Sustainable Grazing ColoradoView Spring 2017

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Project Overview:

The Pawnee National Grasslands are designated as an area of ecological concern in terms of Colorado's endangered, indigenous species such as the Mountain Plover or *Charadrius montanus*. The Mountain Plover relies on a proportional amount of shortgrass prairie for nesting and bare soil for hunting (He et al., 2006). Fledgling success is shown to be related to drought conditions, which determine proportion and health of shortgrass species (Yackel Adams, et al., 2006). The balance of bare ground and shortgrass depends on the amount of grazing upon the land, which used to be maintained by wild bison (White et al., 2009). In more recent years, there has been significant decline in shortgrass due to alternating as well as simultaneous effects of drought, changes in fire regimes, and over-grazing (Finch, 2012); it is difficult to monitor and distinguish between these multiple factors (Yackel Adams et al., 2006). Shortgrass is considered to be the highest priority vegetation species for conservation in Colorado prairies (Rondeau et al., 2011). By monitoring drought conditions, one can identify decreasing trends in NDVI when drought is not present which may indicate potential over-grazing. However, when drought is present, the effects of such can be analyzed by the severity of drought in comparison to the significance of the decrease in NDVI to determine any other potential influences on NDVI. This study follows the methodology developed by Wan et al., 2004.

Objectives and Goal:

Our primary objective is to assess drought conditions within the Pawnee National Grasslands (Figure 1) between 2012 and 2016 using Aqua/MODIS 8-day reflectance (250 m) and thermal (1000 m) composites. Using a simple ratio of Land Surface Temperature (LST) to the Normalized Difference Vegetation Index (NDVI), drought conditions can be identified at a given point within the growing season due to the tightly coupled relationship between these factors (Tian, Miao, Pengxin Wang, and Jahangir Khan, 2016). The goal for this study is to produce a data product that will be useful in a model of "real-time drought" (Patel et al., 2011; Wan Z., P. Wang, and X. Li, 2004) so that agricultural management in the Pawnee National Grasslands can implement a proactive response that preserves short-grasslands and its rare and indigenous species.

Questions:

- Has drought been present in the Pawnee National Grasslands between 2012 and 2016?
- If drought is present, what is the severity of such incidents?
- If drought is not present and NDVI deviates from the median for a given 8-day period, can grazing be determined as the cause?

Methodology:

- Download Aqua/MODIS data from https://reverb.echo.nasa.gov/reverb
- Identify agricultural growing season in Colorado
- Derive NDVI from Aqua/MODIS surface reflectance data using IDL
- Identify median NDVI for each 8-day composite using RStudio and write the value for each pixel out to a ".csv" file
- Determine the seasonal peak of NDVI through the most frequent peak date among all pixels in each year

- Derive surface temperature (LST) in Celsius using the conversion units ((Pixel Value * 0.02) – 273)
- Identify median LST for each 8-day composite
- Examine plots of median NDVI, LST, and LST/NDVI over each season
- Identify estimated lag time in vegetation response to daily precipitation events

Datasets:

- Growing season from May 1st through October 1st for 2012 through 2016
- Aqua/MODIS (V006) 8-day reflectance composites (MYD09A1) at 250 m
- Aqua/MODIS (V006) 8-day thermal composites (MYD11A2) at 1,000 m
- Precipitation data from https://www.cocorahs.org/WaterYearSummary
- Monthly Palmer Drought Severity Index from http://www.ncdc.noaa.gov/cag/

Final Products:

- Time lapse of NDVI 2012 - 2016
- Median NDVI comparison 2012 - 2016
- 2012 and 2013 median NDVI, LST, and LST/NDVI
- Analysis of 2012 and 2013 utilizing precipitation data

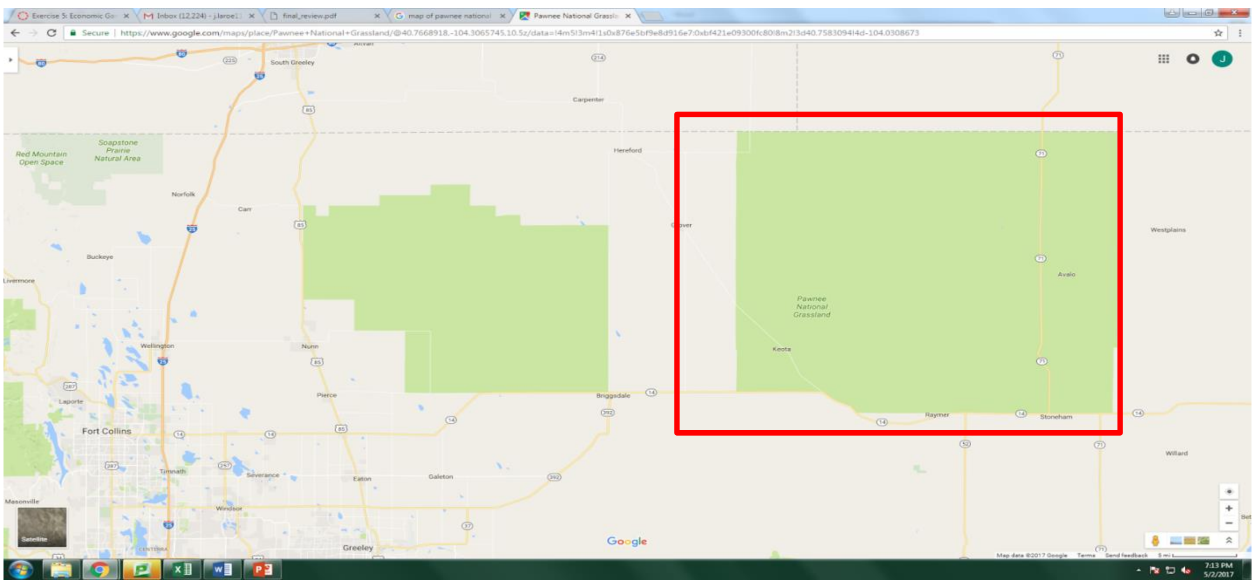

Figure 1. Selected study area within the Pawnee National Grasslands, image credited to **www.googlemaps.com**

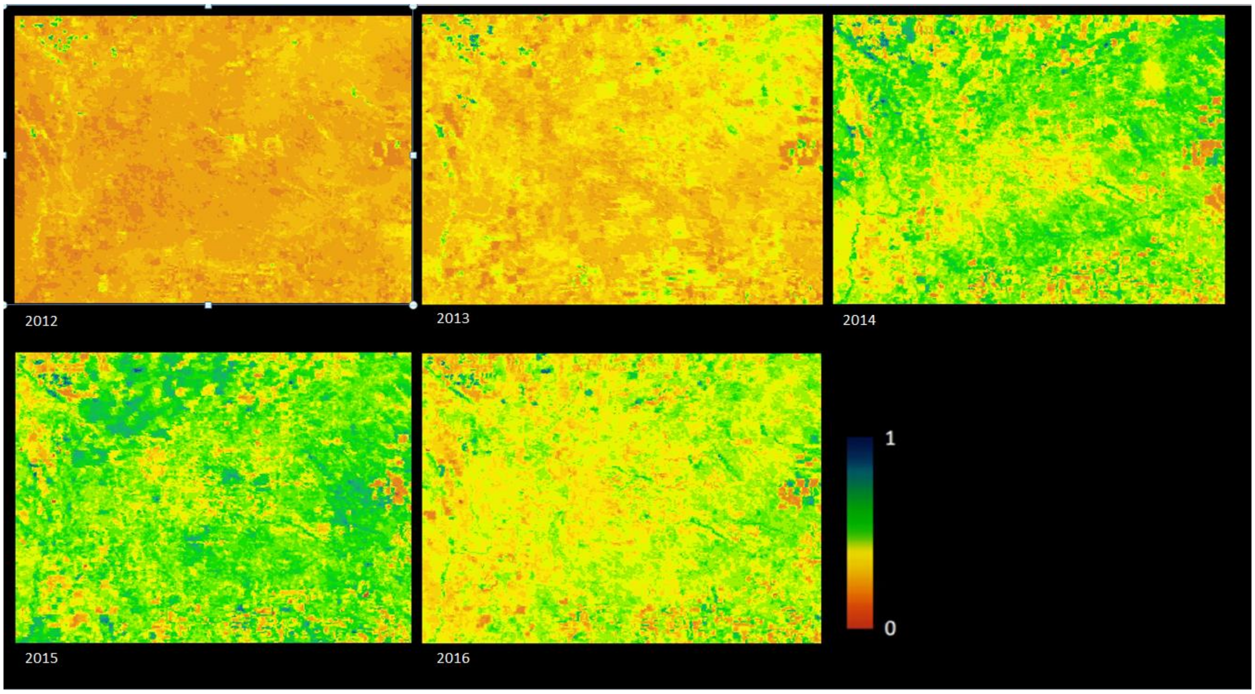

Figure 2. Median NDVI for each 8-day composite covering the peak of the growing season, June 9th/10th for each given year in the Pawnee National Grasslands.

By comparing Figure 2 with a land cover map, it was confirmed that the pixels that attain NDVI values greater than 0.7 (dark green to blues) are irrigated croplands. The dramatic differences between growing seasons and points with the greatest vulnerability are evident.

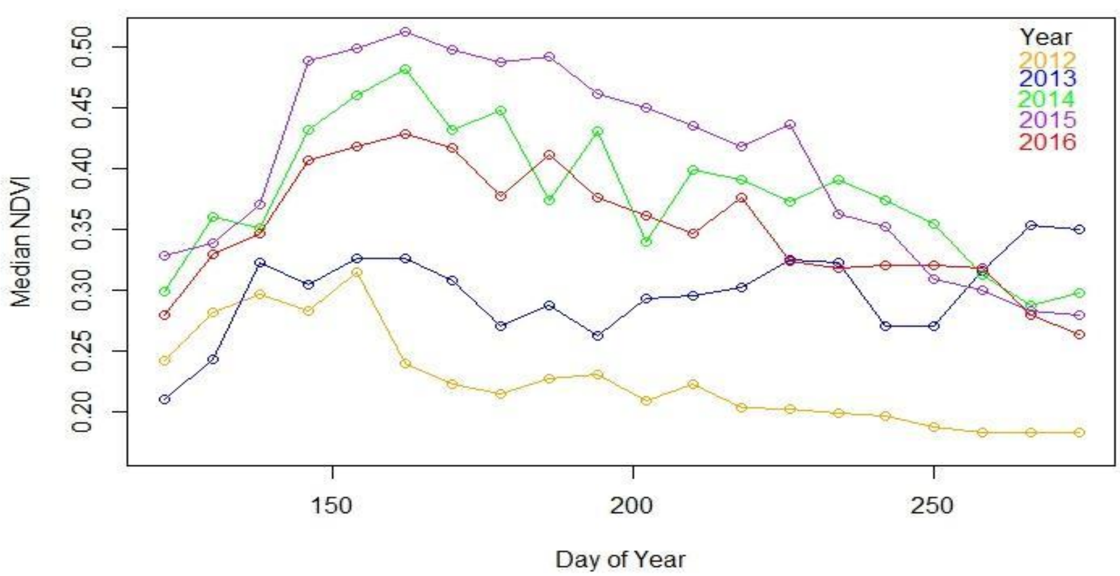

Figure 3. Median NDVI for each 8-day NDVI composite in the Pawnee National Grasslands for 2012 through 2016.

As seen in Figure 3, the peak of the growing season occurs most commonly during June 9th/10th (Julian dates 160/161 through 168/169) with the only exception to this being 2013. Precipitation data in 2013 indicated that peak NDVI occurred September 22nd (Julian 266) due to rainfall at the start of the month. Vegetation was highly sensitive to precipitation inputs from the extended and severe drought beginning in 2012 which was classified as an extreme drought year by the Palmer Drought Severity Index (PDSI) (Table 1). In contrast, 2014 was classified as extremely moist by the PDSI. However, the peak NDVI data does not follow the same ranking order as the PDSI.

Table 1. Palmer Drought Severity Index of Platte Drainage region retrieved from *"Monthly Palmer Drought…"(NCEI).*

Year	PDSI Value	Rank for Oct. 2011-Oct. 2016 Period	Departure from Mean (1.05) in Oct. 2011- Oct. 2016 Base Period	Rank for Past 30 Years (Oct. 1986-Oct. 2016)	Departure from Mean (0.44) of Past 30 Years (Oct. 1986-Oct. 2016)
2011	2.32	3	1.27	23	1.88
2012	-4.84	1	-5.89	2	-5.28
2013	3.14	4	2.09	25	2.70
2014	4.67	6	3.62	30	4.23
2015	3.98	5	2.93	29	3.54
2016	-1.7	2	-2.75	8	-2.14

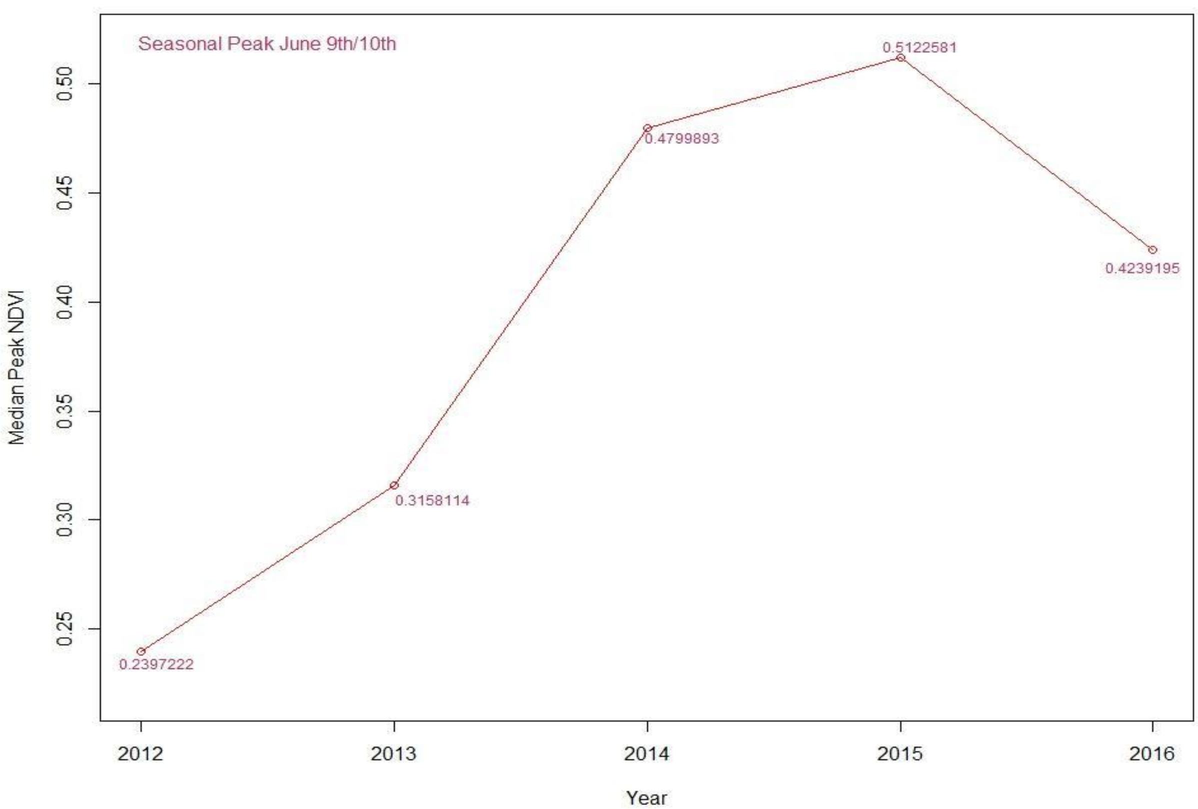

Figure 4. Change in peak (June 9th/10th) median NDVI between 2012 and 2016 for the Pawnee National Grasslands.

As shown in Figure 4, the median peak NDVI in 2015 is more than twice the value in 2012. This demonstrates the potential range of peak NDVI with 2015 representing one of the wettest years and 2012 representing the one of the most extreme droughts in this region (when ranked upon the past 30 years by PDSI).

As a result of the dry conditions, the High Park Fire began June 9th in 2012, and ended approximately 3 weeks later. This fire occurred in the mountains of northwest Colorado and was the second largest wildfire in Colorado history. The edge of the burn extent was only 43 miles from the Pawnee National Grasslands. It would be worthwhile to explore if air pollution from smoke can have an effect (if so, to what extent or radius) on the surrounding vegetation health.

Table 2. Cumulative precipitation and snowfall (inches) for the 2011-2012 and 2012-2013 Water Year Summary from Station CO-WE-335 (Briggsdale 0.6 NW) and Station CO-WE-81 (located in order of: 40.635228 N, -104.327929 E and 40.9753 N, -104.3063 E) nearest the Pawnee National Grasslands.

2011-2012 Water Year			2012-2013 Water Year		
Month	Cumulative Precipitation (inches)	Cumulative Snow Fall (inches)	Month	Cumulative Precipitation (inches)	Cumulative Snow Fall (inches)
Oct. 2011	0	0	Oct. 2012	0	0
Nov. 2011	0.17	0	Nov. 2012	0	0
Dec. 2011	0.22	1	Dec. 2012	0	0
Jan. 2012	0.22	1.2	Jan. 2013	0	0
Feb. 2012	0.44	7.4	Feb. 2013	0.36	5.5
Mar. 2012	0.44	7.4	Mar. 2013	0.59	12
Apr. 2012	0.44	7.4	Apr. 2013	2.01	24
May. 2012	0.54	7.4	May. 2013	2.84	27.5
June. 2012	1.54	7.4	June. 2013	2.84	27.5
July. 2012	3.62	7.4	July. 2013	2.84	27.5
Aug. 2012	3.62	7.4	Aug. 2013	2.84	27.5
Sept. 2012	4.2	7.4	Sept. 2013	4.98	27.5

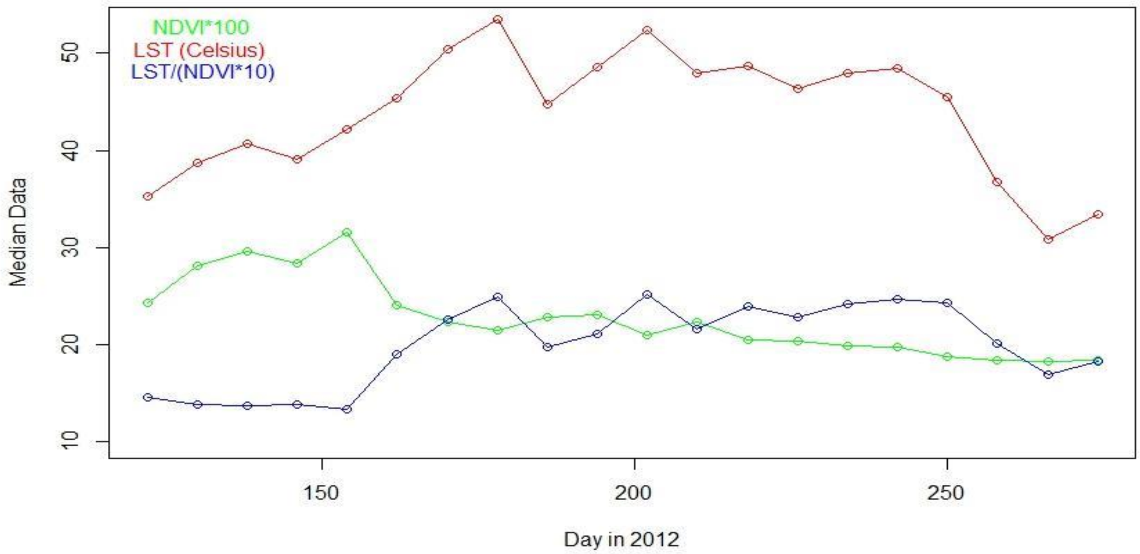

Figure 5. Median NDVI, LST, and simple ratio of LST/NDVI from each pair of 8-day composites scaled to show on single plot for the Pawnee National Grasslands in the 2012 growing season.

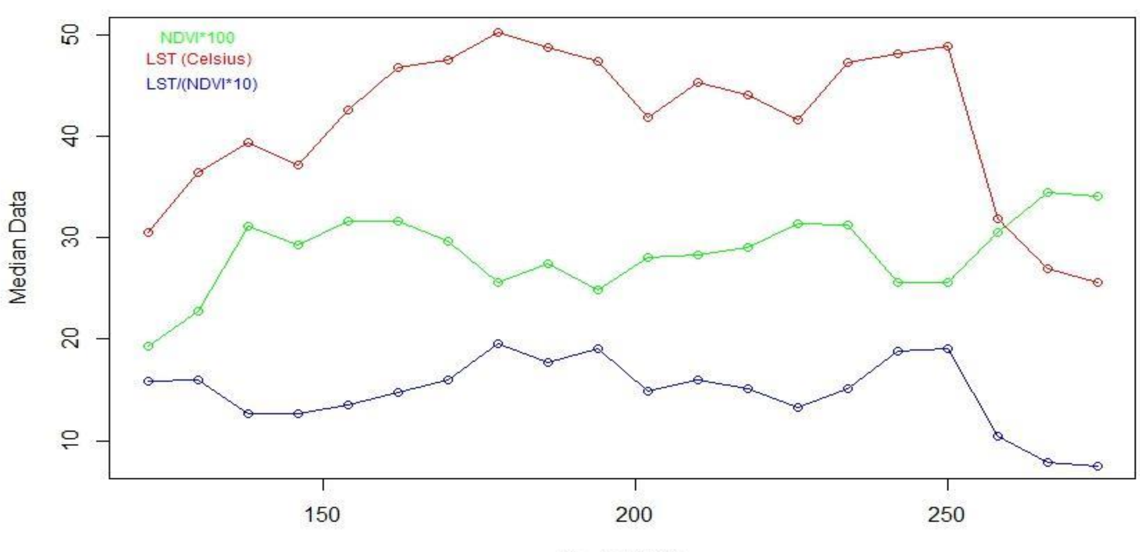

Figure 6. Median NDVI, LST, and simple ratio of LST/NDVI from each pair of 8-day composites scaled to show on single plot for the Pawnee National Grasslands in the 2013 growing season.

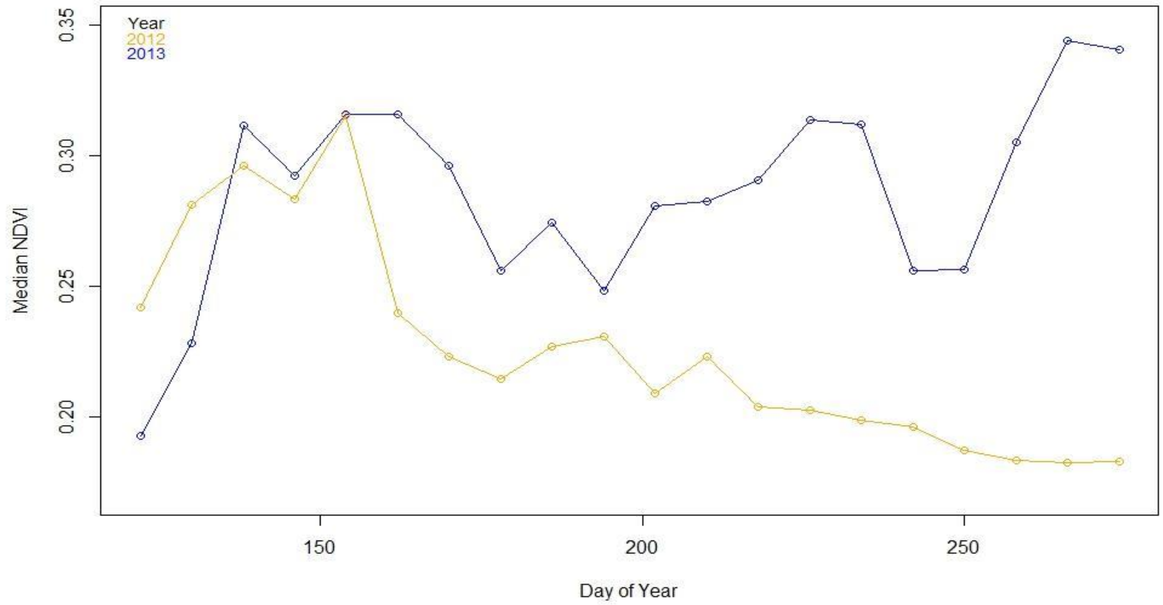

Figure 7. Comparison of median NDVI values in 2012 and 2013 for each 8-day composite through the growing season in the Pawnee National Grasslands.

Table 3. Precipitation (inches) for the 2011-2012 and 2012-2013 Water Year from Station CO-WE-335 (Briggsdale 0.6 NW) and Station CO-WE-81 (located in order of: 40.635228 N, -104.327929 E and 40.9753 N, -104.3063 E) nearest the Pawnee National Grasslands.

Water Year 2011-2012	Precipitation (inches)	Water Year 2012-2013	Precipitation (inches)
11/3/2011	0.17	2/21/2013	0.26
12/22/2011	0.05	2/24/2013	0.1
2/3/2012	0.12	3/9/2013	0.05
2/11/2012	0.2	3/10/2013	0.01
5/6/2012	0.1	3/12/2013	0.05
6/7/2012	1	3/23/2013	0.03
7/7/2012	0.6	3/24/2013	0.04

7/8/2012	1	3/31/2013	0.05
7/25/2012	0.2	4/9/2013	0.2
7/26/2012	0.19	4/10/2013	0.27
7/30/2012	0.09	4/14/2013	0.4
9/12/2012	0.3	4/15/2013	0.03
9/13/2012	0.28	4/16/2013	0.31
		4/21/2013	0.11
		4/23/2013	0.05
		4/29/2013	0.05
		5/1/2013	0.25
		5/9/2013	0.58
		9/10/2013	0.69
		9/11/2013	0.13
		9/12/2013	0.06
		9/13/2013	0.17
		9/14/2013	0.99
		9/15/2013	0.01
		9/16/2013	0.09
Total Precipitation (inches)	4.3		4.98

By comparing Table 2 and Table 3 with the median NDVI data of 2012 and 2013 (in Figure 7), it is clear that vegetation generally has a slight lag time in response to precipitation. The severe drought in 2012 produced a shorter NDVI response time (less than 8 days) than in 2013(8 days +). The interesting trend is the increase of this lag time throughout each of the the growing seasons. NDVI responses to precipitation are shorter early in the growing season, and increase through the growing season. In 2012, severe drought decreased vegetation response time to precipitation, but it followed the same increasing trend through the season.

In 2013 (Figure 6), the peak NDVI occurred on September 22nd, which was the only year with the peak not occurring around June 9th/10th. This peak was seen due to the intense precipitation events between September 10th and 16th, which added two inches of precipitation. Here, the lag time in vegetation response of such events is seen within 8 days. However, lower evapotranspiration rates and the dramatic decrease in LST during September were also responsible for the peak of NDVI in September.

There were major differences in soil water storage leading into the growing seasons of 2012 and 2013 which resulted in dramatic difference between median NDVI values of the two years. Although rainfall was similar between these two years during the growing season, the lack of soil water reserves (lack of preceding winter snowfall) produced very different responses in NDVI throughout each season. Figure 5 and Figure 6 indicate drought at various times through each season by the increasing trends in LST/NDVI. However, the response of NDVI to precipitation events in 2012 was more pronounced, possibly due to the recovery from the high stress conditions through the growing season.

Time Lapse of NDVI 2012-2016

This time lapse video can be viewed by opening the following link. To view in higher quality, please download the video.

https://drive.google.com/file/d/0B1tosTA3BIPuWFZCMDBqc1JMTWc/view?ts=59a07403

Conclusions

PDSI may not be the best indicator of real-time drought or accurately reflect vegetation health. It is based on the current values of precipitation for the year and does not account the timing of those precipitation events. Vegetation is very sensitive to changes in precipitation in years with high drought indications or high amounts of stress, so the lag time of NDVI will be shorter due to the lack of water reserves. Evapotranspiration rates rise with increased surface temperatures, which allow LST/NDVI to be a good indication of current drought. Through this ratio used in 2012, along with precipitation data, it appears drought was the most influential factor on NDVI values.

Further studies are needed to detect grazing impacts. A potential option for such would be estimating percent cover at the seasonal peak of NDVI for each year, and then estimating change in percent cover after a period of grazing on a particular plot. This could also be examined through the season as well using known grazing plots, but a model that accurately predicts short grass cover would be necessary. By estimating percent cover of each vegetation species through randomly sampled plots each containing a 5m radius, this will provide insight on how species composition is changing each year in relation to drought events. It appears that blue gramma tends to become the dominant species within a plot that is exposed to heavy grazing conditions according to David Augustine when questioning him about his research in the Pawnee National Grasslands. Blue gramma is a C4 plant which will best resist drought conditions (having the capability to moderate evapotranspiration rates with their stomata) and is quick reproduce. This study will continue further utilizing combined efforts with David Augustine and other USGS researchers to compare and analyze research.

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Final Reflection (LaRoe)

By analyzing current drought conditions and improving a model for real-time drought analysis, agricultural systems can provide a more proactive response to such. This would assist land management teams in their pursuit of conservation of rare species and better preserve shortgrass prairies. In contrast to models like the Palmer Drought Severity Index (PDSI) which only provides drought information based on a yearly or monthly water supply, this method for analyzing vegetation's response to drought more accurately reflects the current state of an ecosystem.

I started out fairly new to working with spatial data. I had not downloaded nor had a carried a research project from start to finish. I selected a larger scale project in hopes that the results could be useful to others researching the Pawnee National Grasslands. The biggest challenges came from the learning curve I faced and the overall scope of the project I selected.

These products could have potential use in developing a model for real-time drought monitoring. My next ideal step would be to develop a program in R that pulls the latest daily MODIS data and runs these tests with an additional Vegetation Temperature Condition Index (VTCI) to monitor real-time drought. This would involve a change from the publication of MODIS data, which would need to publish data weekly instead of the following year, combined with methodology to automate and standardize the fitted regression process for VTCI (. This program could simplify the process for new or unfamiliar RStudio users and allow the analysis to be performed daily to monitor current drought conditions at any given time.

Analyzing the variation of lag time response of NDVI to drought indications given by VTCI, this method could develop a vegetation classification system based upon the differences in species evapotranspiration rates. This method could potentially give an initial indication of short grass, shrub/scrub land, cropland, etc. through the differences in drought resistance. This would not be an effective method in areas that do not experience drought or areas with dense vegetation cover in which NDVI is no longer a good indicator. There is potential to provide proactive responses to drought and more accurate analyses (instead of the current method of driving between ranchers and farmers to ask how conditions are and making land management decisions based off of the accounts).