is representative of the pixels less than 80% grassland.

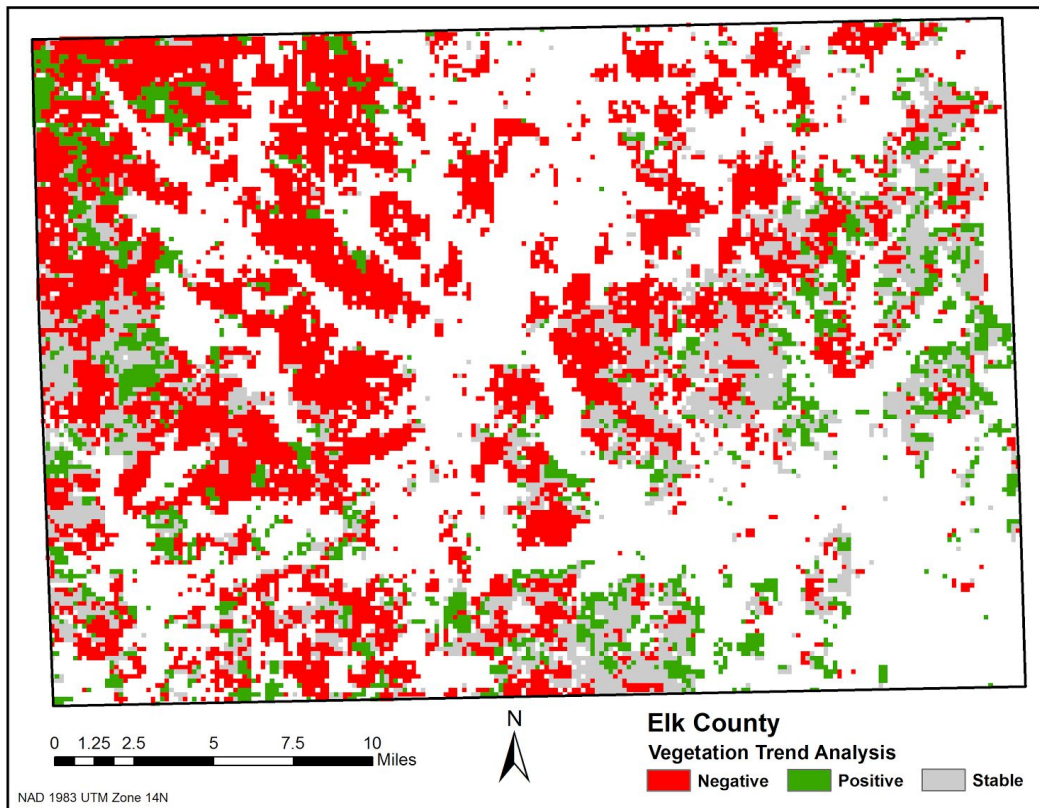


Fig. 13. Individual Pixel Trend Analysis. Only pixels that were comprised of at least 80% were taken into account. The white space within the Elk study area is representative of the pixels less than 80% grassland.

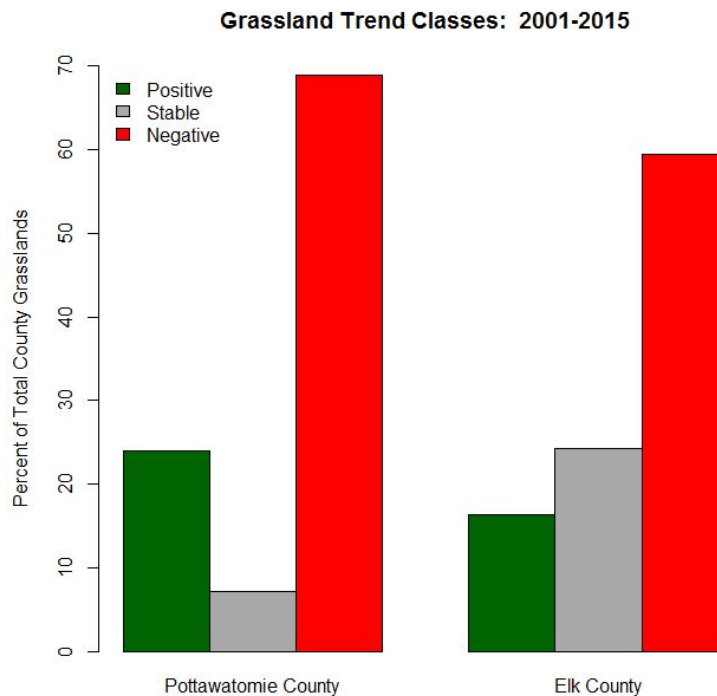


Fig. 14. Percent of grassland pixels in the three possible trend categories.

Of the 16,415 pixels of grassland pixels in Pottawatomie county, 12,262 (75 percent) pixels exhibited zero significant breaks over the period of the time series. The overall gradual trend of Pottawatomie county is negative, but a majority of its land cover exhibited no abrupt change events. 3,528 Pottawatomie pixels only had one significant break during the study period. These are likely due to burning and range management practices used to maintain the region's vegetation and control invasive species. Only 502 of the pixels exhibited two breaks within the time series, 98 pixels had three, 22 had four, and three pixels had five breaks over the time series.

Elk county varies greatly from Pottawatomie. 5,469 pixels (38 percent) in Elk county did not have any breaks over the time series. 95% of the land cover within Pottawatomie county experienced one or less breaks over the 15 year study. Only 43.8% of the Elk county study experienced one or less breaks in contrast. Over 55% of the Elk study area experienced two or more breaks within the time series. Elk also exhibited pixels with up to seven breaks. Pottawatomie county had just a few pixels reach the county maximum of five breaks.

Pottawatomie County			
# of Breaks	# of Pixels	% of Area Pixels	Land Cover Hectares
0	12,262	74.70%	65,800.00
1	3,528	21.49%	18,931.86
2	502	3.06%	2,693.82
3	98	0.60%	525.88
4	22	0.13%	118.06
5	3	0.02%	16.10
Total Pixels	16,415.00	Total Hectares	88,086

Table 2. Breaks analysis of Pottawatomie county.

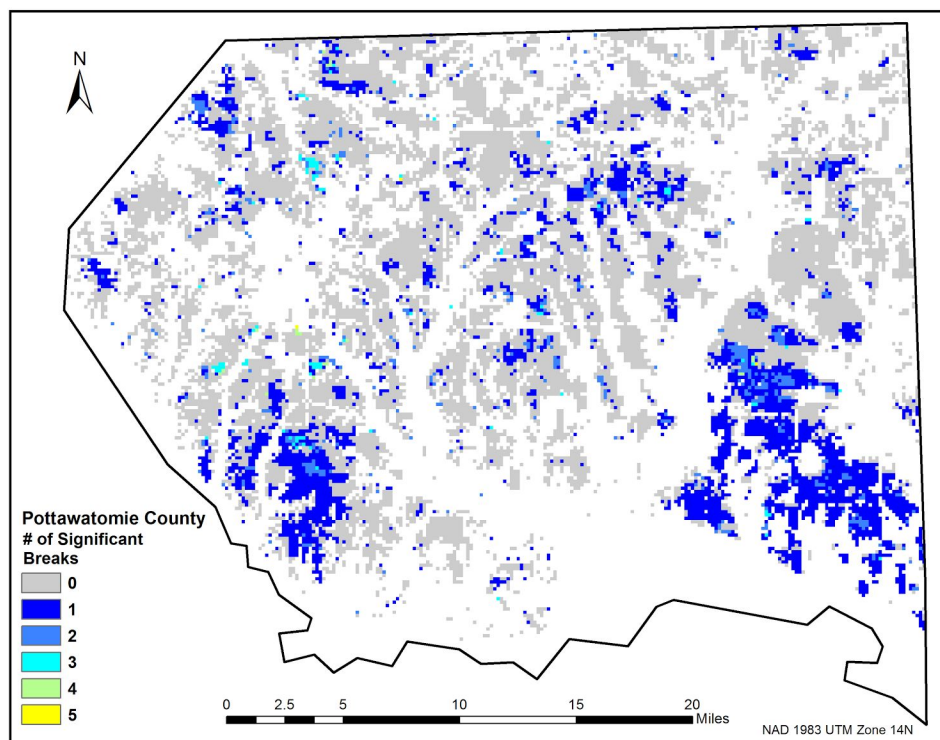


Fig. 15. Map of pixel breaks in Pottawatomie county.

Elk County			
# of Breaks	# of Pixels	% of Area Pixels	Land Cover Hectares
0	5,470	38.38%	29,353
1	770	5.40%	4,132
2	2,017	14.15%	10,824
3	1,779	12.48%	9,546
4	3,733	26.19%	20,032
5	473	3.32%	2,538
6	10	0.07%	54
7	1	0.01%	5
Total Pixels	14,253	Total Hectares	76,484

Table 3. Breaks analysis of Elk county.

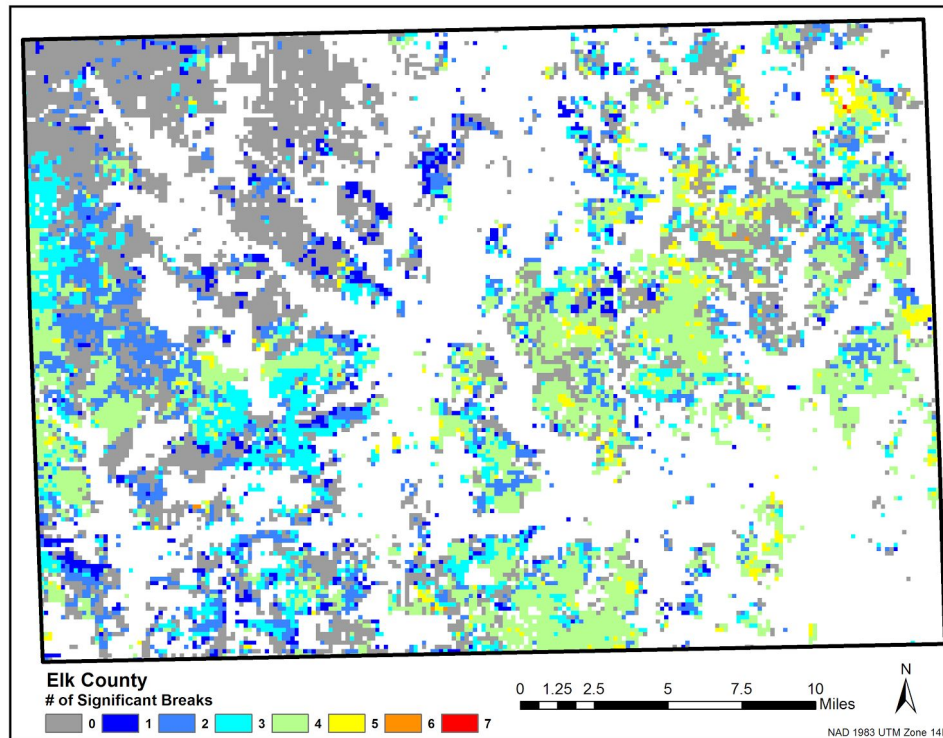


Fig. 16. Map of pixel breaks in Elk county.

Conclusion

Phenometrics

A broad view of phenometric data indicates that there are indeed differences in phenometric developed between Pottawatomie and Elk counties, this can be seen from statistical data presented in Table 1. Our group hypothesized that phenometrics occur at relatively similar times and see similar growth throughout the ecoregion, but this was not the case. There were three instances where phenometrics data had little differences between the two counties; they included 2005 and 2008 season lengths, as well as the 2008 end of season. The D-values in these three instances approached zero and were relatively smaller than D-values seen in other phenometric categories and years.

From our phenometric data we can see a significant difference in the year 2012. In 2012, Elk county vegetation growth started earlier and had a higher maximum NDVI value than Pottawatomie but had a lower small season integral. This was likely due to hot, dry conditions that may have resulted in an early end of season for some pixels in Elk county.

When examining weather patterns within 2012 it is clear why there is such a trend, because there was a significant drought throughout much of the Central Great Plains, in fact it was the most severe drought in 117 years (Hoerling et al. 2014). Based on Figures 17 through 19 both Pottawatomie and Elk county experienced severe if not extreme drought. If you examine precipitation trends between 2011 and 2012 for both counties, in 2011 Elk county received 31 inches and 26 inches in 2012, a 5 inch difference, whereas Pottawatomie county received 34 inches in 2011 and 24 inches in 2012, a 10 inch difference. So even though Elk county was hit harder in the drought than Pottawatomie county, the difference between drought precipitation and normal precipitation was not as drastic for Elk as it was for Pottawatomie. The proof of this data is found in the phenometric trends for 2012, which is why Elk county did so much better in terms of max NDVI than did Pottawatomie county in the year 2012. Interestingly, Elk had a lower small season integral than Pottawatomie in the year 2012.

For 2005 and 2008, most phenometric trends followed what would be considered reasonable due to geographic locations and differences in average weather patterns for the two counties. Elk generally saw an earlier green up, a later end of season, and as a result, more grassland productivity. For 2005 and 2008, Pottawatomie county saw larger maximum NDVI values which could be related to grassland species, management, or a variety of different factors.

The 2012 data shows some significant differences from 2005 and 2008. Maybe the most interesting piece of 2012 data was found in the end of season CDF plot of Elk county. Approximately 10 percent of pixels reached end of season in mid-August. Our group believes

this was due to drought conditions or disturbances related to drought. A higher maximum NDVI was seen in Elk county in 2012 but because of the shortened season of some pixels, the small season integral was smaller than Pottawatomie county.

Trends and Breaks

The number of breaks within the two counties were significantly different. Elk county saw multiple breaks on a larger percentage of its pixels. Elk county also had pixels that reached higher numbers of breaks with the maximum number of breaks reaching seven.

The majority of pixels in the two counties have seen negative trends in grassland greenness over the 15 year time span from 2001 to 2015. Our group hypothesized that vegetative health trends would be stable throughout the time series but this was not the case. This negative trend could be a result of multiple factors such as climate change, land use change, invasive species, etc. The declining health of grasslands in the Flint Hills has significant implications for livestock grazing, carbon storage, water cycling, and prairie preservation just to name a few.

Future Work

Problems exist with our research data model in regards to land cover changes over the past 15 years. Land use changes or invasive species such as, coniferous evergreen could give false indication of greening pixels within a remotely sensed time series if not accounted for when classifying pixel land cover. Our study assumed that land cover classifications in 2011 remained consistent throughout the entire time series. Future work may need to include multiple land cover evaluations to truly distinguish only grassland pixels.

Trend classifications, as illustrated in figure 14, were made using starting conditions and ending conditions. These negative trends could be contributed to recent warm, dry years at the end of the time series as compared to possibly cool, wet years at the beginning of the time series. If the time series were continued several years and climatic conditions were favorable, we could see a reversal in these trends. Impacts of this variability could be reduced by using a larger time series or large spatial scales that saw a variety of climatic conditions.

Final Thoughts

The methods outline for this study allow ranchers, biologists, government agencies, and other interested parties the ability to continually track vegetation dynamics on large spatial scales within the Flint Hills. An understanding vegetation dynamics can be used to improve land management practices, assist policy decisions, and understand climate changes.

Appendix

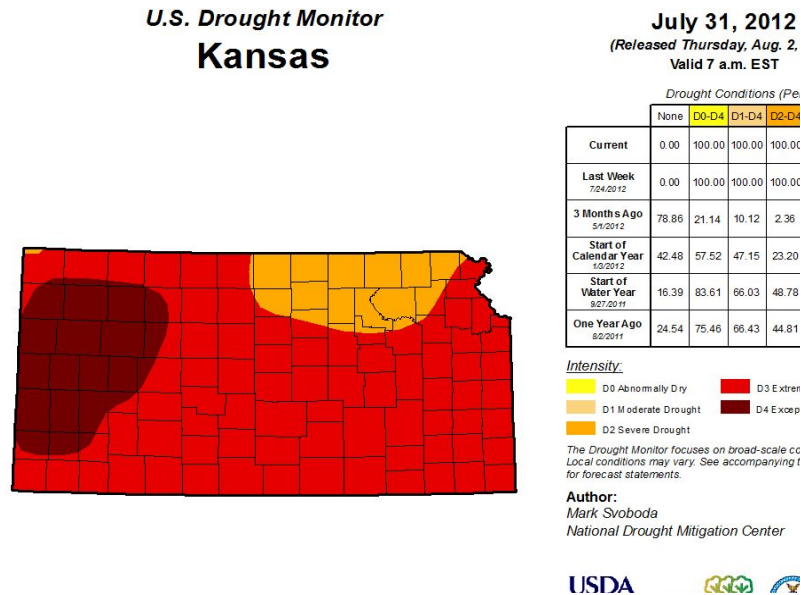


Fig. 17. Weather conditions in Kansas on July 31, 2012.

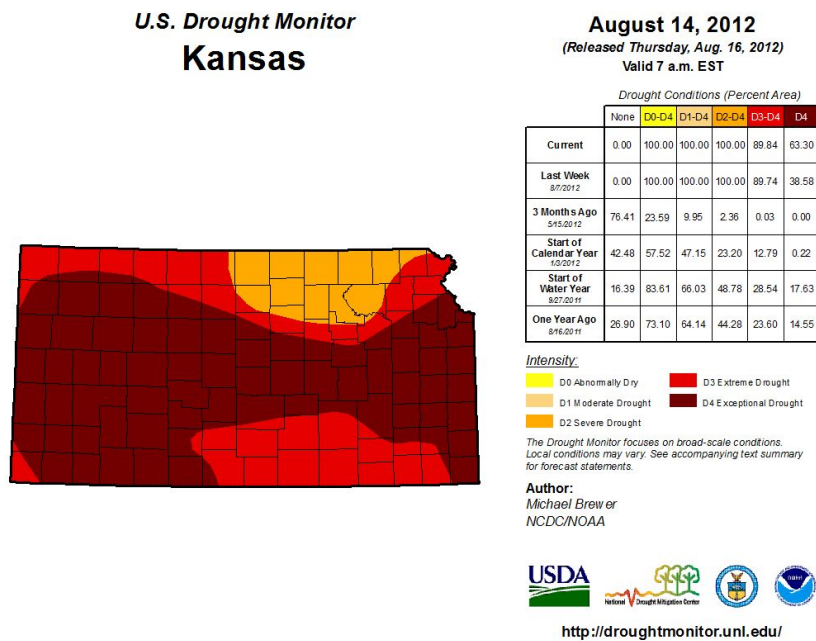
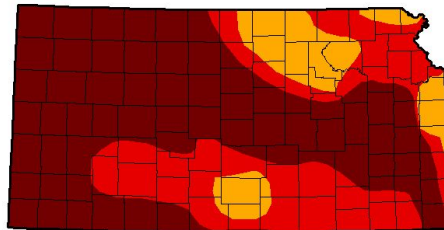


Fig. 18. Weather conditions in Kansas on August 14, 2012

U.S. Drought Monitor
Kansas

September 11, 2012
(Released Thursday, Sep. 13, 2012)
Valid 7 a.m. EST



Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.00	100.00	100.00	100.00	88.34	60.61
Last Week 8/4/2012	0.00	100.00	100.00	100.00	88.34	60.61
3 Months Ago 6/12/2012	9.09	90.91	71.46	23.22	0.15	0.00
Start of Calendar Year 1/2/2012	42.48	57.52	47.15	23.20	12.79	0.22
Start of Water Year 9/27/2011	16.39	83.61	66.03	48.78	28.54	17.63
One Year Ago 9/13/2011	19.89	80.11	63.29	49.90	32.26	17.63

Intensity:

D0 Abnormally Dry
D1 Moderate Drought
D2 Severe Drought
D3 Extreme Drought
D4 Exceptional Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author:
David Simeral
Western Regional Climate Center



<http://droughtmonitor.unl.edu/>

Fig. 19. Weather conditions in Kansas on September 11, 2012.

Season Length

2005

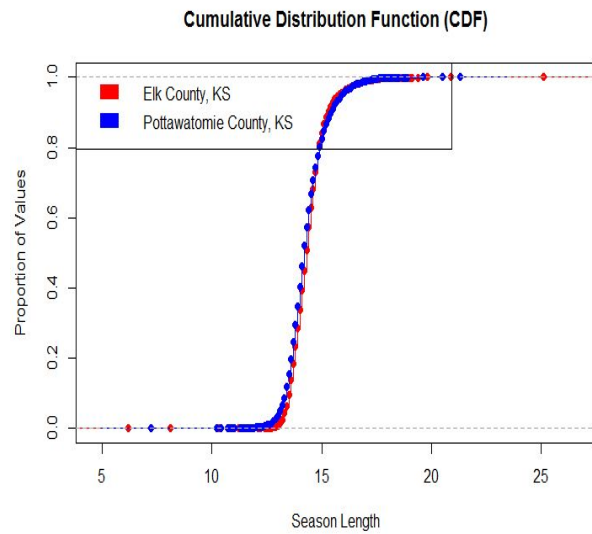


Fig. 20. Season length (2005)

2008

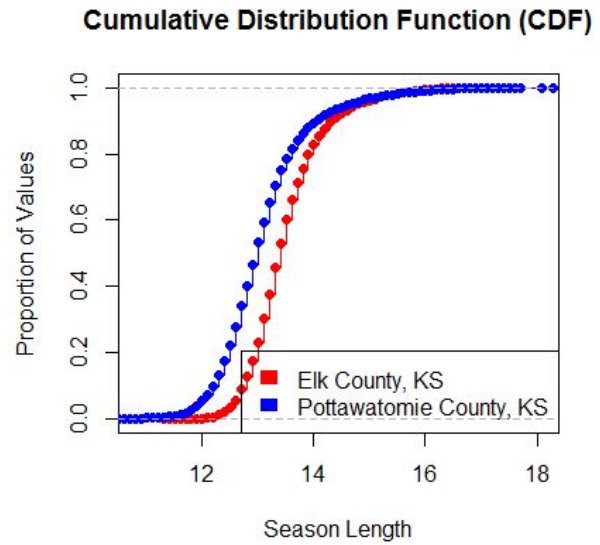


Fig. 21. Season length (2008)

2012

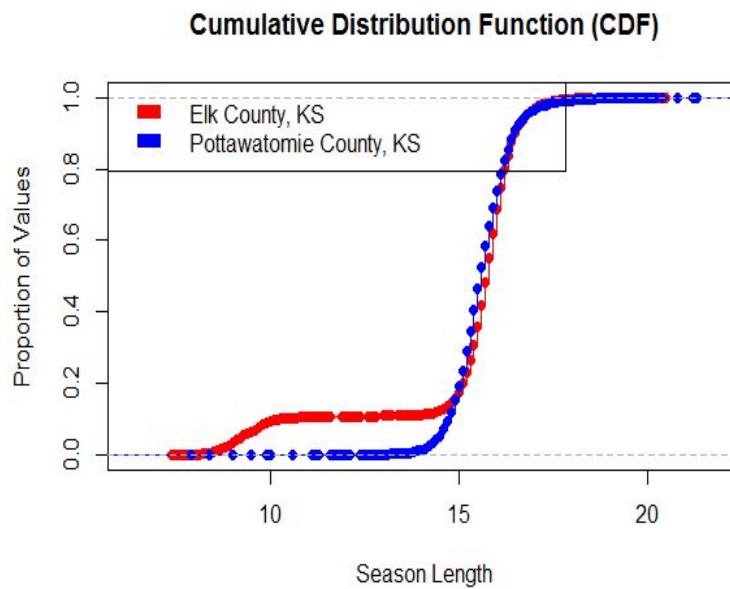


Fig. 22. Season length (2012)

Small Season Integral

2005

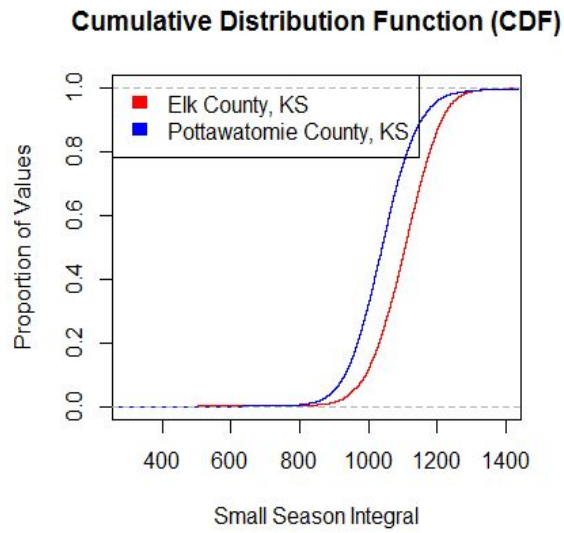


Fig. 23. Small Season Integral (2005)

2008

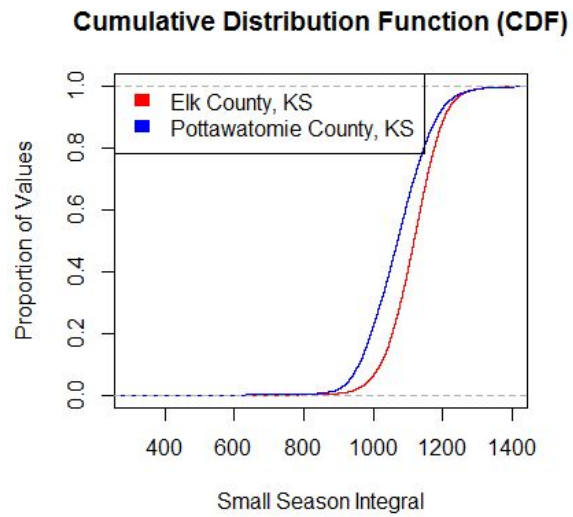


Fig. 24. Small Season Integral (2008)

2012

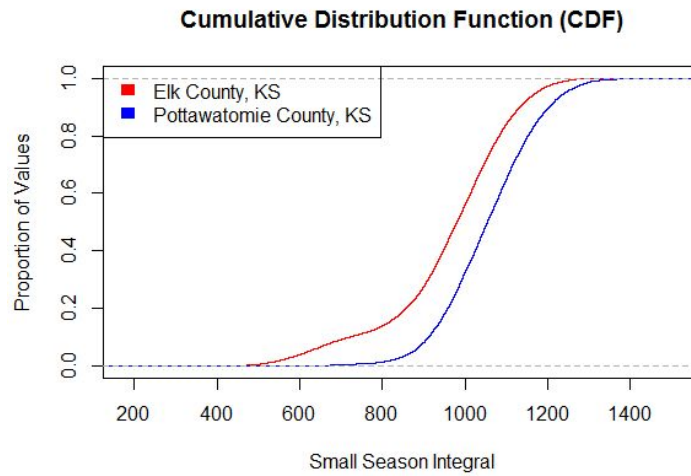


Fig. 25. Small Season Integral (2012)

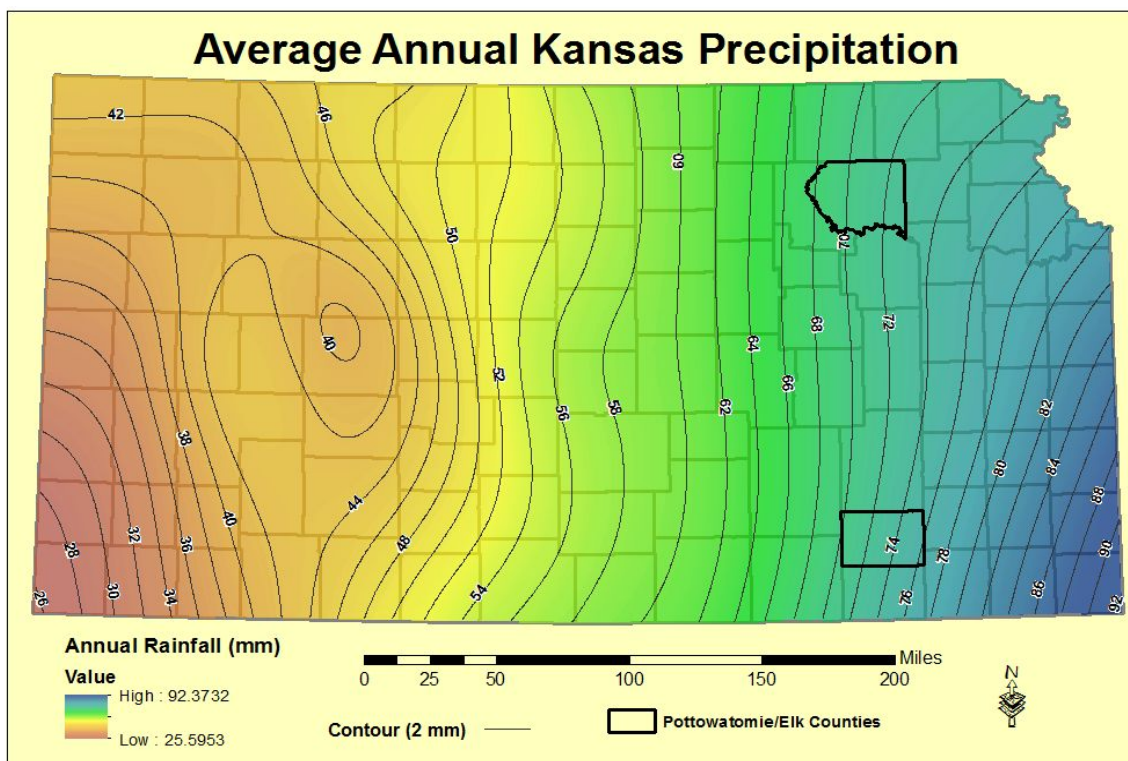


Fig. 26. Average annual precipitation throughout Kansas

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