Changing Fire Regimes and Management Strategies

Southern Climate Impacts Planning Program
University of Oklahoma
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1. Introduction

Fire is a natural and common part of the landscape in the South Central Plains. Native Americans were the first in North America to understand that in order to prevent woody encroachment in the grasslands, it was necessary to set fires to the land (Stewart 2002). However, in modern times, fire suppression and urban development in the Plains have allowed some species, such as various juniper trees, to spread quickly throughout the prairies and grasslands, reducing the natural biodiversity of the region (Ansley and Rasmussen 2005). This increased fuel load has created a risk for hotter and more damaging wildfires. Climate projections have shown that drought and temperature is expected to rise in this area, further increasing wildfire risk (Liu et al. 2013, Shafer et al. 2014).

Prescribed burning is a management tool used to reduce fuel loads and lessen the risk of severe wildland fire across the South Central Plains, but little is known about the change in weather conditions suitable for these days over time. To conduct a prescribed burn, weather conditions must be in a certain safety range. For example, there must be enough wind to start a fire and allow the smoke plume to disperse, but excessively strong winds would allow the fire to grow out of control. A rising issue is climate change, for if prescribed burns are only safe within a distinct threshold, then changing climate conditions may alter this small window of opportunity. This project documents the seasonal and inter-annual variability of suitable burn conditions across the South Central Plains region of Nebraska, Kansas, Oklahoma, and Texas. Prescribed Burn Associations from the included states were contacted for minimum and maximum thresholds of temperature, wind speed, and relative humidity in order to obtain the appropriate values for data analysis. Hourly data for the time period of 1996-2015 were analyzed in order to produce a climatological analysis of burn conditions, and a glimpse into future conditions indicates a potential change in the frequency of these suitable burn conditions by the end of the century.

2. Methodology

2.1 Prescribed Burn Associations

To begin the climatological analysis, it was first mandatory to gather information from all possible Prescribed Burn Associations in the region of Nebraska, Kansas, Oklahoma, and Texas. Desired information included thresholds of temperature, wind speed, and relative humidity that the associations used to determine if weather conditions were favorable for a safe prescribed burn (Table 1). Some Prescribed Burn Associations have additional criteria, such as number of days between precipitation events, soil moisture, or fuel load. Because these were not uniform across the region, only temperature, wind speed, and relative humidity which were defined at all Prescribed Burn Associations were used in the analysis. If weather conditions fell within their threshold for a consecutive four-hour period, then that day was considered to be a suitable burn day with low risk of wildland fire danger. Some states, such as Nebraska, had a statewide set of thresholds, while others, like Oklahoma, had a potential set of thresholds for the state that could be altered depending on experience of the team, equipment, and location (Oklahoma Cooperative Extension Service 2015). Of all of the Prescribed Burn Associations contacted throughout the region, there were 4 responses from Nebraska, 2 from Kansas, 6 from Oklahoma, and 5 from Texas. A map of all Prescribed Burn Associations in the region is shown in Figure 1.

Table 1. Prescribed Burn Association (PBA) weather thresholds

State	PBA/ Region	Temperature (°F)	Wind Speed (mph)	Relative Humidity (%)	Rainfall
NE	Entire state	35-80	5-20	25-75	
KS	Eastern KS	55-80	5-15	40-70	4+ inches
	Western KS	40-110	5-20	15-70	
OK	Big Pasture PBA / SW OK	35-95	5-15	30-70	
	Northwest Range Fire Management Assoc. / NW OK	60-95	5-20	15-45	
	Arbuckle Restoration Assoc. / S Central OK	35-95	5-20	20-60	
	Indian Territory PBA / NE OK	35-95	5-15	30-80	
	Cross Timbers PBA / Central OK	35-90	5-15	30-60	
	North Central Range Improvement Assoc. / N Central OK	35-100	5-15	40-80	
	Pontotoc Ridge PBA / Central – SE OK	35-100	5-15	30-80	
TX	West Central TX PBA / W Central TX	35-100	6-23	20-60	A month of little to no rain in summer
	Southwest TX	50+	6-23	50+	
	South TX PBA / S TX	40-85	5-15	25-60	None 7 days prior to burning

	Edwards Plateau – Hill Country PBA / Central TX	40+	5-15	10-55	
	South Central TX PBA / S Central TX	35-90	6-23	20-60	

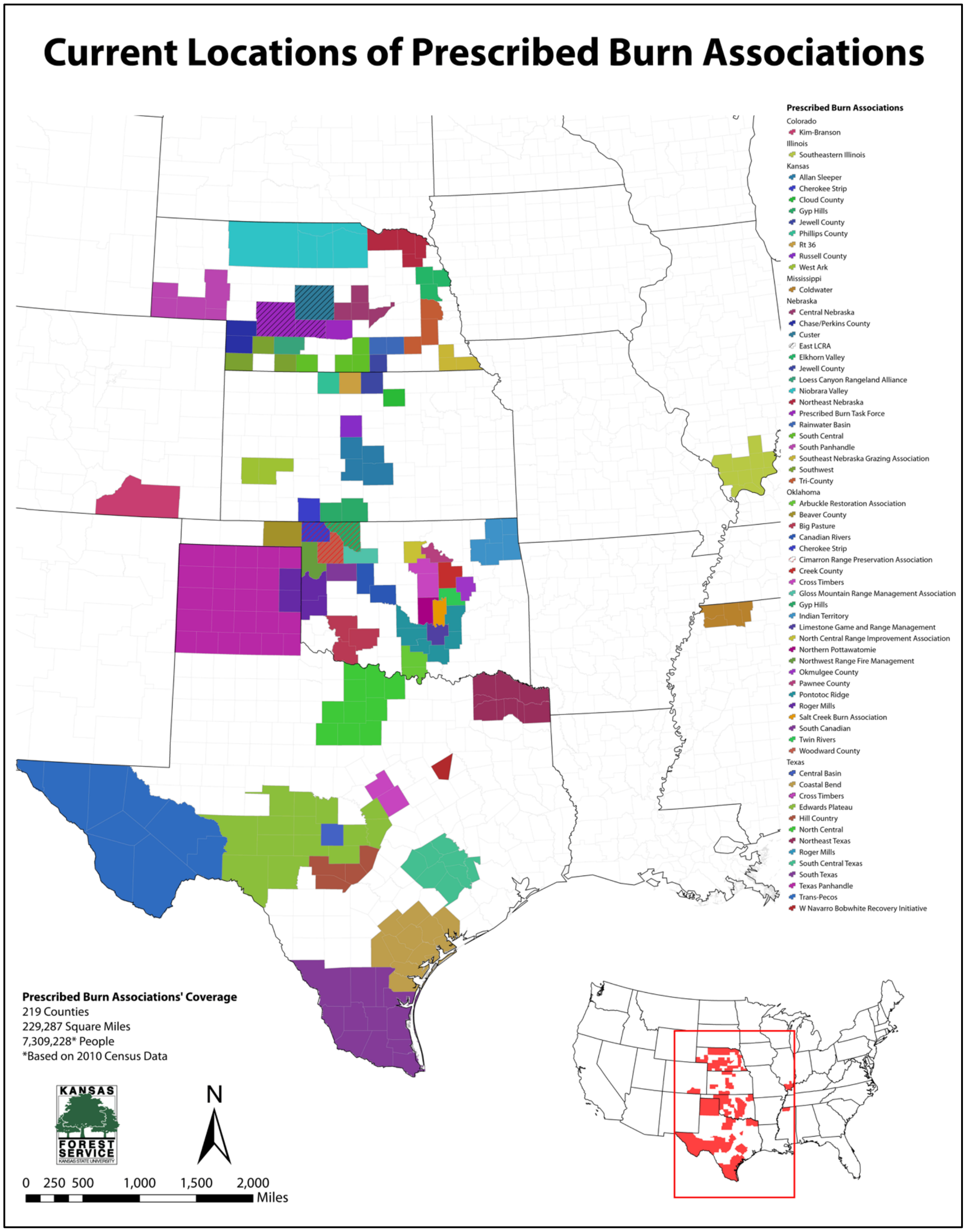


Figure 1. Locations of Prescribed Burn Associations in the region

2.2 Data Gathering and Manipulation

Once the responses were received from the Prescribed Burn Associations, temperature, wind speed, and dew point data were gathered from the National Centers for Environmental Information (NCEI) Integrated Surface Data. This included hourly observations for all Automated Surface Observing Systems (ASOS) that had data available from 1996-2015. In total, there were 43 ASOS stations that met these criteria. Because there were only 4 available ASOS stations in Oklahoma with this timeframe, data from 8 stations in the Oklahoma Mesonet were used to supplement the ASOS data to provide a better spatial representation of the state and obtain sufficient data for analysis. Note that the Mesonet temperature record began in 1997. Each ASOS and Mesonet station was then matched to the Prescribed Burn Association of that location in order to assign the appropriate weather thresholds. Once all data were gathered, it was imported and organized in Microsoft Excel.

The ASOS station data included temperature and dew point temperature in degrees Fahrenheit and wind speed in miles per hour. Because relative humidity was not provided, it was necessary to convert the temperature and dew point temperature to calculate vapor pressure (1) and saturation pressure (2) for the computation of relative humidity (3).

$$e = 6.11 \times 10 \exp\left[\frac{7.5 \times T_d}{273 + T_d}\right] \tag{1}$$

$$e_s = 6.11 \times 10 \exp\left[\frac{7.5 \times T}{273 + T}\right] \tag{2}$$

$$RH = \frac{e}{e_s} \times 100 \tag{3}$$

The Mesonet data included temperature, wind speed, and relative humidity.

2.3 Data Analysis

R Studio software was used for data analysis. First, all Mesonet data were provided in 5-minute intervals, which had to be reduced to hourly data in order to be equivalent to the hourly ASOS data. Once this was complete, the code was operational for all 49 stations. After missing data were removed, each station's data were reduced to only include values that fell within the appropriate Prescribed Burn Association's threshold for weather conditions suitable for a safe burn. For example, the Wichita, Kansas station fell within a Prescribed Burn Association's jurisdiction that required temperature to remain between 55-80°F, wind speed to be in the range of 5-15 mph, and relative humidity to occur in the 40-70% range. Therefore, after the code was implemented, all data that fell outside these boundaries were removed, leaving only suitable weather conditions. This process of matching the station to a Prescribed Burn Association's specific set of thresholds was repeated for each station.

Weir (2011) discussed that most prescribed burns are conducted between 8 AM and 6 PM. Most burns last from 2-4 hours, depending on the size of the area burned and characteristics of the land and vegetation. With this information, the data were further reduced to only include this time frame. The goal of this study was to discover if the frequency of suitable burn days has changed over this 20-year time period; therefore, if at least one consecutive 4-hour period in the day had weather conditions suitable for a prescribed burn, then that day was classified as a suitable burn day with low risk of wildland fire. Then, it was possible to analyze seasonal and inter-annual variability. To find seasonal variability for each station, the program counted the average number of suitable burn days per month from 1996-2015. Inter-annual variability was found by counting the yearly totals of suitable burn days for the period.

2.4 Climate Change Estimation

Part of this project focused on how the frequency of suitable burn days could alter in the future under changing climate conditions. This study provides only a rough estimation of average monthly frequency, however, it does provide a general idea of the possible future seasonality. The Nature Conservancy created the Climate Wizard, an interactive graphic of the globe and the United States, overlaying the IPCC Fourth Assessment categories for temperature changes under a High (A2), Medium (A1B), or Low (B1) emission scenario (Girvetz et al. 2009). The user can also select a General Circulation Model and choose a time period of the past 50 years, mid-century, or end-of-century estimations to view (Figure 2).

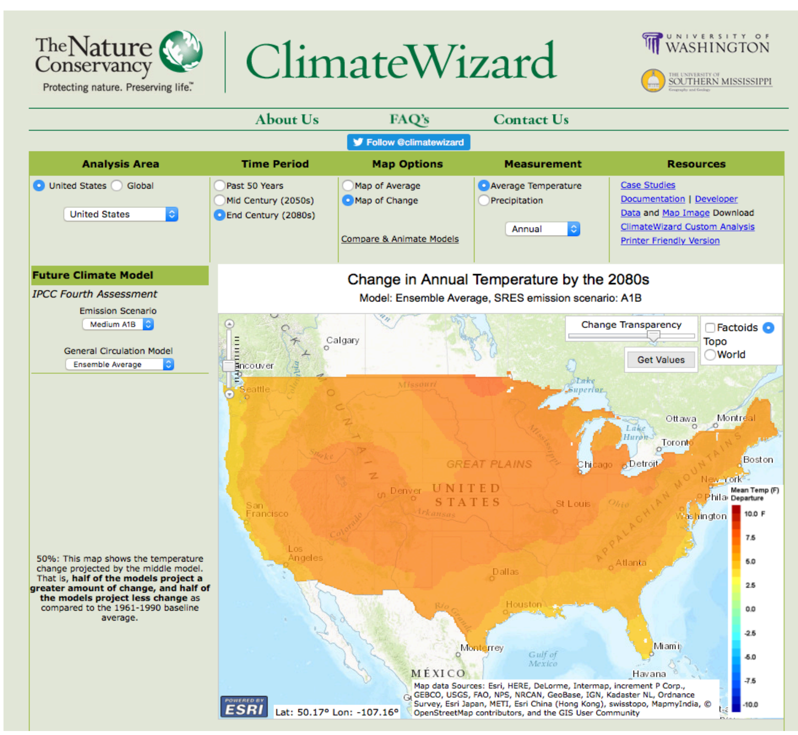


Figure 2. Climate Wizard tool for end-of-century temperature change

For this analysis, the end-of-century average temperature change was found for each station's location under a medium emission scenario (A1B) and model ensemble average. Each station's temperature change was then added to the entire temperature column in the original dataset. For example, Wichita, Kansas was estimated to have a 7°F average temperature change, so this value was added to every hourly observation in the ASOS data. Next, the code was run again with these new temperature values, using the same Prescribed Burn Association thresholds shown previously, to determine the future average monthly frequency of suitable burn days. While there will be differential changes throughout the day and seasons, this rough estimate was used as a simple thought exercise. A more rigorous process using downscaled climate projections should be used for planning purposes.

In addition, 9 stations were selected to explore how the frequency would differ for mid-century projections. Continuing to use Wichita, Kansas as an example, the average temperature change was estimated to be 4.5°F. The code was run with the thresholds used previously to find the average monthly frequency of suitable burn days for mid-century. With this information, it was hoped that stakeholders in the area may benefit from this estimation of the trend of the number of days suitable for conducting prescribed burns.

3. Results

For each station, a bar plot was generated for the average monthly frequency of suitable burn days from 1996-2015 to represent the location's seasonality. Again, note that the Mesonet stations' analysis began in 1997. A line plot was also created to display the inter-annual variability for the time period by showing the yearly total of suitable burn days. In addition, a bar plot was produced for a climate change estimation of the end-of-century average monthly frequency for each station, and another bar plot was constructed for a mid-century representation for 9 stations. Table 2 includes the annual results using weather thresholds for each Prescribed Burn Association used for the analysis.

Table 2. Number of suitable burn days per year using nearest Prescribed Burn Association criteria.

State	City	Minimum	Maximum	Average	Range
NE	Omaha	86	178	143.3	92
NE	Lincoln	120	170	150.3	50
NE	Grand Island	139	193	156.6	54
NE	Norfolk	119	180	151.7	64
NE	North Platte	130	183	156.8	53
NE	Scottsbluff	116	166	143.6	50
KS	Wichita	2	15	8.3	13
KS	Chanute	1	8	3.7	7
KS	Dodge City	180	222	199.5	42
KS	Topeka	26	69	47.2	43
KS	Russell	153	221	191.5	68
KS	Salina	17	50	33.4	33
KS	Goodland	190	227	205.9	37
KS	Hill City	176	254	220.9	78

OK	Hobart	67	138	113	71
OK	Oklahoma City	87	158	133.9	71
OK	Tulsa	149	216	181.4	67
OK	McAlester	165	236	207.5	71
OK	Breckinridge	69	130	105.1	61
OK	Hinton	42	100	62.1	58
OK	Lahoma	37	96	58.8	59
OK	Mt Herman	83	125	104.1	42
OK	Red Rock	66	136	114.3	70
OK	Tipton	74	150	114.8	76
OK	Westville	135	215	177.2	80
OK	Woodward	64	104	81.8	40
TX	Port Arthur	45	149	101.2	104
TX	Houston	73	154	115.9	81
TX	Lufkin	92	164	124.3	72
TX	Longview	8	175	123.2	167
TX	Corpus Christi	30	61	43.5	31
TX	Kingsville	21	78	46.5	57
TX	Cotulla	27	94	66.2	67
TX	San Antonio	105	161	130.2	56
TX	Victoria	37	88	56.7	51
TX	Palacios	25	73	49.9	48
TX	Waco	97	178	140.5	81

TX	Grapevine	148	243	195.8	95
TX	Fort Worth	141	249	192.4	108
TX	Mineral Wells	94	250	185.5	156
TX	Del Rio	49	88	71	39
TX	San Angelo	196	246	221.2	50
TX	Midland	182	248	224.2	66
TX	Wink	16	67	39.7	51
TX	Abilene	174	249	213.6	75
TX	Lubbock	197	239	218.4	42
TX	El Paso	6	35	20.5	29
TX	Wichita Falls	111	173	135.4	62
TX	Amarillo	167	242	202.9	75

3.1 Nebraska

Nebraska's seasonality was fairly consistent between stations, with the lowest frequency of suitable burn days being in the winter and summer months, having a bimodal distribution. April, September, and October were typically the months with the highest frequency in the state. These months included approximately 15 to 19 days suitable for conducting prescribed burns on average. An example from Lincoln and North Platte can be found below in Table 3 and Figure 3. The yearly frequency of the Nebraska stations ranged from 86 to 193 days per year that were suitable for prescribed burns. Each station had little inter-annual variability and no significant trend over time, with a correlation coefficient near zero. For example, Lincoln and North Platte's yearly frequency plots are displayed in Figure 4.

Table 3. Average monthly data for (a) North Platte, NE and (b) Lincoln, NE

	(a) North Platte				(b) Lincoln			
Month	Highest Frequency	Lowest Frequency	Range	Average Frequency	Highest Frequency	Lowest Frequency	Range	Average Frequency
1	13	5	8	**8.4**	17	1	16	**8.1**
2	15	4	11	**8.7**	14	3	11	**8.8**
3	21	9	12	**13**	19	5	14	**13.5**
4	22	12	10	**16.1**	20	12	8	**16.6**
5	25	14	11	**18.9**	21	12	9	**16.9**
6	23	6	17	**15.0**	18	5	13	**12.0**
7	15	2	13	**7.5**	14	2	12	**6.4**
8	18	5	13	**10.9**	17	2	15	**8.7**
9	22	11	11	**15.3**	22	9	13	**15.4**
10	26	13	13	**18.6**	25	13	12	**19.7**
11	21	6	15	**14.9**	22	9	13	**15.1**
12	16	2	14	**9.8**	18	2	16	**9.4**

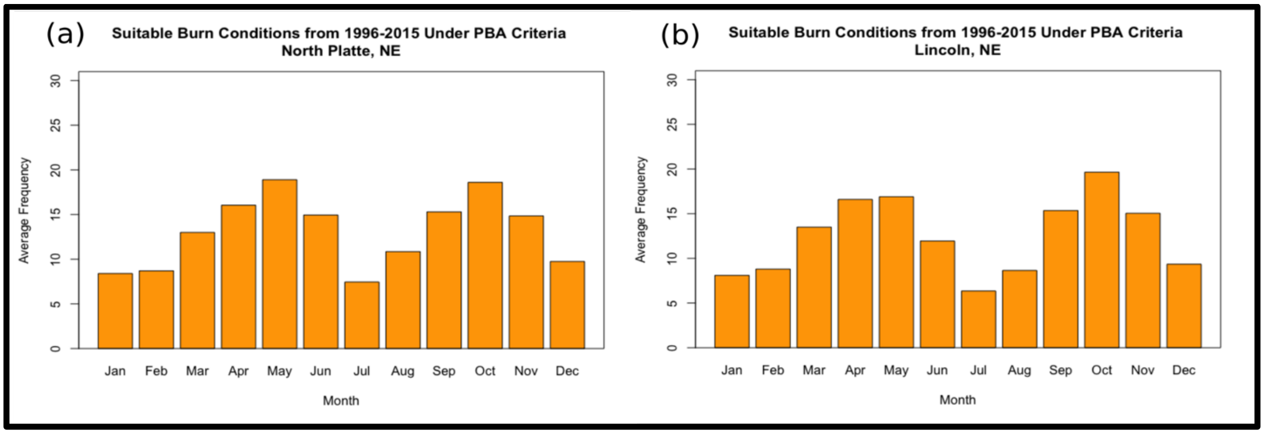
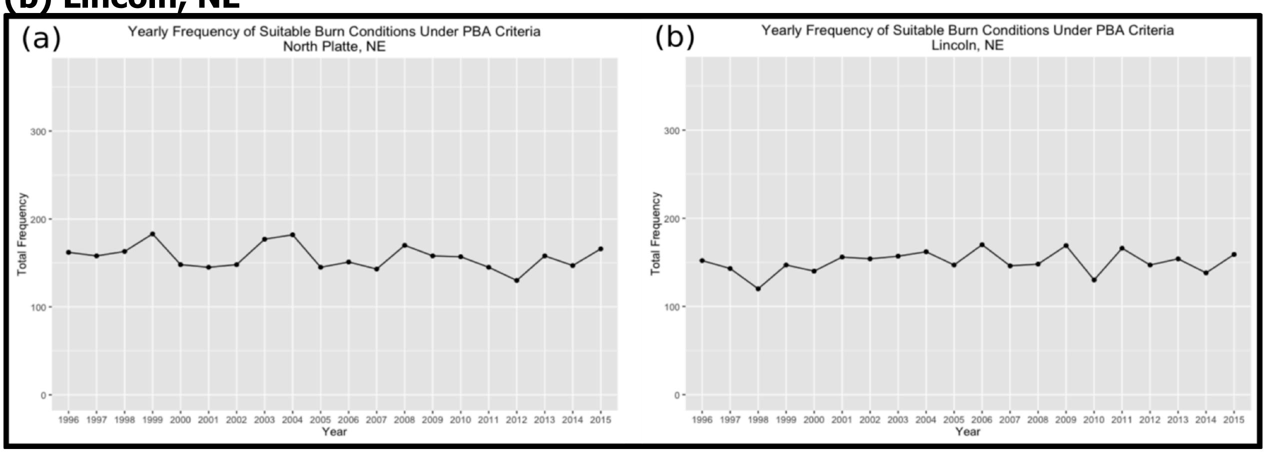


Figure 3. Monthly average suitable burn days for (a) North Platte, NE and (b) Lincoln, NE

Figure 4. Annual number of suitable burn days for (a) North Platte, NE and (b) Lincoln, NE



3.2 Kansas

Responses from Kansas Prescribed Burn Associations exhibited two categories of thresholds for suitable burn days: one threshold for eastern Kansas and another for western Kansas. This created two characteristics in seasonality across the state. Stations in eastern Kansas had smaller ranges for prescribed fire criteria for all three variables (temperature, wind, and relative humidity); consequently, there were fewer hours on any given day within a burn window causing fewer days in any month or year to be within acceptable parameters. All stations had a suitability of fewer than 5 days per month, except for two stations that had a slight peak in the spring and fall. However, even these stations remained below 10 suitable days during those months. Western stations yielded different results, having the highest frequency of suitable burn days in the late summer and early fall of approximately 25 days per month. Winter held the lowest suitability, however, these months were still higher than eastern stations. This is evident in Table 5 that displays monthly average data for Dodge City and Topeka. An example of the differences between eastern and western stations is shown in Figure 5 for Topeka and Dodge City.

These results are comparable to yearly frequency as well. Figure 6 demonstrates the distinct difference between western and eastern station frequency, with western Kansas having many more opportunities for prescribed burns than eastern Kansas. Yearly frequencies ranged from 1-69 days in eastern stations and 153-254 days in western stations. This is likely due to the difference in Prescribed Burn Association thresholds, which had a 30°F maximum temperature difference and a 25% minimum relative humidity difference. Inter-annual variability of each station was not significant and there was no trend over the time period, having a correlation coefficient near zero.

Table 5. Average monthly data for (a) Dodge City, KS and (b) Topeka, KS

	(a) Dodge City, KS				(b) Topeka, KS			
Month	Highest Frequency	Lowest Frequency	Range	Average Frequency	Highest Frequency	Lowest Frequency	Range	Average Frequency
1	18	7	11	**10.6**	2	1	1	**1.5**
2	15	4	11	**9.8**	2	1	1	**1.2**
3	21	9	12	**13.9**	7	1	6	**3.2**
4	20	10	10	**15.4**	9	1	8	**5.3**
5	24	12	12	**18.8**	17	3	14	**8.9**
6	23	14	9	**18.9**	9	1	8	**5.2**
7	28	19	9	**23.7**	8	2	6	**4.2**
8	29	17	12	**24.3**	12	1	11	**4.2**
9	24	16	8	**19.4**	13	3	10	**7.7**
10	25	10	15	**18.5**	17	1	16	**7.6**
11	22	7	15	**15.0**	8	1	7	**3.9**
12	17	6	11	**11.4**	3	1	2	**1.5**

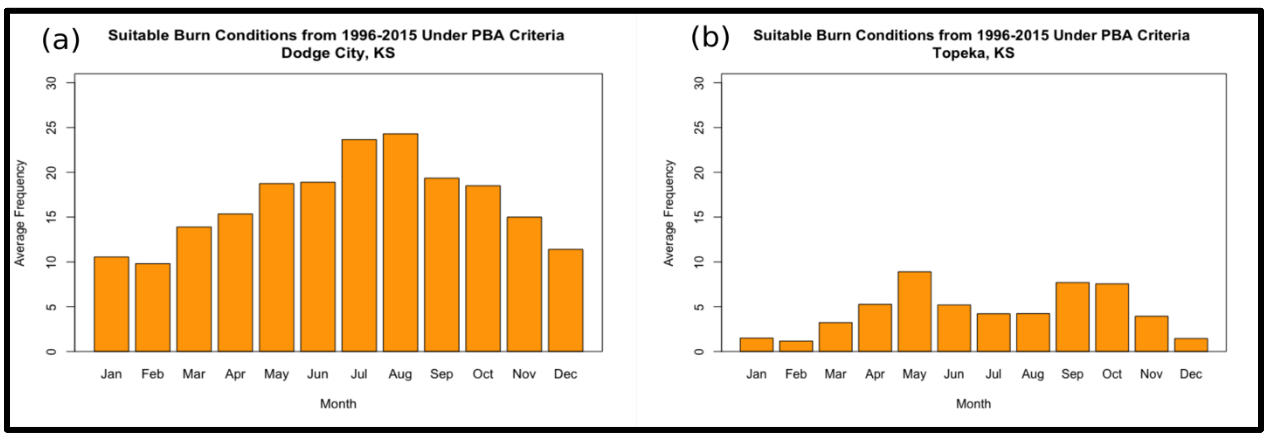


Figure 5. Monthly average suitable burn days for (a) Dodge City, KS and (b) Topeka, KS

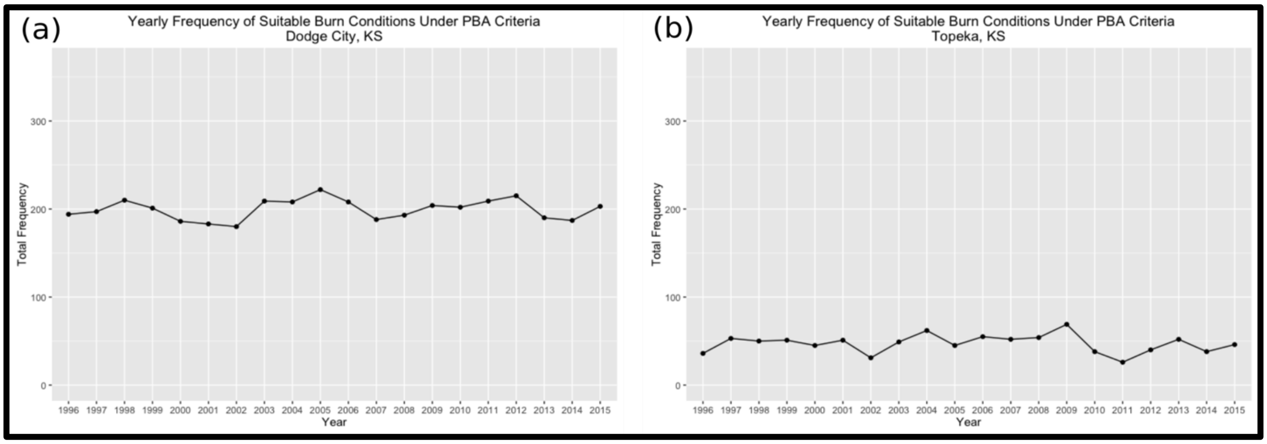


Figure 6. Annual number of suitable burn days for (a) Dodge City, KS and (b) Topeka, KS

3.3 Oklahoma

There were only 4 available ASOS stations in Oklahoma, therefore, 8 Mesonet stations were selected based on their locations to add a more complete picture to the state. Furthermore, there were 6 Prescribed Burn Associations that responded to this project with their weather thresholds for suitable burn conditions. There was not a response for the Tulsa area Prescribed Burn Association, so this area's thresholds were interpolated from surrounding thresholds in order to estimate the Tulsa Metropolitan area frequencies. Therefore, stations were categorized into 7 regions. Maximum temperature thresholds were higher than in Nebraska and Kansas, ranging from 90-100°F.

Stations in the northwest portion of the state had a higher minimum temperature threshold of 60°F, versus 35°F that all other areas included, which could explain the lower average monthly frequencies in that area (Table 7a and Figure 7a). In addition, northwest Oklahoma has a higher average wind speed, which also likely impacted their suitability for prescribed burns. All other regions in the state had higher average monthly frequencies for suitable burn conditions. McAlester, OK ranged from approximately 11 to 23 suitable days per month, which suggests that most months of the year have a reasonable chance of having a low wildfire risk, or the ability to safely conduct a prescribed burn (Table 7b and Figure 7b). Overall, Oklahoma's peak season for prescribed burns was summer, while winter had the least days per month for safe burns. However, most stations' seasonality trend of average monthly frequency was not as noticeable as Nebraska and Kansas. As for inter-annual variability, there was no significant trend over time for any station, with the correlation coefficients still near zero. Plots of the previous examples of Woodward and McAlester are displayed in Figure 8.

Table 7. Average monthly data for (a) Woodward, OK and (b) McAlester, OK

	(a) Woodward, OK				**(b) McAlester, OK**			
Month	Highest Frequency	Lowest Frequency	Range	Average Frequency	Highest Frequency	Lowest Frequency	Range	Average Frequency
1	5	1	4	**2.1**	18	4	14	**11.3**
2	5	1	4	**2.1**	17	6	11	**11.9**
3	13	1	12	**5.7**	19	6	13	**13.9**
4	17	4	13	**9.4**	24	8	16	**15.9**
5	14	4	10	**8.4**	27	15	12	**21.2**
6	17	1	16	**7.3**	28	16	12	**22.8**
7	13	2	11	**7.1**	29	14	15	**22.9**
8	13	2	11	**8.7**	28	15	13	**22.6**
9	16	8	8	**12.7**	23	12	11	**18.8**
10	18	4	14	**11.3**	22	12	10	**17.8**
11	12	2	10	**6.8**	22	10	12	**15.3**
12	3	1	2	**1.9**	23	4	19	**13.6**

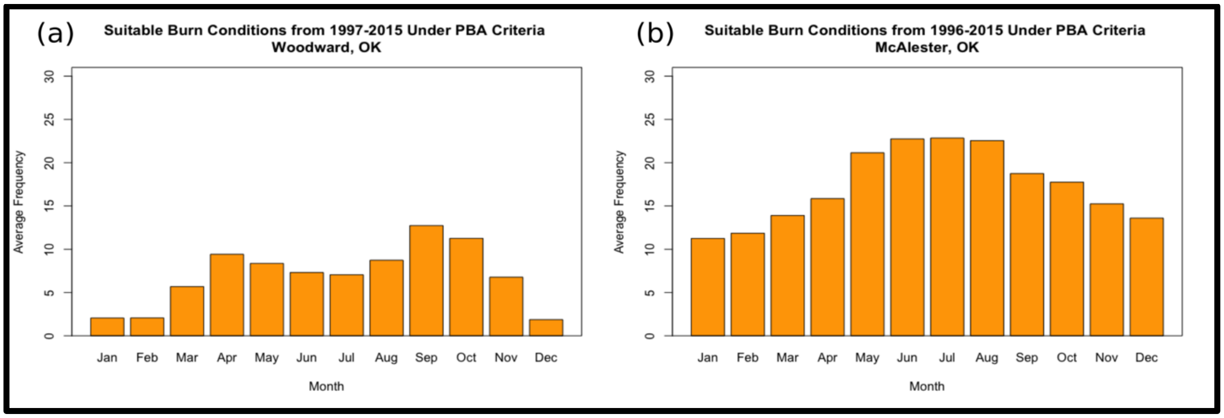


Figure 7. Monthly average suitable burn days for (a) Woodward, OK and (b) McAlester, OK

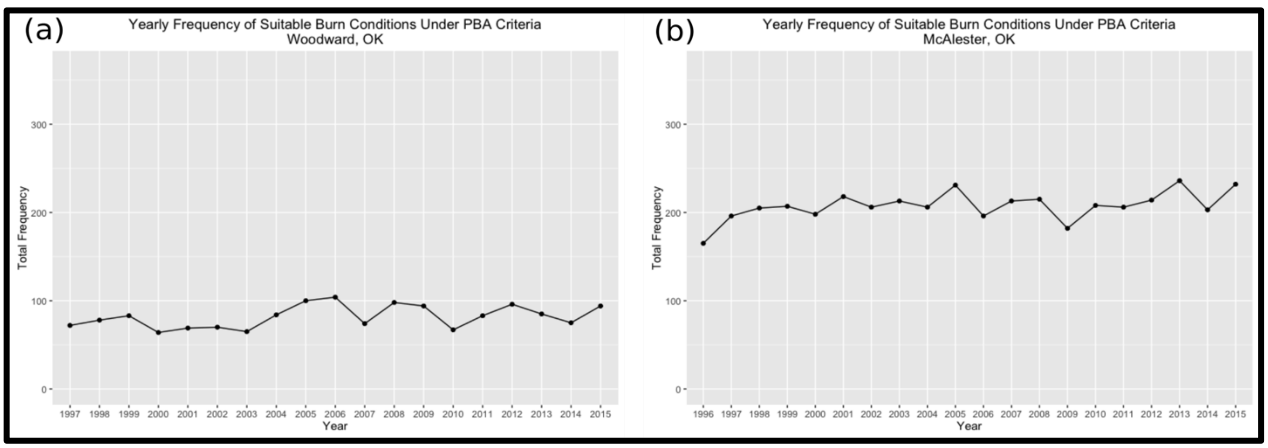


Figure 8. Annual number of suitable burn days for (a) Woodward, OK and (b) McAlester, OK

3.4 Texas

There were 26 ASOS stations with the available data in Texas, and 5 Texas Prescribed Burn Associations responded to this study with their weather condition thresholds. There were no thresholds implemented statewide because Texas is very diverse, but the Texas Commission on Environmental Quality did state that wind should remain in the bounds of 6 to 23 mph and there should be no atmospheric temperature inversion at the time of the burn (Texas Commission on Environmental Quality 2015).

All stations in west central Texas had a relatively high frequency of suitable burn days year-round, with most stations in this area exceeding 11 days per month for all months and a peak in the summer of up to 25 suitable days per month (Tables 9 and 10b, Figures 9 and 10b). While there was not a Prescribed Burn Association response in northern Texas, stations in this area were nearest to the west central Texas region. For example, Wichita Falls and Fort Worth were categorized here and experienced highest frequencies in the summer as discussed for west central Texas stations. It could be estimated from these stations and those in southern Oklahoma that north Texas stations include a peak in late summer with reasonable opportunity for burns year-round. Stations that fell in the south central Texas area had a greater number of suitable burn days per month in the spring and fall, but there was not a dramatic decline in the winter season like was seen in other states. For example, see Table 10b and Figure 10b. This region ranged from 2 to 18 days per month that were suitable for prescribed burns on average.

Southern Texas had a distinct shift in seasonality, with a rapid decline in burn days during summer months. This may be attributed to higher humidity levels common along the Gulf Coast in summer. These months typically had fewer than 5 days that were suitable for burning. Unlike other regions and states that have been examined thus far, this area had the highest frequency of average suitable burn days in the winter months but the overall monthly frequency ranged from 0 to 12 days. Examples can be found in Appendix A.

There were a few stations that fell in the southwest Texas/Alpine region, including El Paso, TX. With the very dry and hot climate in this area, the Prescribed Burn Association did not classify a maximum temperature or maximum relative humidity. Therefore, if any day held conditions that were above the minimum threshold for these parameters and were within wind criteria, the day was considered a suitable burn day. The minimum allowed temperature and relative humidity for prescribed burning here was higher than in other Texas regions. Monthly average frequency ranged from 1 to 7 days, where the peak months were August through September. Winter months experienced the least opportunity for burns.

There was inter-annual variability in Texas, however, correlation coefficients were still very low for most stations. Fort Worth was the only station that exhibited a clear trend of frequency over time, with a correlation coefficient of 0.8 (Figure 11b). Mineral Wells and Junction had correlation coefficients of 0.5 which was not as strong of a signal to give confidence of a statistically significant trend. Stations in the south central Texas Prescribed Burn Association experienced their lowest yearly total frequency in 1997-1998, which may be explained by the 1997-1998 El Niño that affected the state as well as a drought that occurred in those years (Changnon 1999). This feature is seen in Figure 12b. While many Texas stations exhibited a yearly frequency of at least 100 suitable burn days (Figure 11), south Texas stations had a range of only 21 to 94 days per year with burning opportunities.

Table 9. Average monthly data for (a) Amarillo, TX and (b) Fort Worth, TX

	(a) Amarillo, TX				**(b) Fort Worth, TX**			
Month	Highest Frequency	Lowest Frequency	Range	Average Frequency	Highest Frequency	Lowest Frequency	Range	Average Frequency
1	19	9	10	**13.5**	22	2	20	**13.5**
2	17	7	10	**10.9**	21	3	18	**12.1**
3	19	9	10	**14.4**	23	9	14	**15.0**
4	20	7	13	**14.8**	22	11	11	**16.2**
5	21	7	14	**15.6**	25	8	17	**16.7**
6	25	13	12	**19.3**	26	13	13	**19.5**
7	29	19	10	**24.4**	27	10	17	**20.0**
8	28	15	13	**22.7**	28	12	16	**18.9**
9	27	13	14	**19.8**	22	2	20	**15.9**
10	25	13	12	**18.3**	24	8	16	**15.2**
11	21	8	13	**15.6**	23	5	18	**15.0**
12	23	6	17	**13.9**	22	7	15	**14.8**

Table 10. Average monthly data for (a) Midland, TX and (b) Houston, TX

	(a) Midland, TX				(b) Houston, TX			
Month	Highest Frequency	Lowest Frequency	Range	Average Frequency	Highest Frequency	Lowest Frequency	Range	Average Frequency
1	20	10	10	**15.4**	21	6	15	**12.0**
2	18	8	10	**12.85**	20	6	14	**11.8**
3	24	11	13	**15.55**	22	9	13	**14.0**
4	23	5	18	**15.45**	20	5	15	**14.8**
5	21	12	9	**17.1**	20	4	16	**12.2**
6	28	18	10	**23.15**	12	1	11	**4.6**
7	30	21	9	**25.25**	4	1	3	**2.1**
8	29	18	11	**24.65**	10	1	9	**2.9**
9	27	12	15	**21.1**	23	1	22	**8.0**
10	26	13	13	**18.8**	22	4	18	**12.8**
11	24	12	12	**18.3**	19	4	15	**12.1**
12	24	12	12	**16.55**	18	3	15	**11.4**

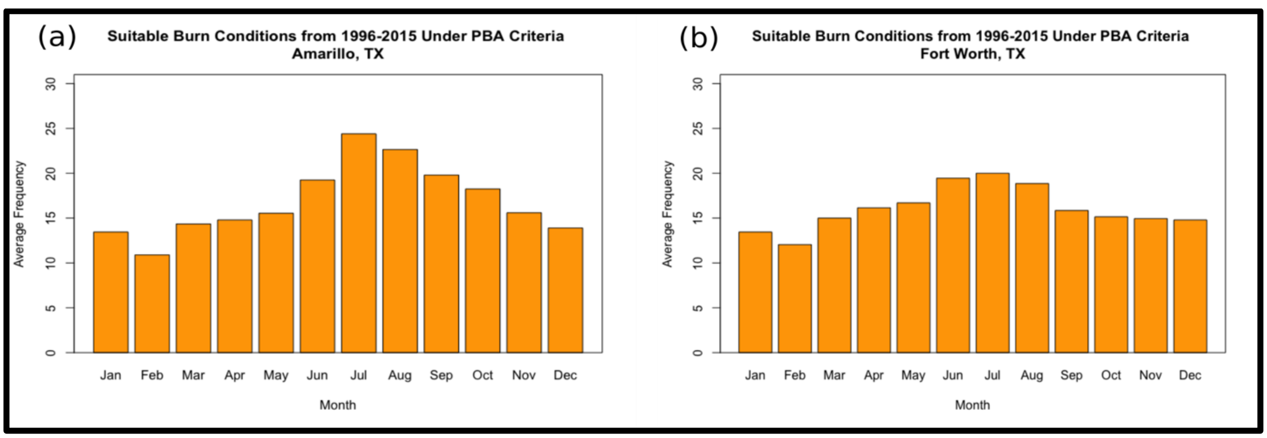


Figure 9. Monthly average suitable burn days for (a) Amarillo, TX and (b) Fort Worth, TX

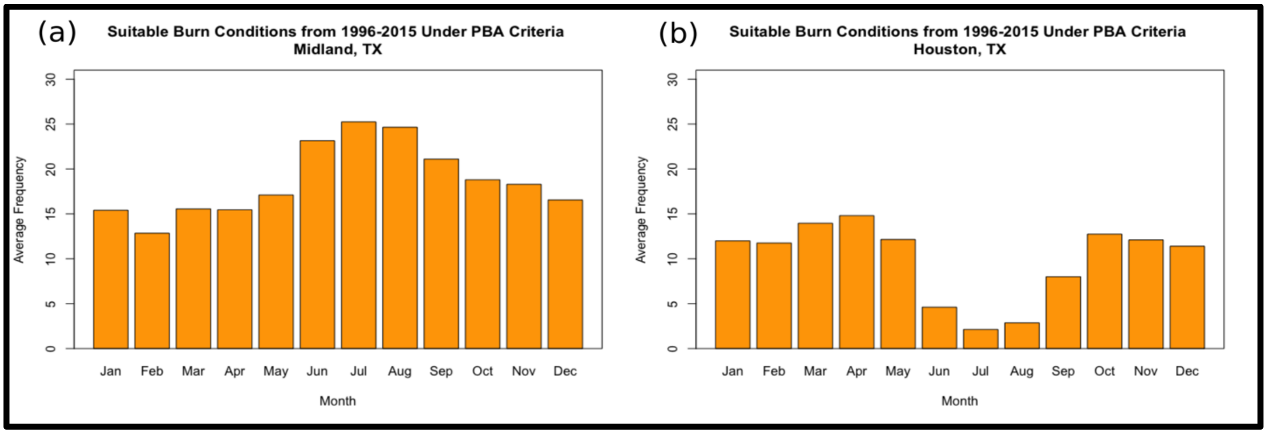


Figure 10. Monthly average suitable burn days for (a) Midland, TX and (b) Houston, TX

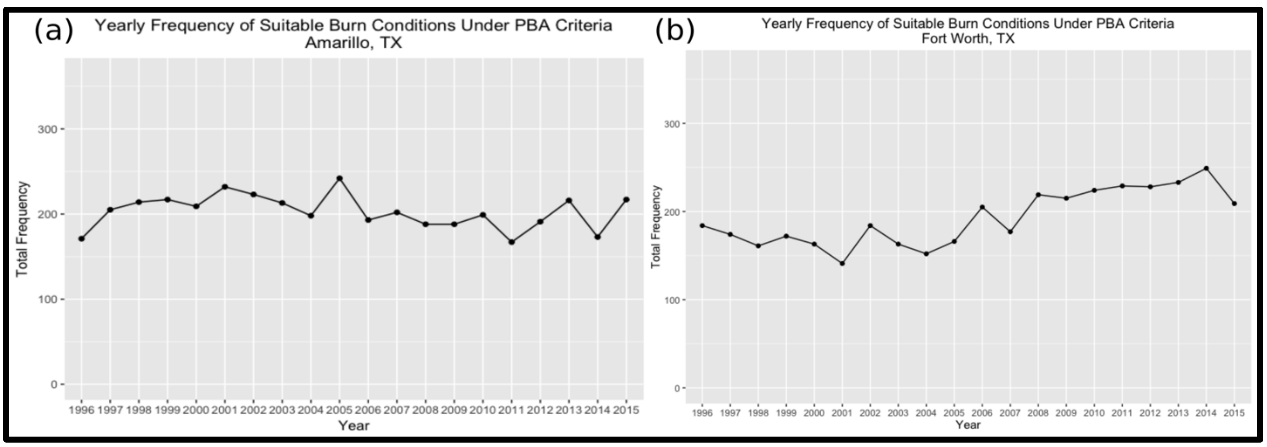


Figure 11. Monthly average suitable burn days for (a) Amarillo, TX and (b) Fort Worth, TX

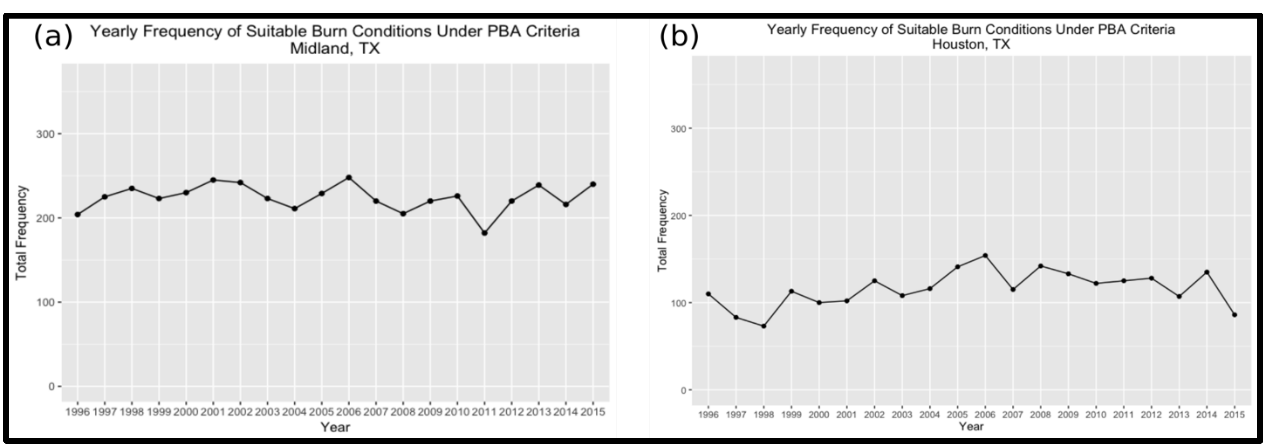


Figure 12. Monthly average suitable burn days for (a) Midland, TX and (b) Houston, TX

4. Spatial Variations

While these analyses are useful for individual locations and specific Prescribed Burn Associations, it is also interesting to look at spatial distributions of the climatology. Maps of the average number of suitable burn days were created from the ASOS and Mesonet station analyses using ArcMap, a GIS software. Two sets of spatial analyses were conducted: first using the nearest PBA criteria as discussed in the individual location discussion in Section 3 and second using a common threshold as described in section 4b.

4.1 Analysis using PBA Criteria

It is evident that there was much variability for frequencies of suitable burn days based on geographic location. The range of yearly frequency spanned from 4 to as many as 224 days per year from 1996-2015 across the study area. Figure 13 is a spatial representation of yearly average frequency from 1996-2015, with warmer colors characterizing a higher number of days with burning opportunities for Prescribed Burn Associations. Each point displays the location of an ASOS or Mesonet station. There was a clear trend of higher frequencies that occurred in a swath that stretched along the western side of Nebraska, Kansas, Oklahoma, and Texas and curved up through much of Texas to southeast Oklahoma. The data show that the eastern half of Kansas had much lower frequencies than the surrounding areas, which is likely due to the thresholds set by the Kansas Prescribed Burn Association. Another area of lower values included southern Texas, which has very high humidity values along the east coast and arid conditions to the far west. These spatial patterns are driven as much by local Prescribed Burn Association criteria as they are climatology. Areas with lower maximum temperature thresholds, in particular, were more limited even with small changes in actual climatology compared to neighboring areas.

Seasonality of the south central Plains can be seen in Figures 14-17. Average spring and fall frequencies were very similar, with the highest frequencies occurring in the same swath described previously. However, fall did have higher frequencies than spring. Summer experienced the largest range of frequencies. The same area of high frequencies in fall was intensified in the summer months, with a decline in suitable burn days in southern Texas and eastern Kansas and an increase along the swath described previously. Winter showed the smallest prospect for prescribed burning, with frequency decreasing in most areas. However, southern Texas had more burning opportunities in the winter than summer. One noticeable pattern in all seasons was eastern Kansas having much smaller frequencies than its surrounding areas. This was due to the differences in the Prescribed Burn Association's weather thresholds for that location, as mentioned previously.

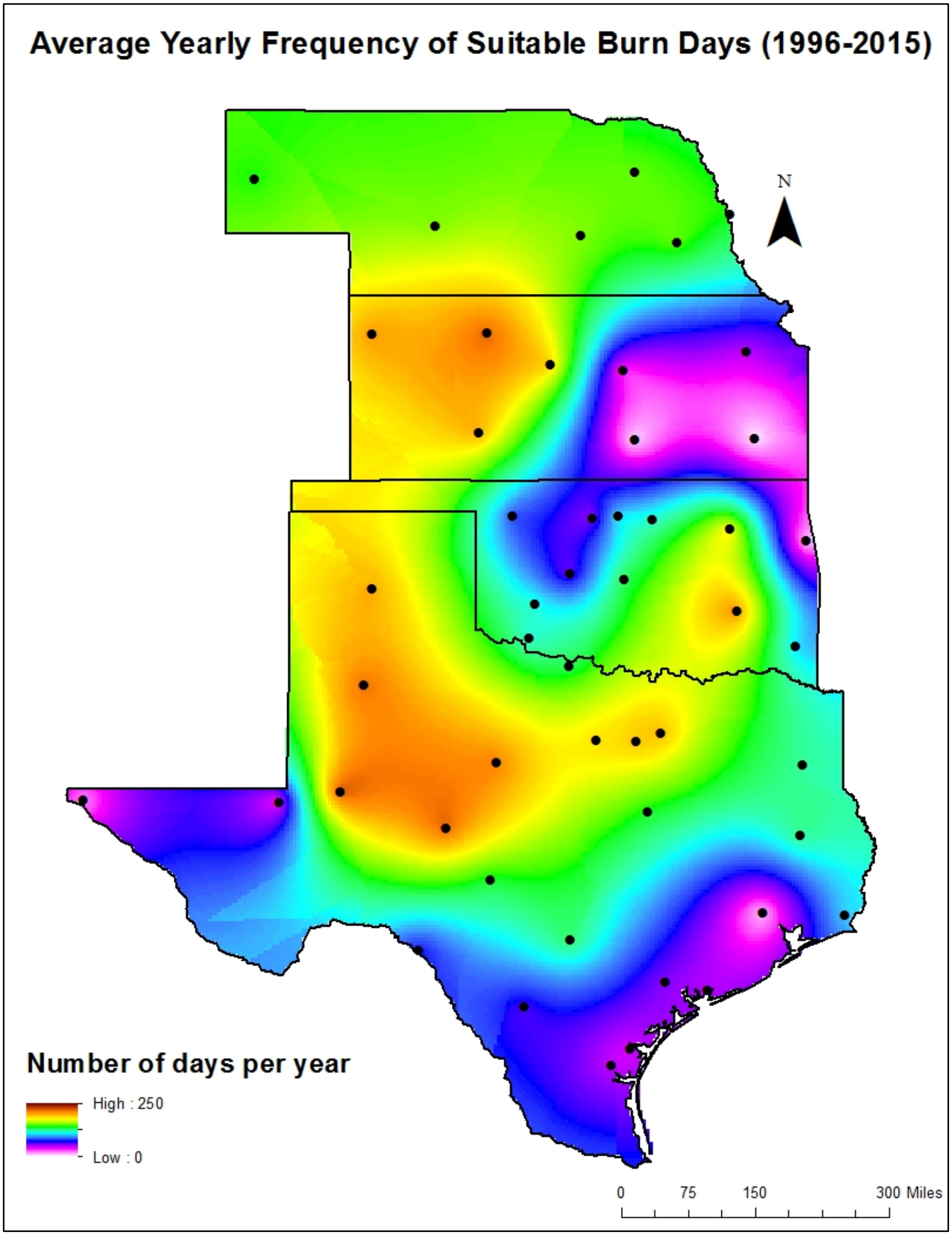


Figure 13. Spatial representation of average yearly frequency

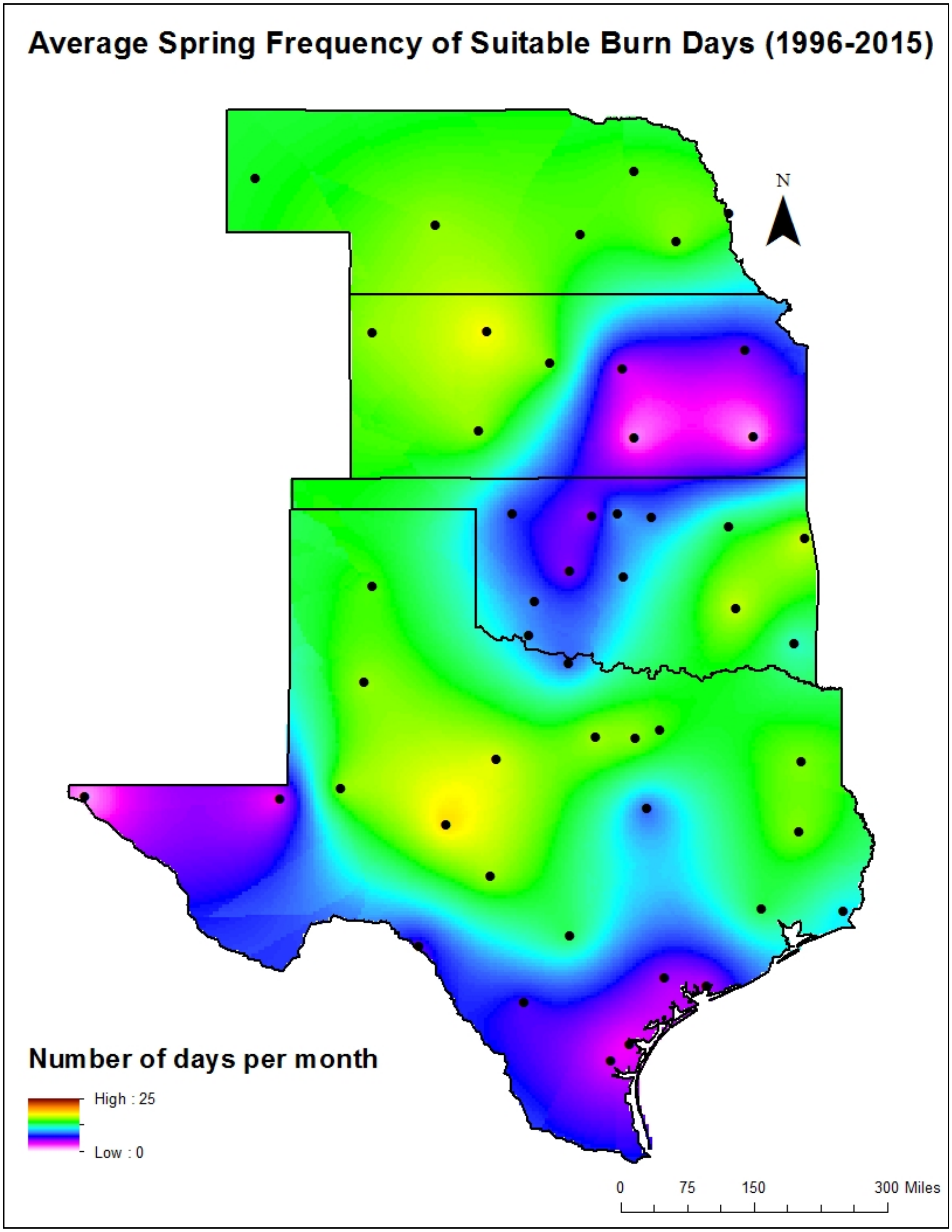


Figure 14. Spatial representation of average spring frequency

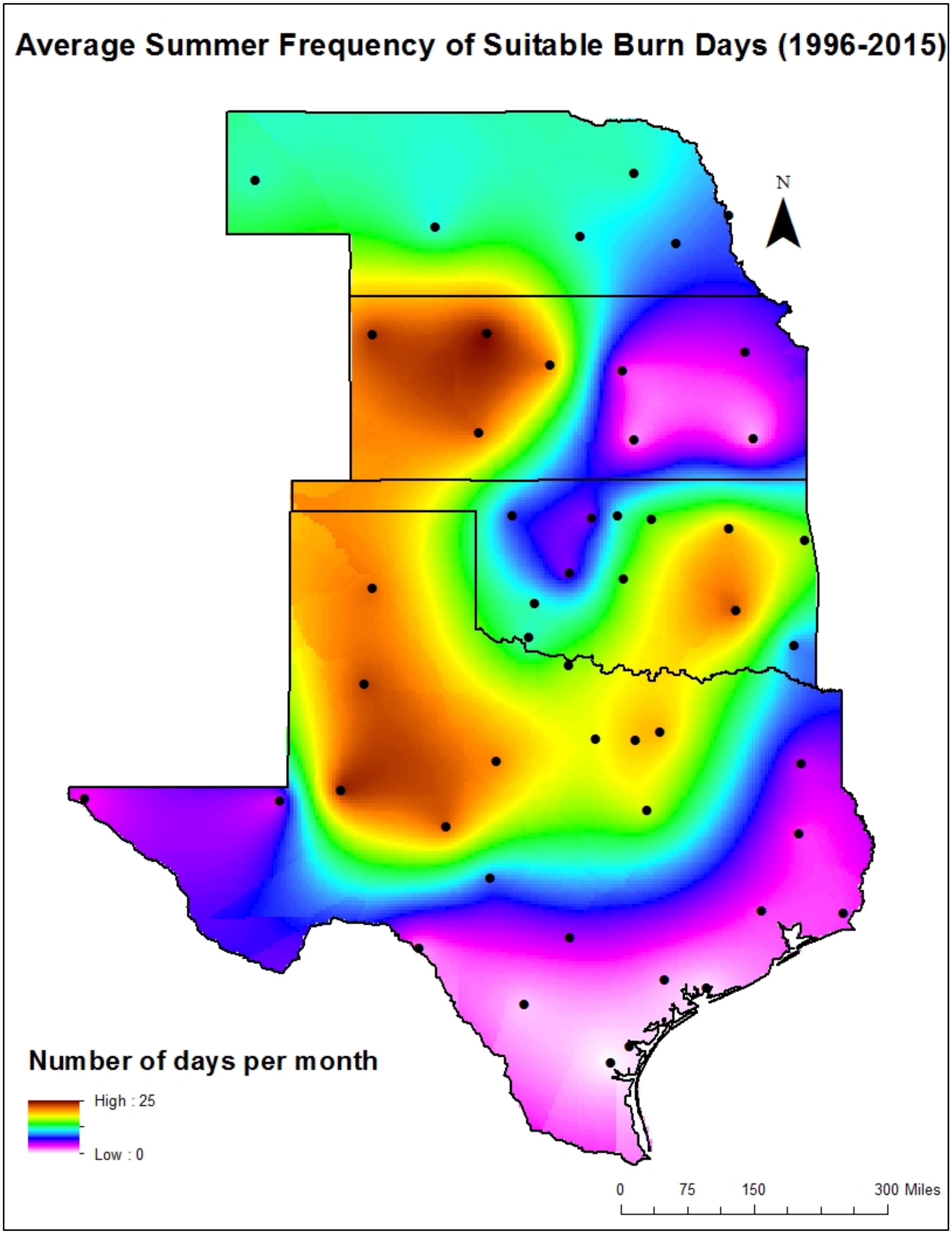


Figure 15. Spatial representation of average summer frequency

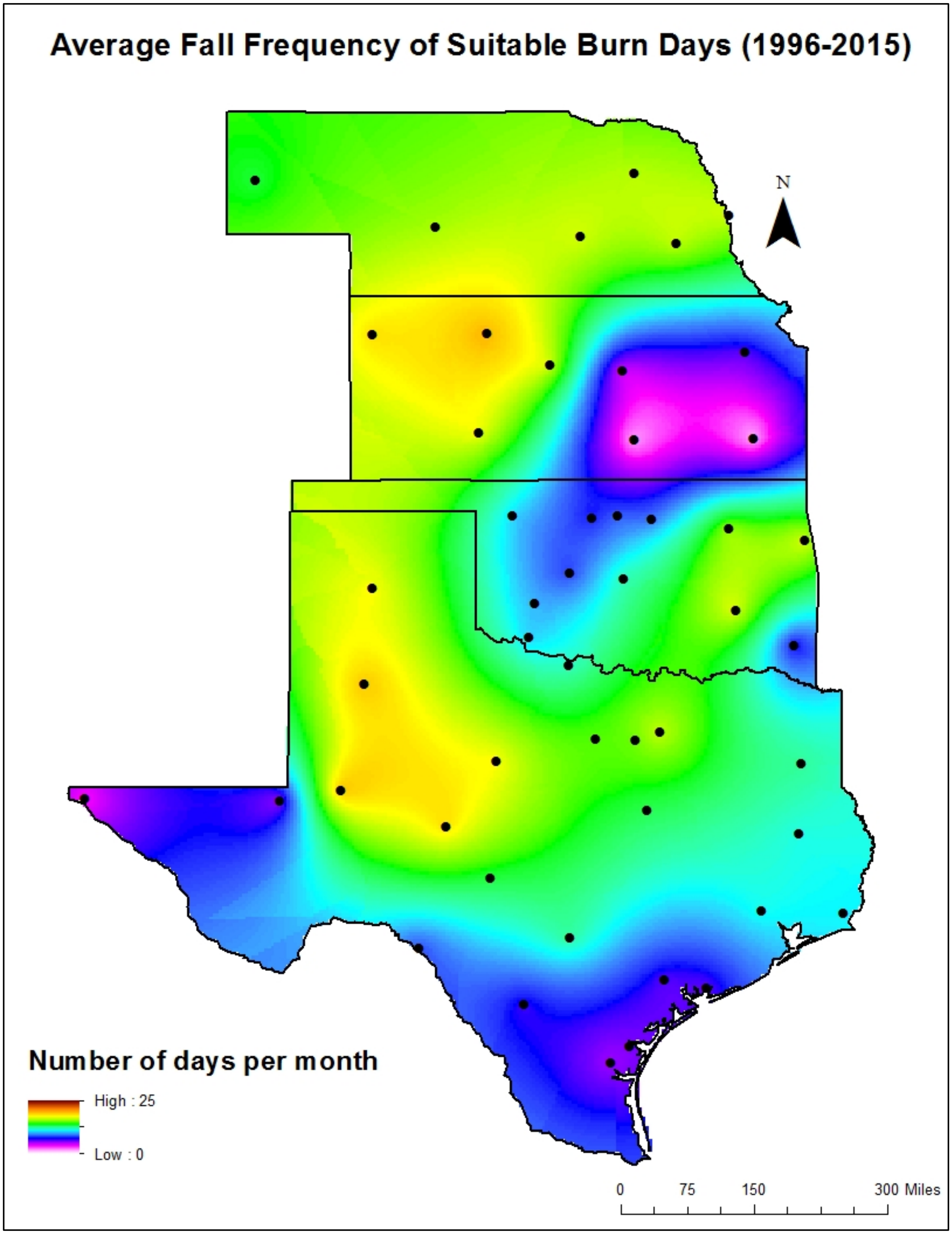


Figure 16. Spatial representation for average fall frequency

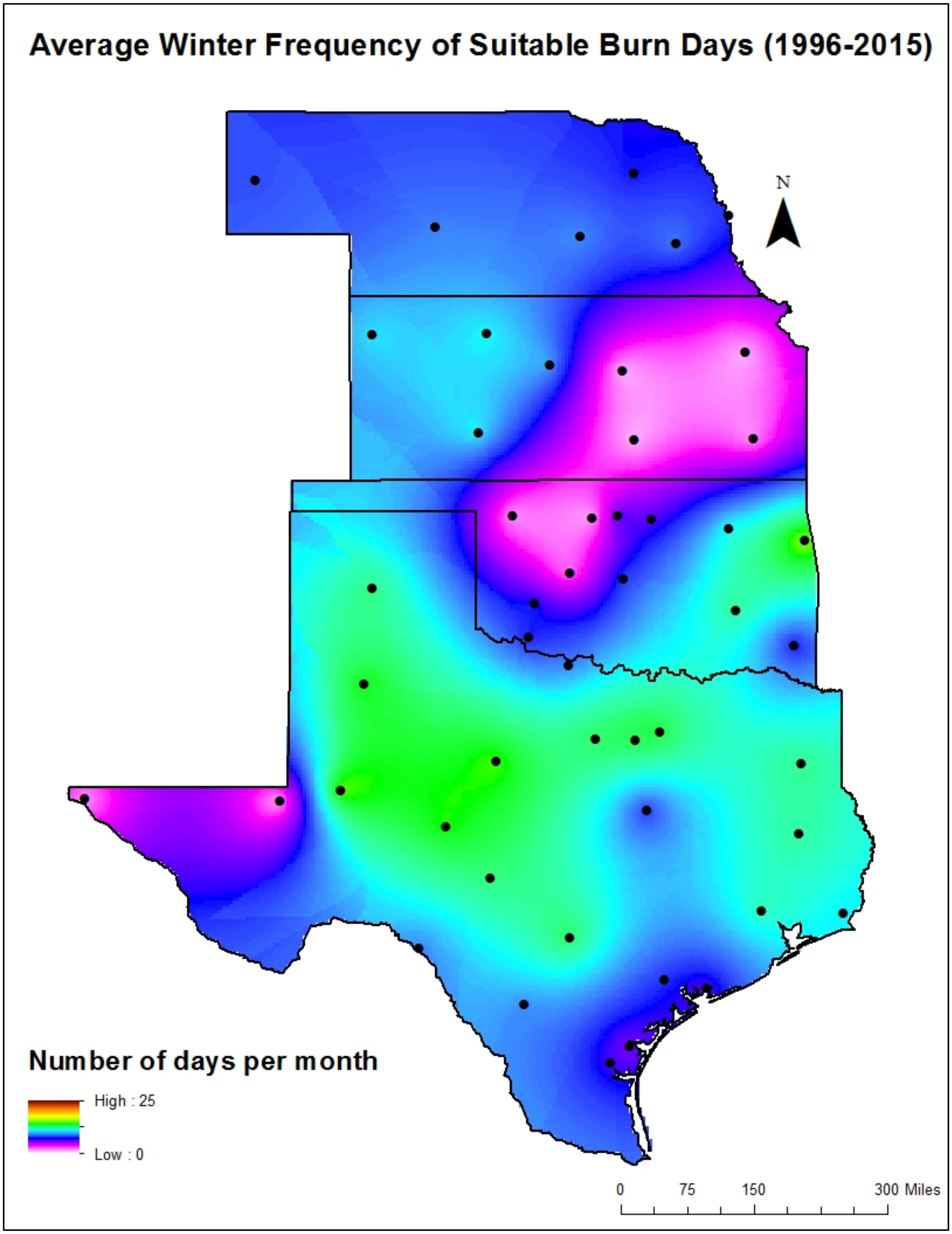


Figure 17. Spatial representation of average winter frequency

4.2 Analysis using a Common Threshold

The spatial analysis appears to be driven by differences in criteria among Prescribed Burn Associations as much, if not more so, than climatology. Therefore, the spatial analysis was repeated using fixed criteria applied to all ASOS and Mesonet stations throughout the four-state region. Using the median values of Prescribed Burn Association criteria across the region, thresholds were set as follows: minimum temperature 35°F; maximum temperature 95°F; wind speed range 5-15 mph; and relative humidity range 25-70%.

Implementing this uniform set of thresholds resulted in a large change in suitability across the region (Figures 19-22). Areas with a strict set of thresholds, such as eastern Kansas and northwest Oklahoma, saw an increase in burning opportunities when the temperature and relative humidity ranges were expanded. For example, the yearly average frequency altered from 81 to 135 days in Woodward, OK and 47 to 177 days in Topeka, KS (Figure 19). An increase was seen in southern Texas as well, with stations like Corpus Christi rising from 43 to 129 days. On the other hand, most areas with the highest number of suitable burn days decreased with a slight reduction in maximum temperature and wind speed. For example, yearly average suitability decreased from 203 to 123 days when the common set of thresholds were applied.

Seasonality changed across the region, with spring being the most noticeable difference. The pattern in this timeframe exhibited lower frequencies in the western portions of all states, with increasing frequencies to the east (Figure 19). Summer and fall frequency became more consistent across the region, without the previous pockets of much lower and higher frequencies than surrounding areas (Figures 20 and 21). Finally, winter consisted of the same general pattern as before, but there was a smooth north to south gradient of frequency (Figure 22). It is evident from this analysis that the thresholds implemented by individual Prescribed Burn Associations have a heavy influence on the prospects for prescribed burns throughout the year. Regions that may benefit the most from an expansion of weather criteria include eastern Kansas and northwest Oklahoma, which saw an overall large increase in suitable burn days with this scenario.

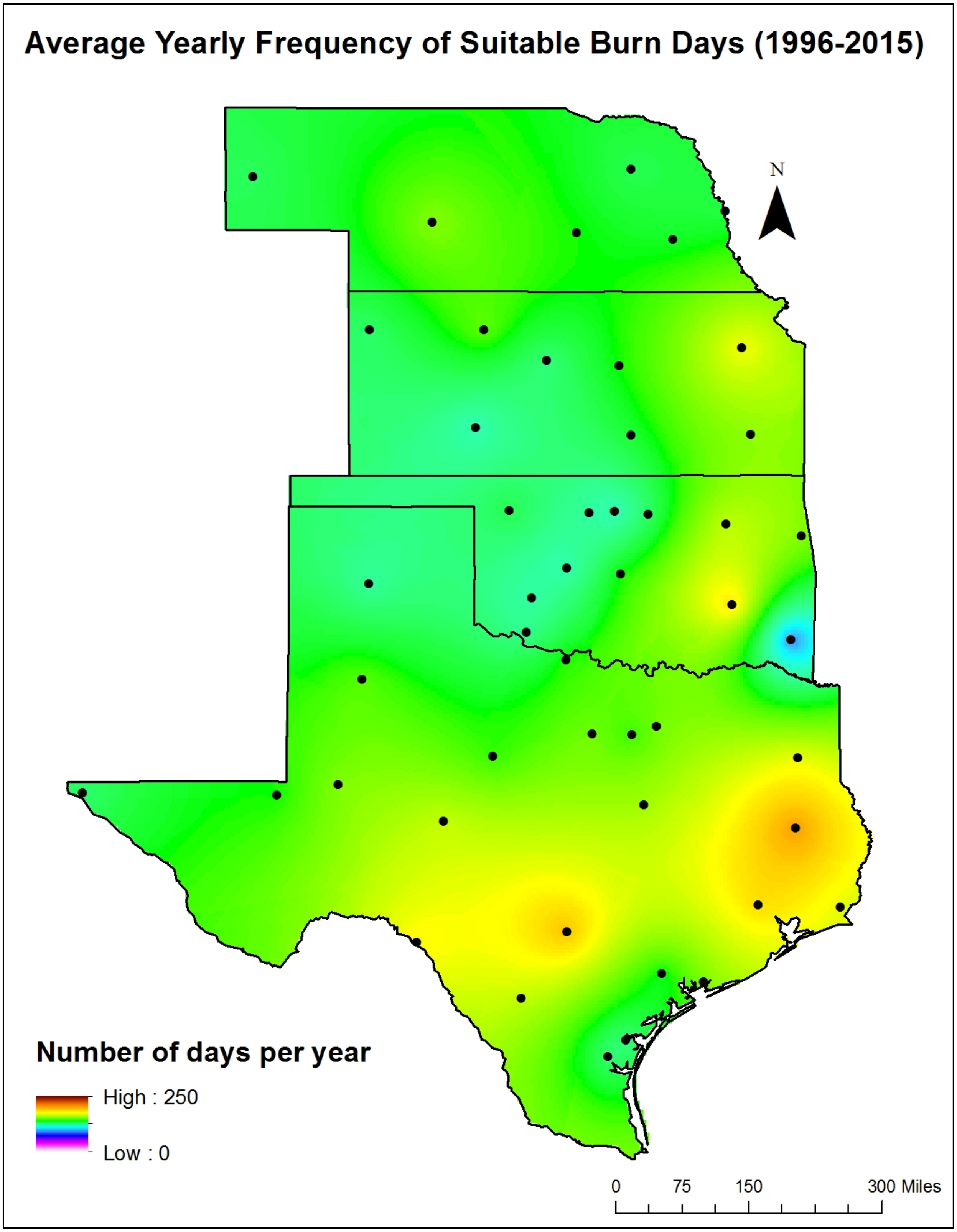


Figure 18. Spatial representation of average yearly frequency with a uniform set of thresholds

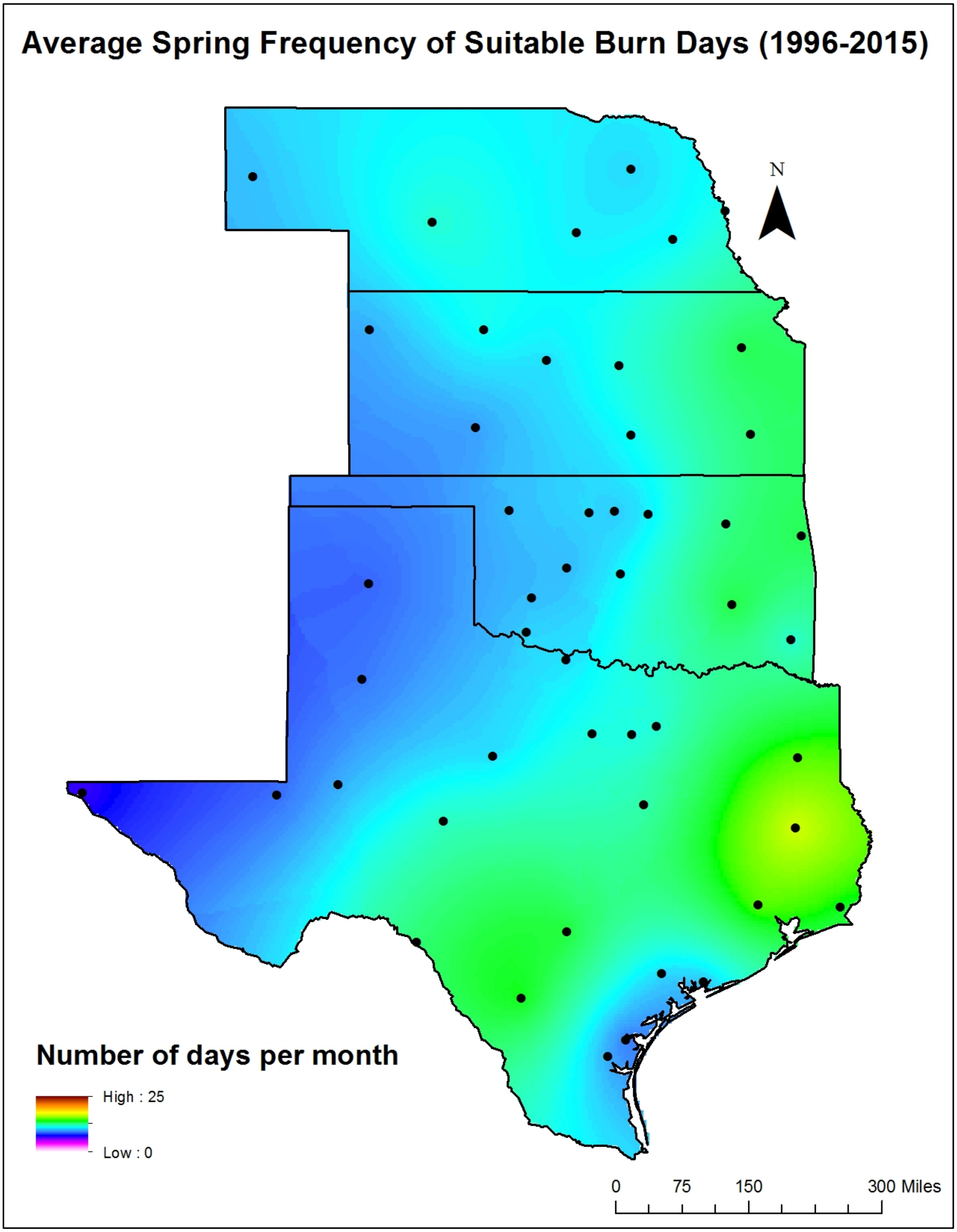


Figure 19. Spatial representation of average spring frequency with a uniform set of thresholds

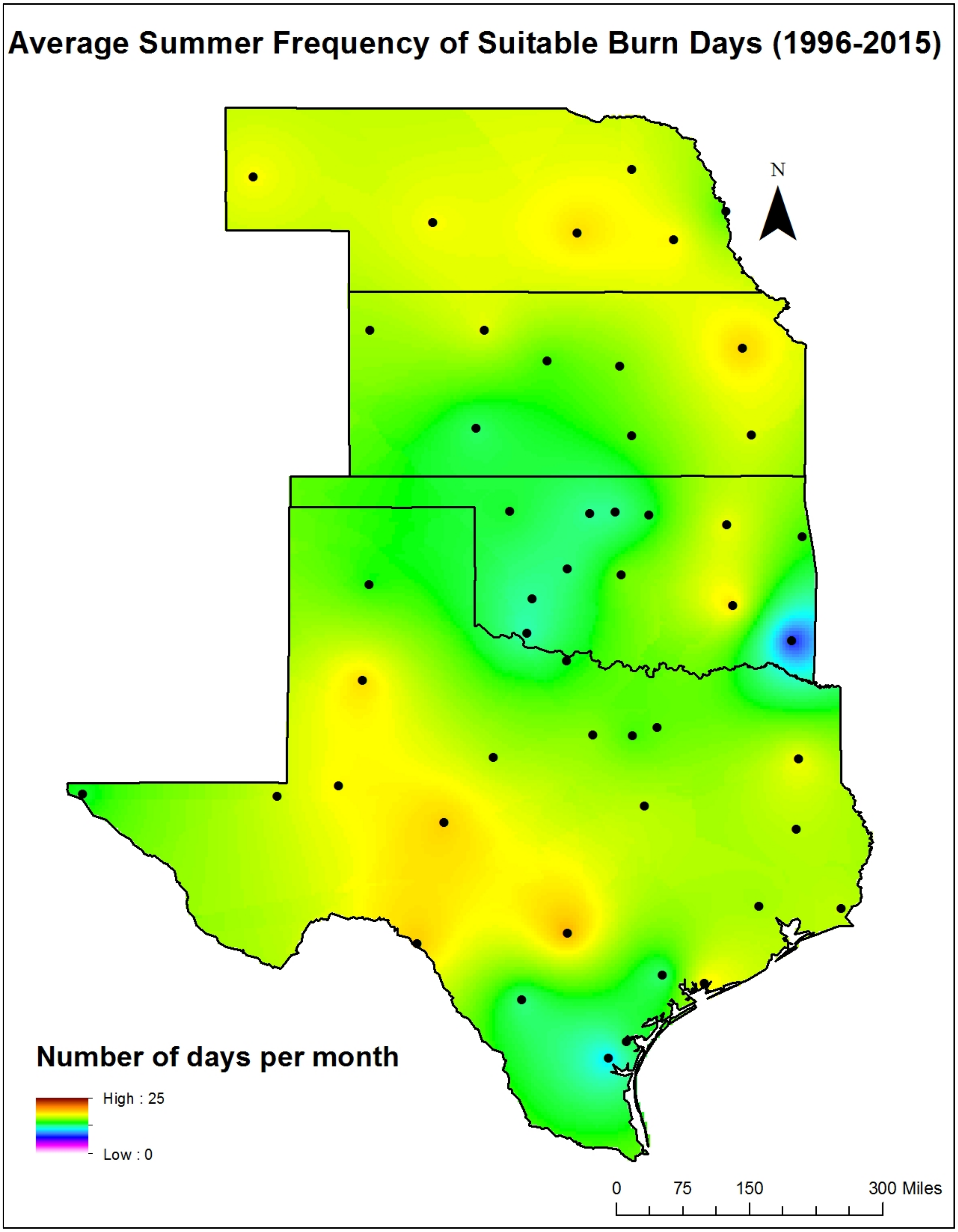


Figure 20. Spatial representation of average summer frequency with a uniform set of thresholds

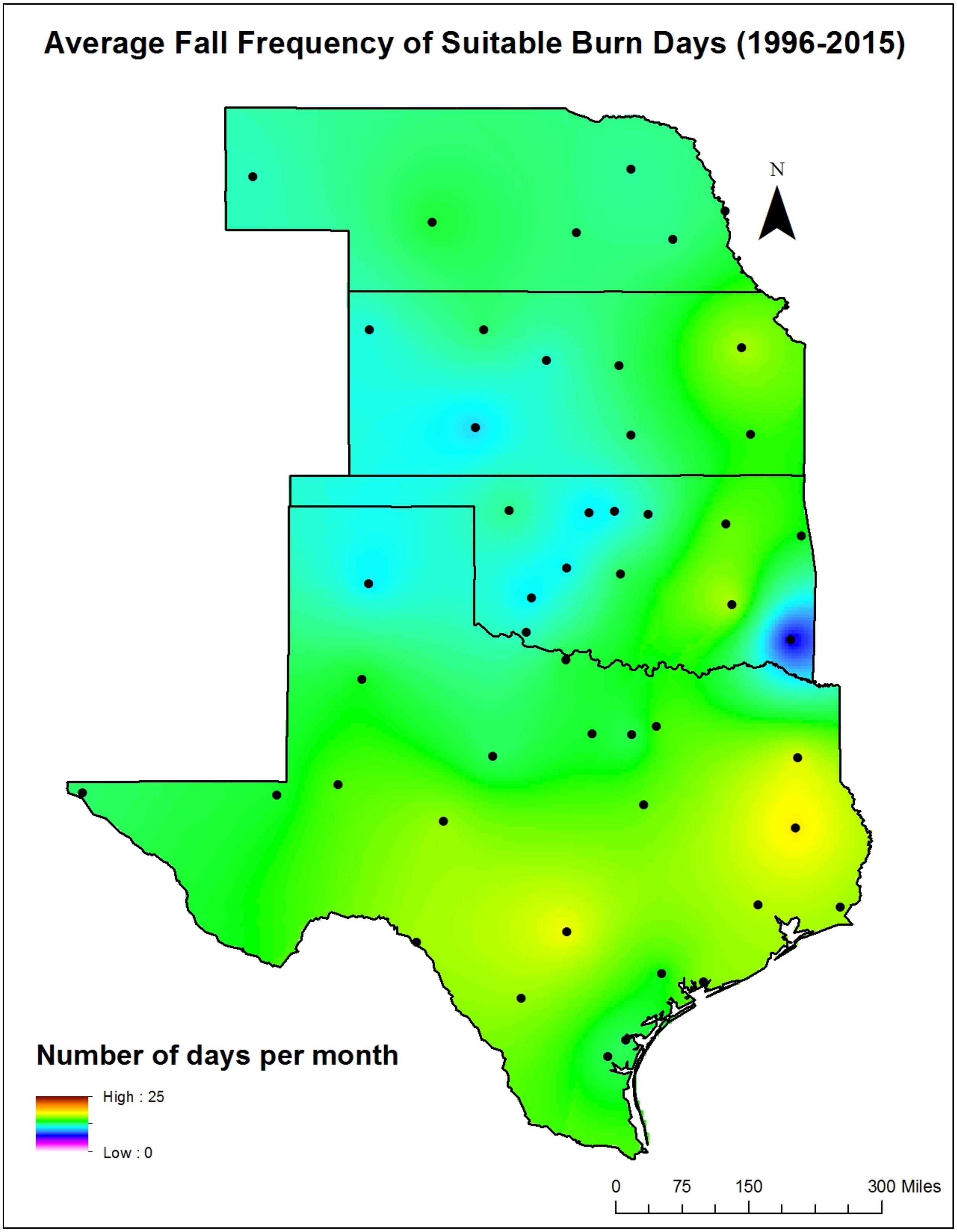


Figure 21. Spatial representation of average fall frequency with a uniform set of thresholds

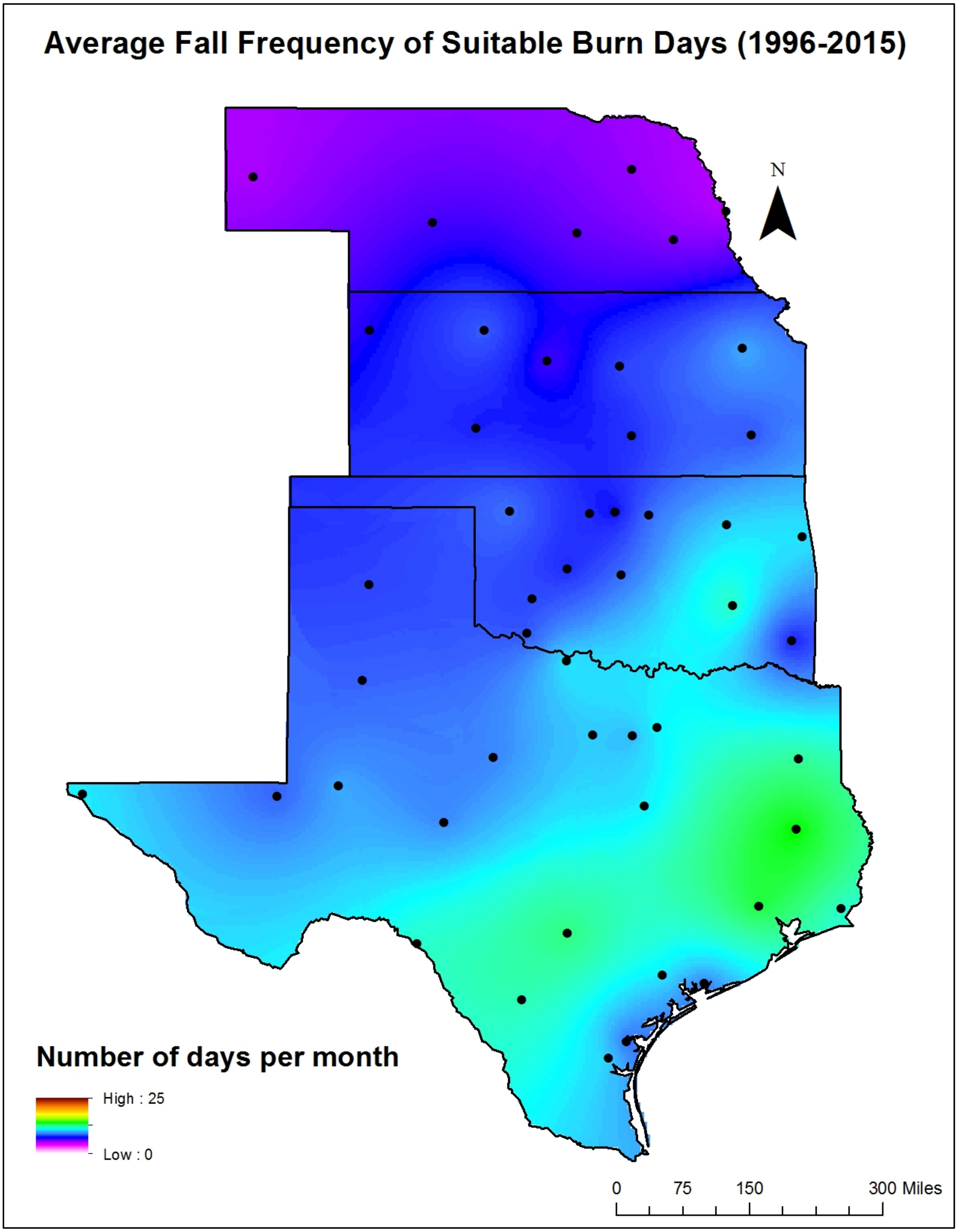


Figure 22. Spatial representation of average winter frequency with a uniform set of thresholds

5. Climate Change Estimation

Using the Nature Conservancy's Climate Wizard tool, the average end-of-century temperature change under a medium emission scenario was found for each station. The temperature change for all stations was added to the hourly temperature observations from 1996-2015. The R code was then run again for these new values with the same appropriate Prescribed Burn Association thresholds. The goal of this was to determine if there would be a potential change in seasonality of days suitable for prescribed burns under warmer conditions. It is understood that this is a very rough estimation, of course, but it still demonstrates the idea that the frequency of burn days will alter with a warmer climate since there is a specific window of opportunity for burns to be conducted.

The main pattern across the region included a decrease in frequency of suitable burn days in the summer. For example, the summer frequency in North Platte, NE decreased from 11 to 4 days in August (Figure 23) and there was a decline from 8 to 2 suitable days in Lincoln (Figure 24). This finding is logical, considering that summer months bring temperatures that are already on the upper end of many of the Prescribed Burn Associations' thresholds. Even a slight rise in temperature in these months could cause a dramatic decrease in summer burning opportunities. Some stations in Oklahoma, such as Oklahoma City, showed a decline in all months of the year. Most stations in Texas that showed the general pattern also included a decline in frequency during late spring and early fall. Another trend was found in Nebraska, eastern Kansas, and Oklahoma that estimated an increase in winter frequency. For example, Omaha, NE was estimated to gain 2-3 suitable burn days for each winter month. On the other hand, many stations in Texas and western Kansas, such as Dodge City, saw a negligible change. Additionally, 9 stations across the region were selected by spatiality to repeat the analysis for mid-century projections. The patterns were comparable with those from end-of-century, only there was a smaller magnitude of change. End-of-century and mid-century plots are shown in Appendix C and D.

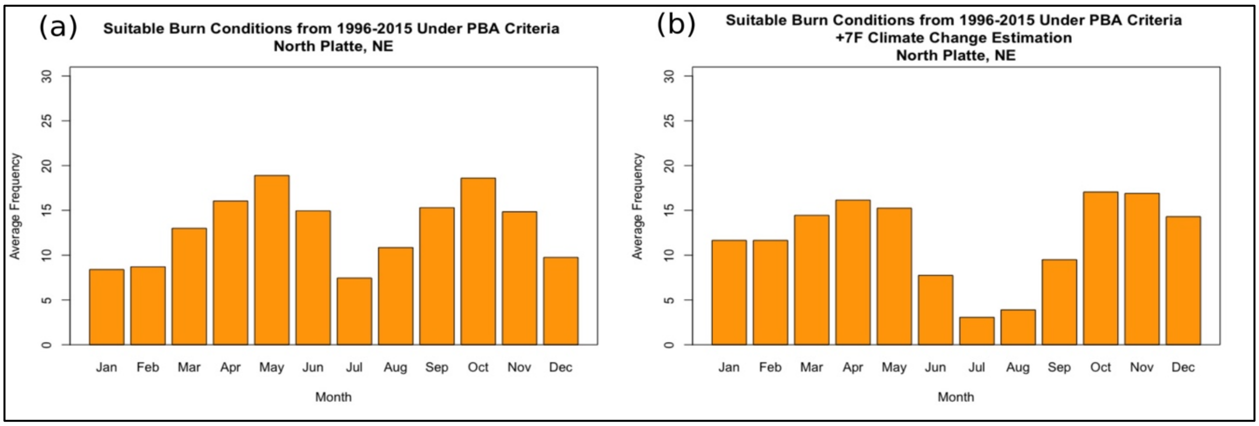


Figure 23. North Platte, NE monthly average suitable burn days for (a) current conditions and (b) conditions under a climate change scenario

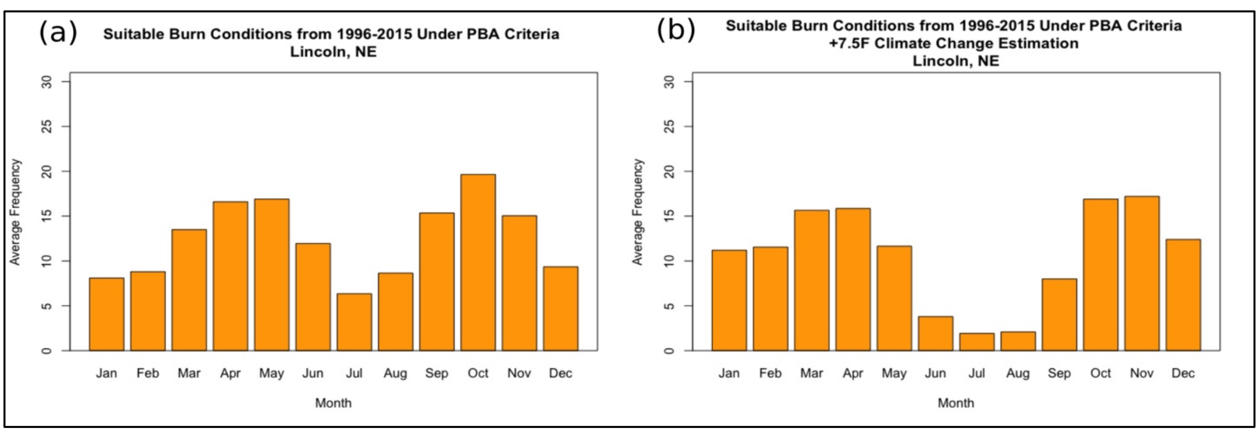


Figure 24. Lincoln, NE monthly average suitable burn days for (a) current conditions and (b) conditions under a climate change scenario

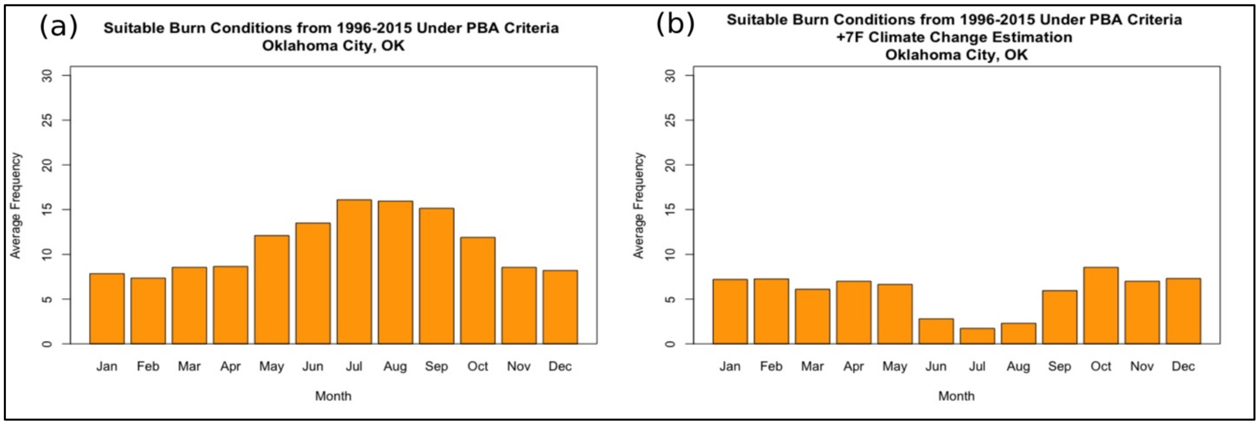


Figure 25. Oklahoma City, OK monthly average suitable burn days for (a) current conditions and (b) conditions under a climate change scenario

6. Discussion and Conclusion

From this study that analyzed the frequency of suitable burn days strictly from a perspective of weather condition thresholds, it is evident that many locations, excluding eastern Kansas and southern Texas, have a reasonable opportunity for prescribed burning during most seasons of the year, depending on location. The analysis is highly dependent on the weather criteria used by the local Prescribed Burn Associations. Thus, those that may exhibit low potential may choose to reevaluate their criteria and assess if loosening the thresholds poses no more than minimal risk.

These results justify that Prescribed Burn Associations can consider creating an updated burn plan that will maximize their goals. They may find that they can burn during seasons that they may not have considered previously. Future climate is an aspect to consider, because climate models have consistently projected warmer and drier conditions in the Southern Plains (Shafer et al. 2014). Fire management strategies need to be considered for this future change, or wildfire risk will increase and create a more severe impact to the environment

7. References

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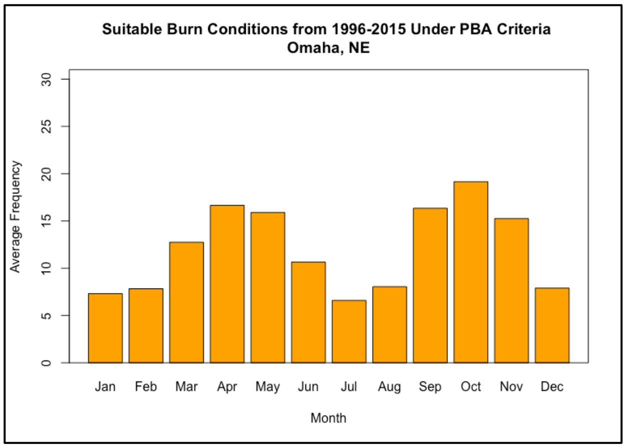
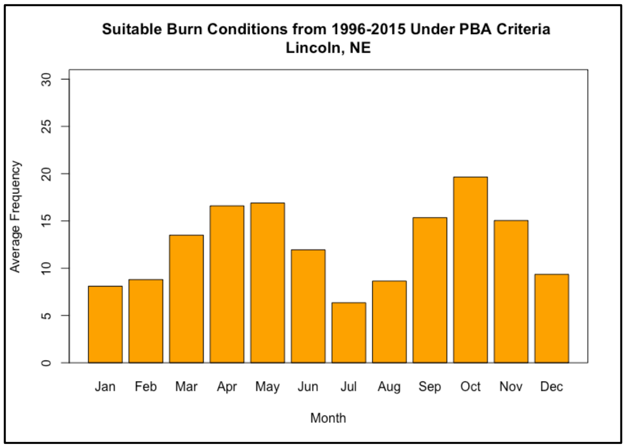
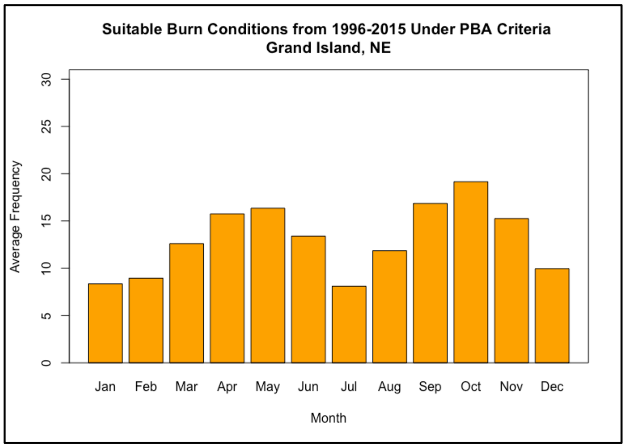
Appendix A: Average monthly frequency of suitable burn days; ordered by Prescribed Burn Association region



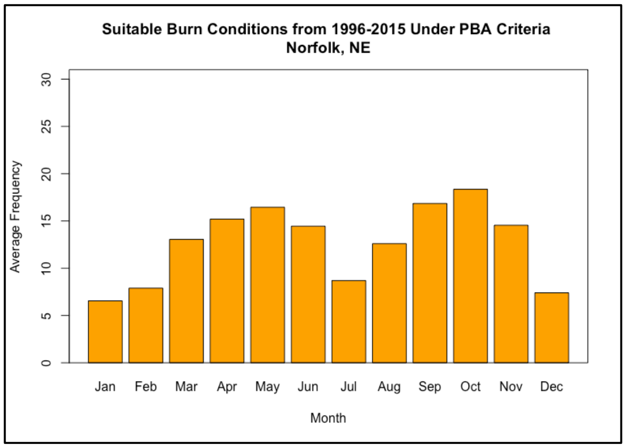
A1. Omaha, NE – All thresholds are constant throughout the state



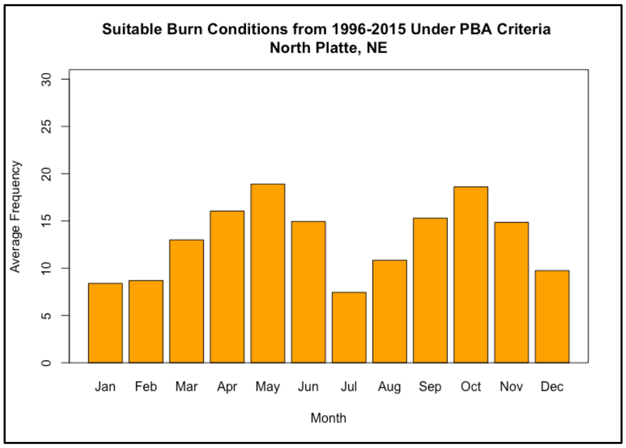
A2. Lincoln, NE



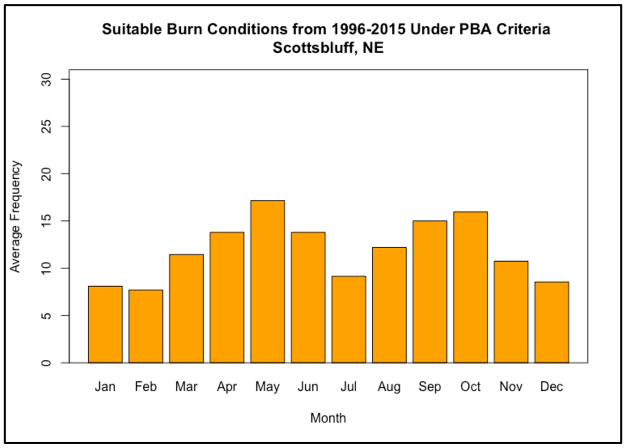
A3. Grand Island, NE



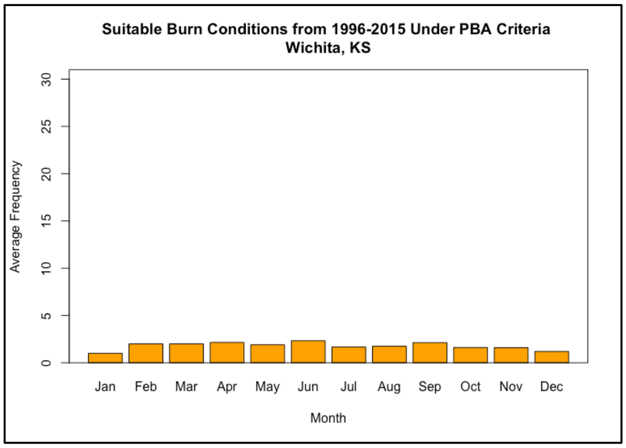
A4. Norfolk, NE



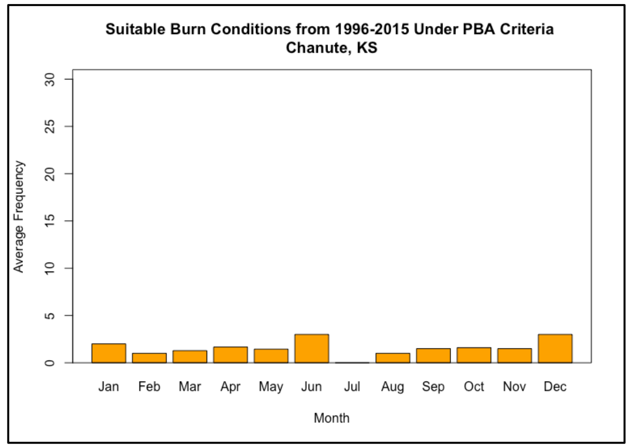
A5. North Platte, NE



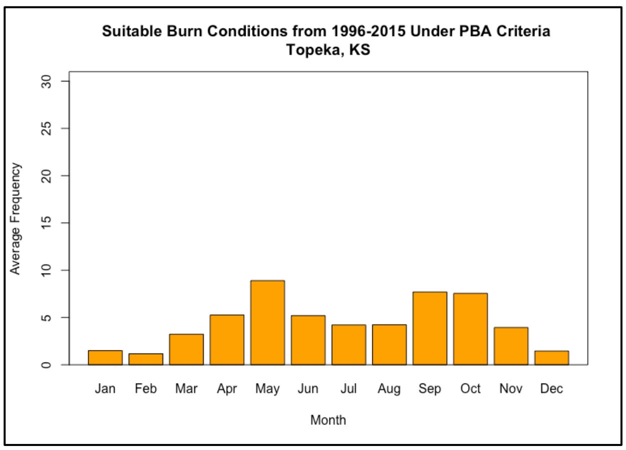
A6. Scottsbluff, NE



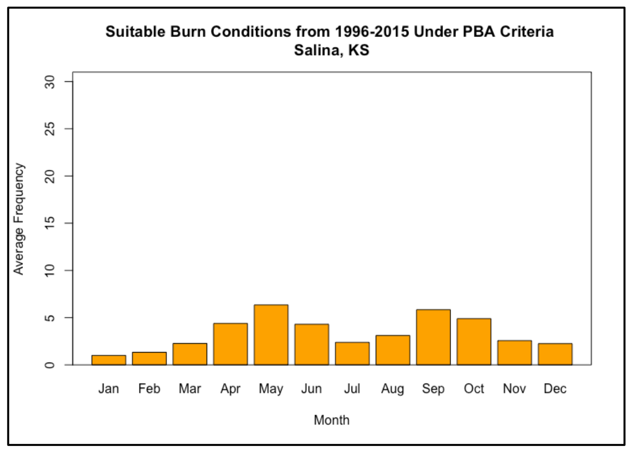
A7. Wichita, KS – Eastern Kansas



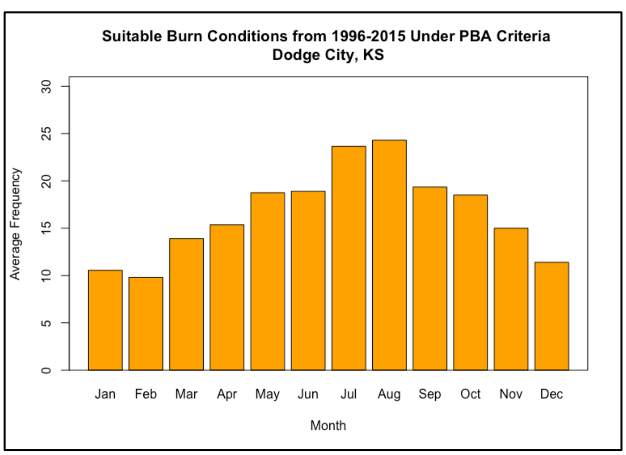
A8. Chanute, KS – Eastern Kansas



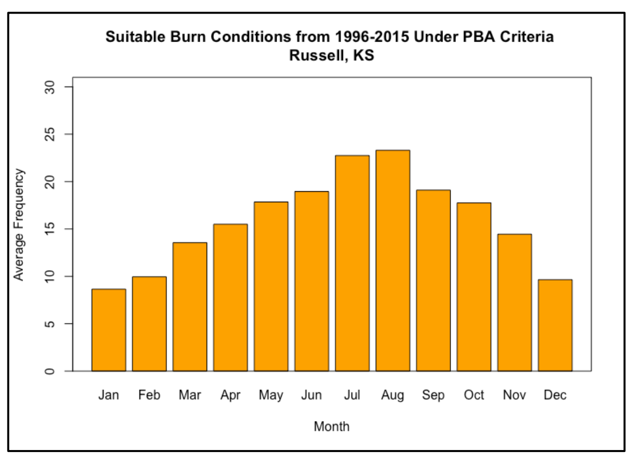
A9. Topeka, KS – Eastern Kansas



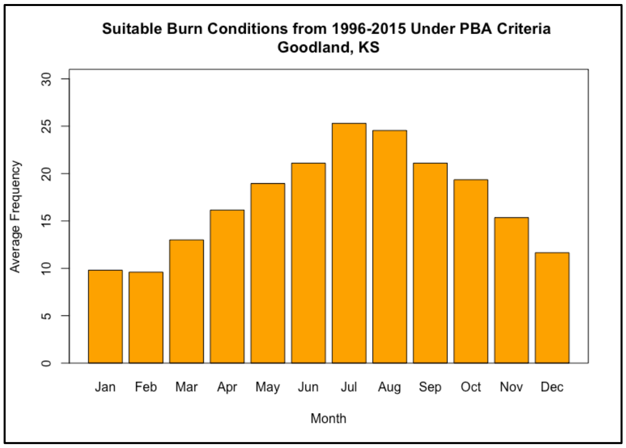
A10. Salina, KS – Eastern Kansas



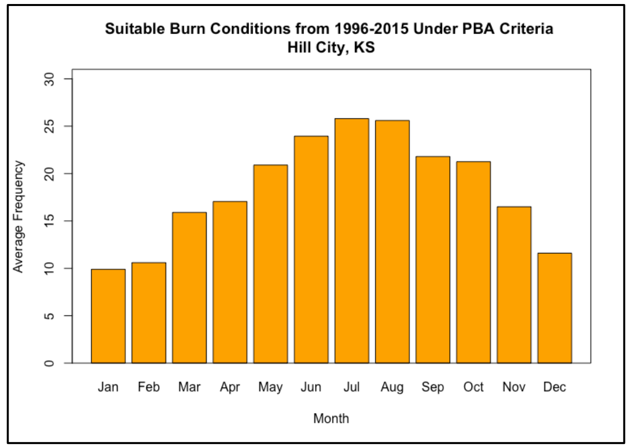
A11. Dodge City, KS – Western Kansas



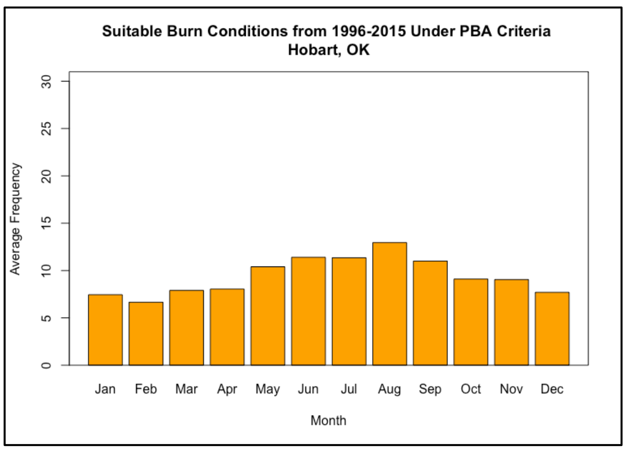
A12. Russell, KS – Western Kansas



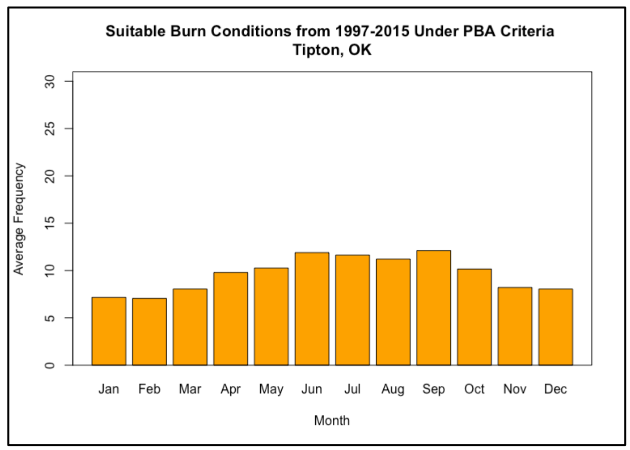
A13. Goodland, KS Western Kansas



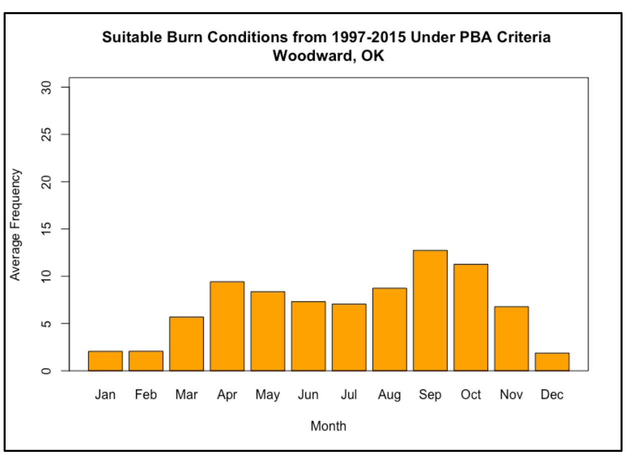
A14. Hill City, KS – Western Kansas



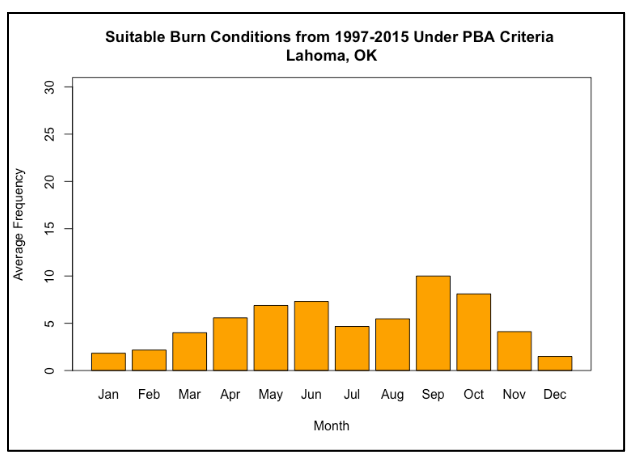
A15. Hobart, OK – Southwest Oklahoma



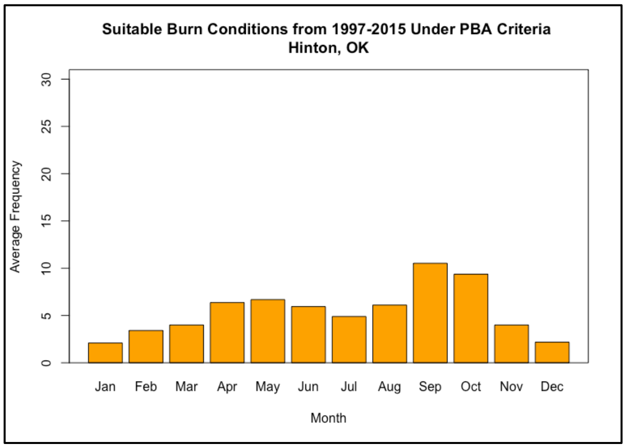
A16. Tipton, OK (Mesonet station) – Southwest Oklahoma



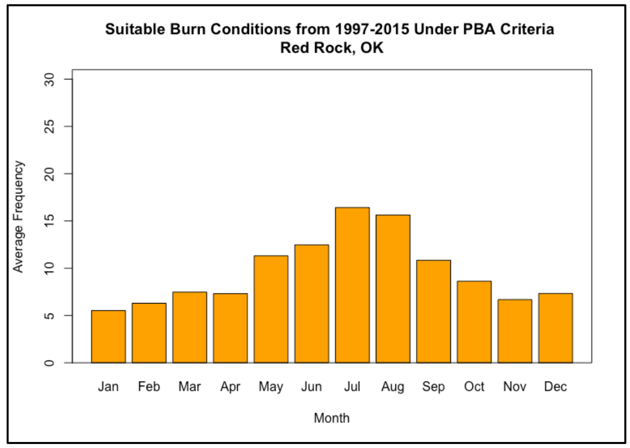
A17. Woodward, OK (Mesonet station) – Northwest OK



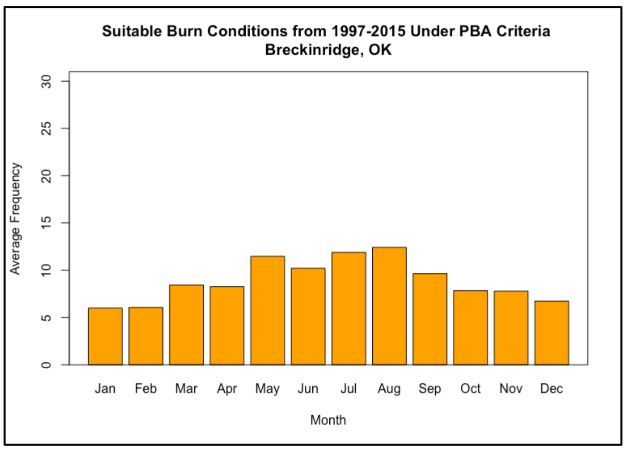
A18. Lahoma, OK (Mesonet station) – Northwest OK



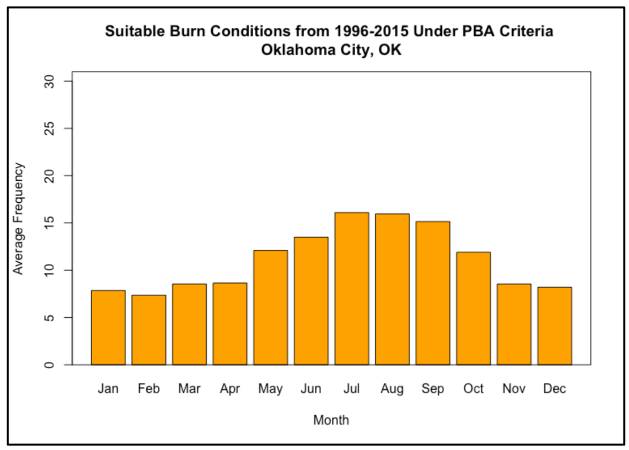
A19. Hinton, OK (Mesonet station) – Northwest Oklahoma



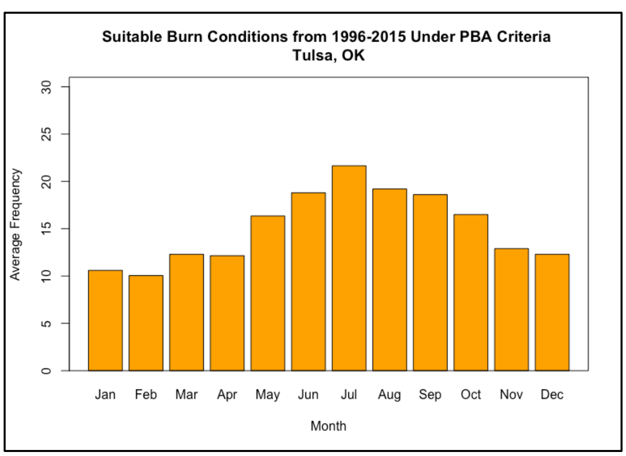
A20. Red Rock, OK (Mesonet station) – North Central Oklahoma



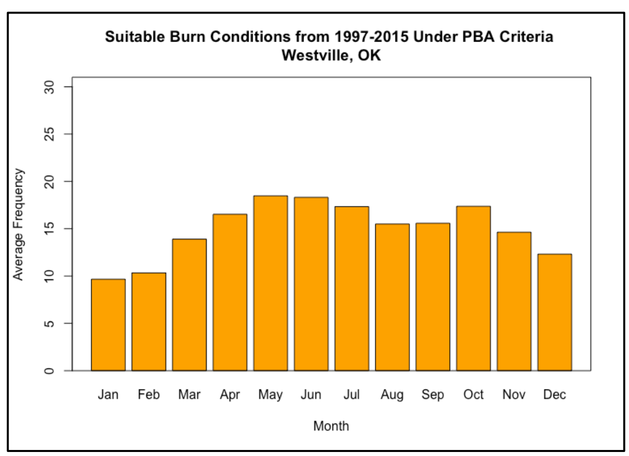
A21. Breckinridge, OK (Mesonet station) – North Central Oklahoma



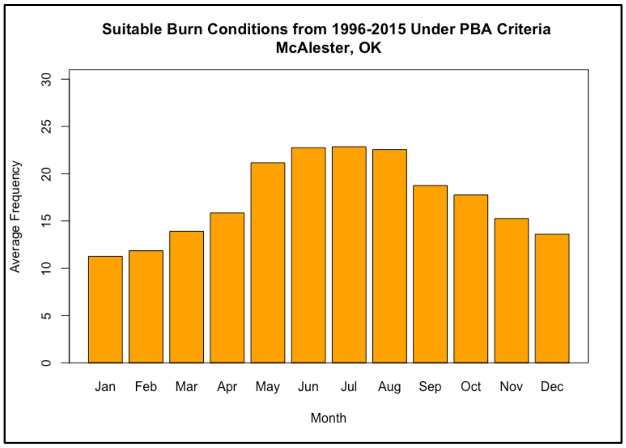
A22. Oklahoma City, OK – Central Oklahoma



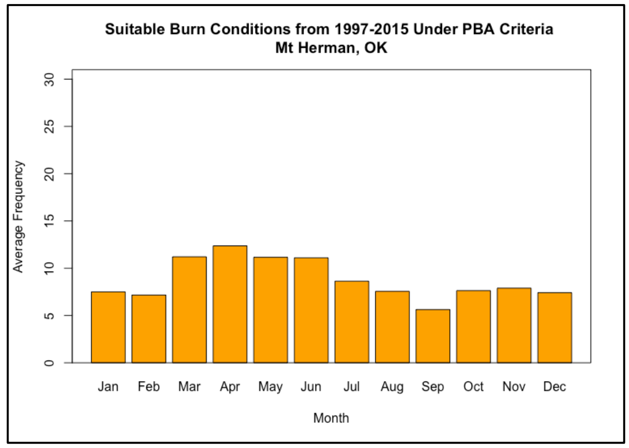
A23. Tulsa, OK – Northeast Oklahoma



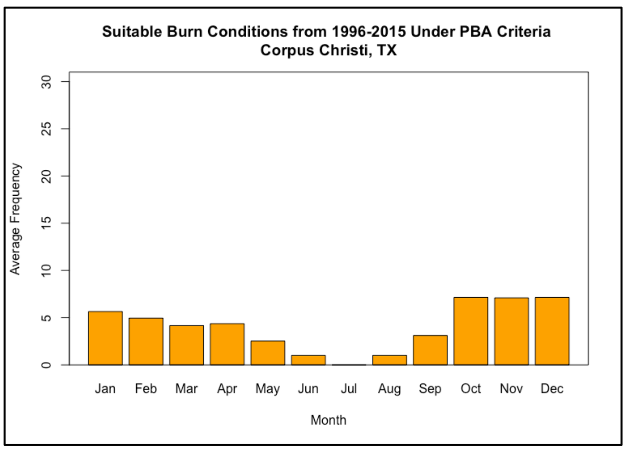
A24. Westville, OK (Mesonet station) – Northeast Oklahoma



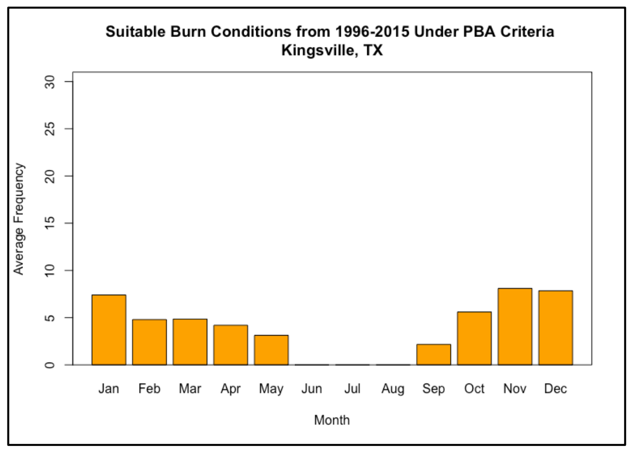
A25. McAlester, OK – Southeast Oklahoma



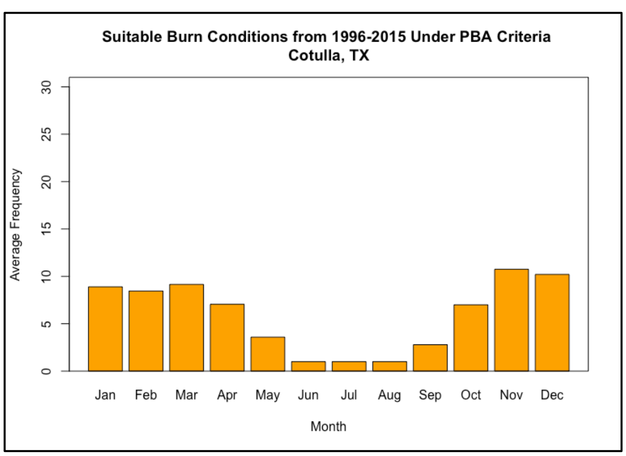
A26. Mount Herman, OK (Mesonet station) – Southeast Oklahoma



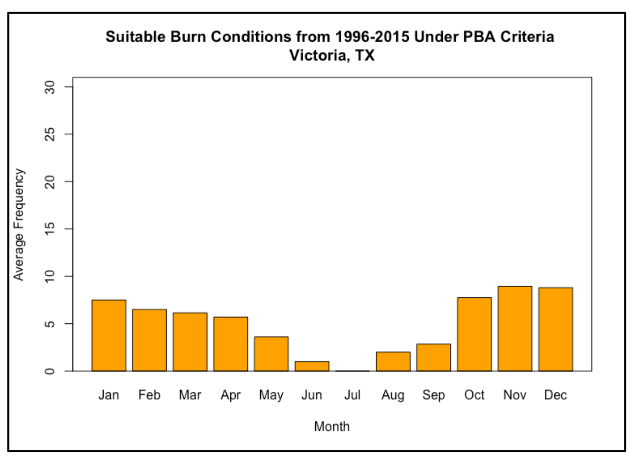
A27. Corpus Christi, TX – Southern Texas



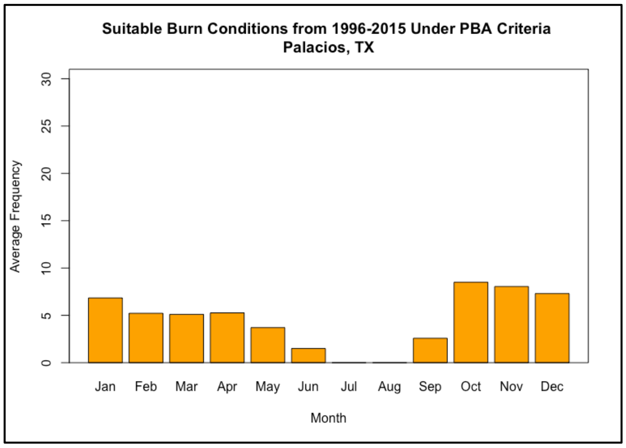
A28. Kingsville, TX – Southern Texas



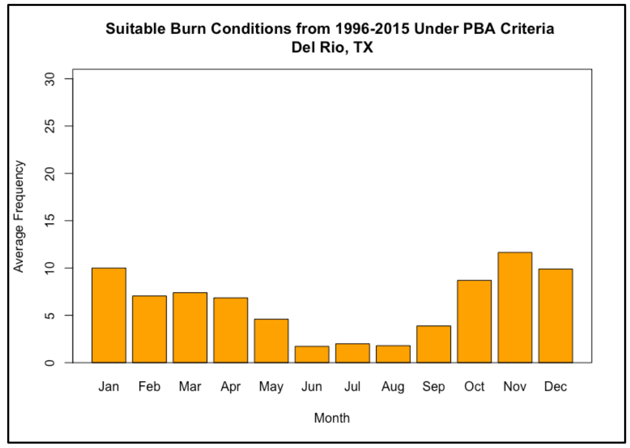
A29. Cotulla, TX – Southern Texas



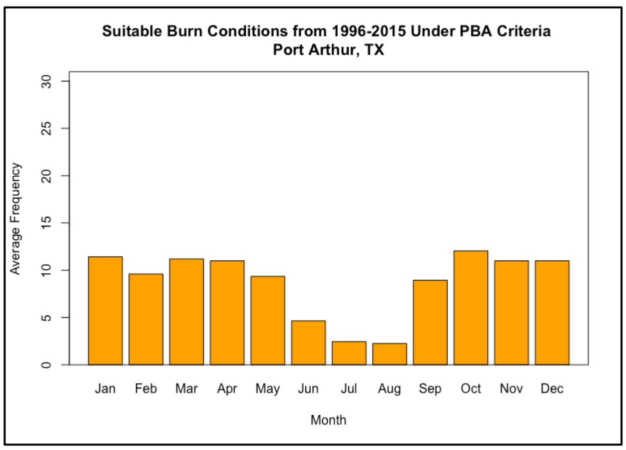
A30. Victoria, TX – Southern Texas



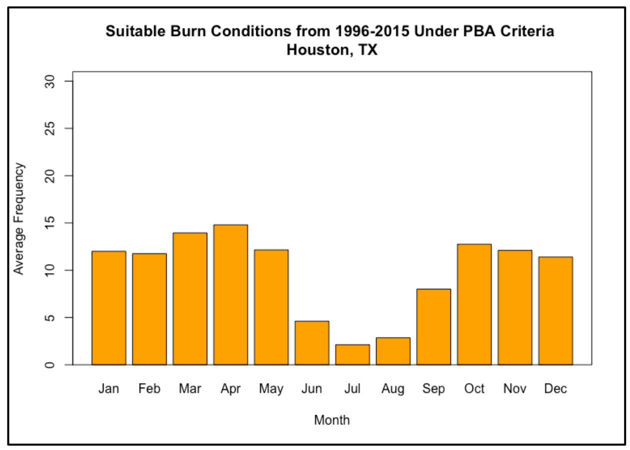
A31. Palacios, TX – Southern Texas



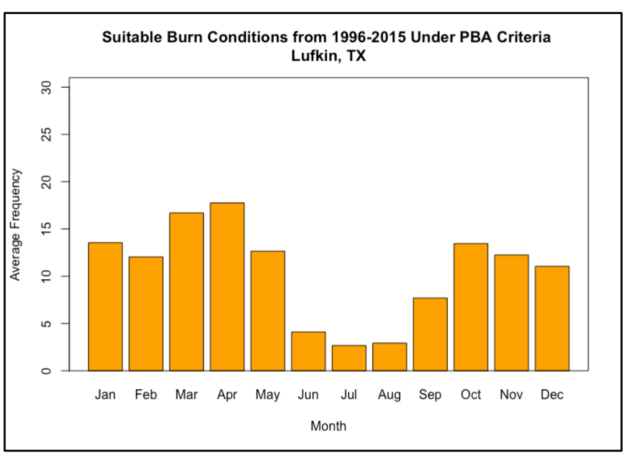
A32. Del Rio, TX – Southern Texas



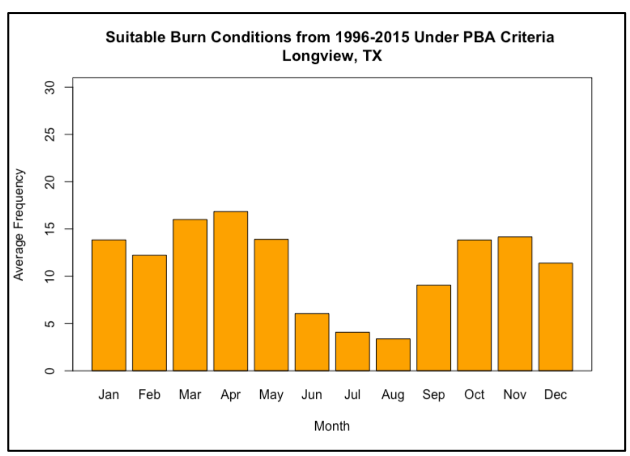
A33. Port Arthur, TX – South Central Texas



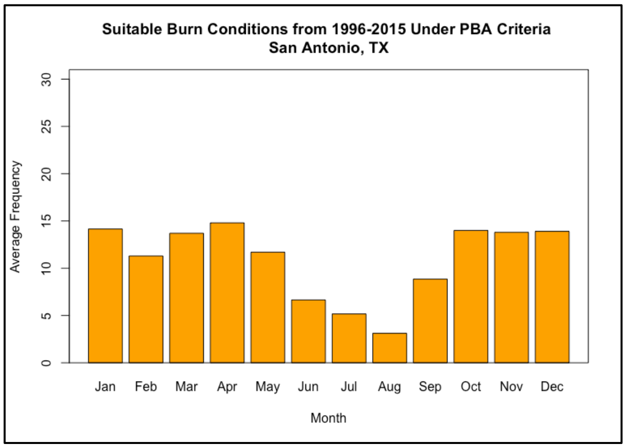
A34. Houston, TX – South Central Texas



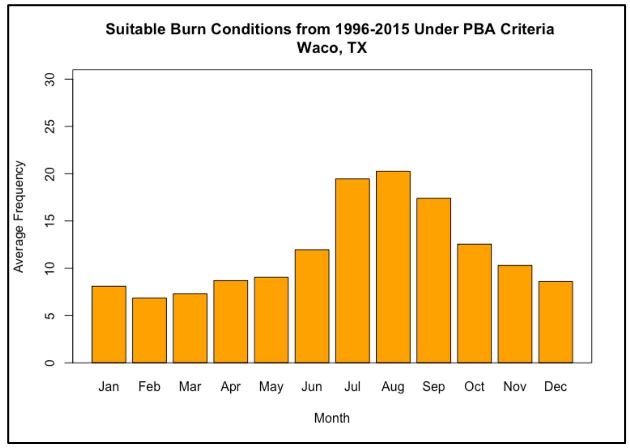
A35. Lufkin, TX – South Central Texas



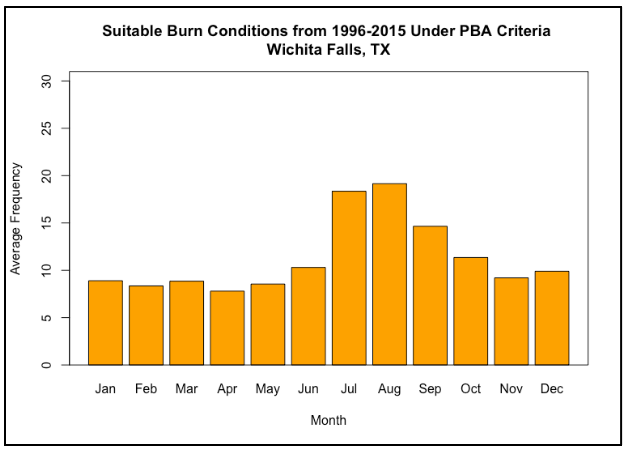
A36. Longview, TX – South Central Texas



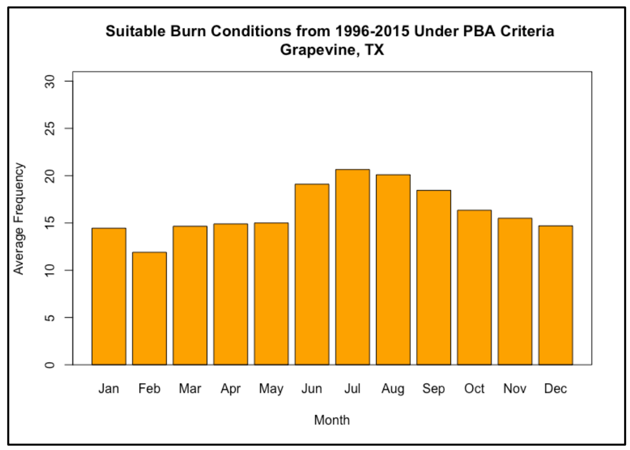
A37. San Antonio, TX – South Central



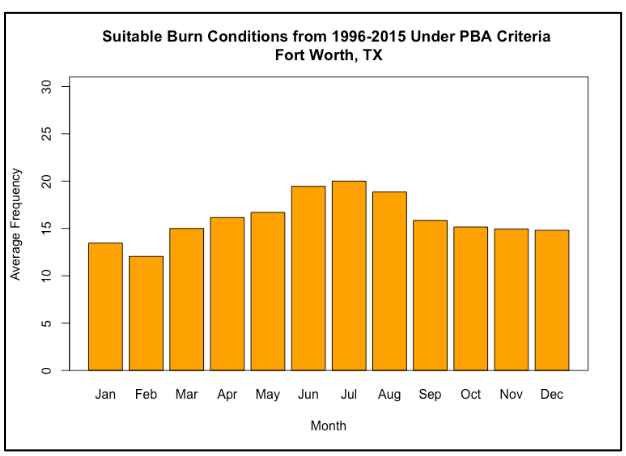
A38. Waco, TX – Central Texas



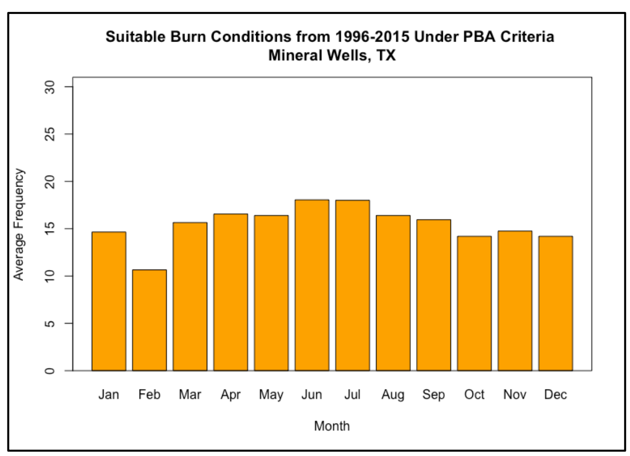
A39. Wichita Falls, TX – West Central Texas



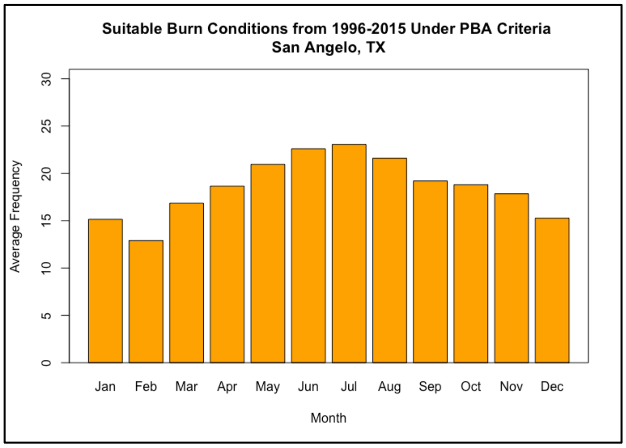
A40. Grapevine, TX – West Central Texas



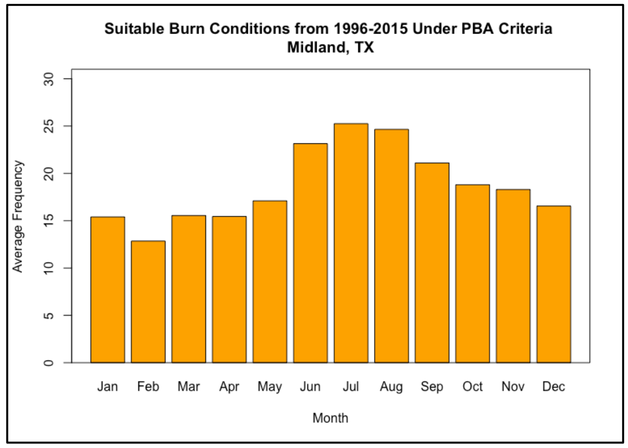
A41. Fort Worth, TX – West Central Texas



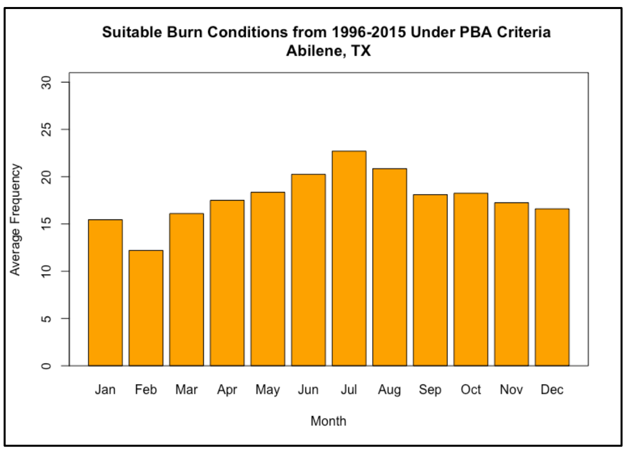
A42. Mineral Wells, TX – West Central Texas



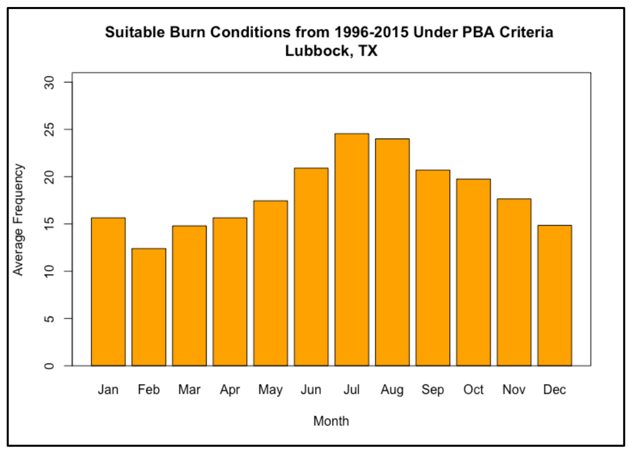
A43. San Angelo, TX – West Central Texas



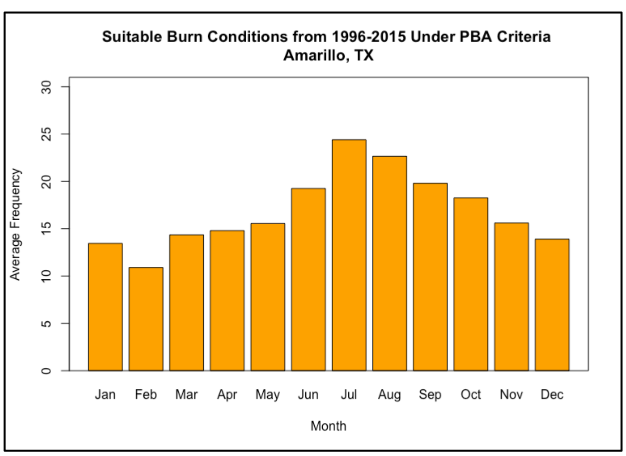
A44. Midland, TX – West Central Texas



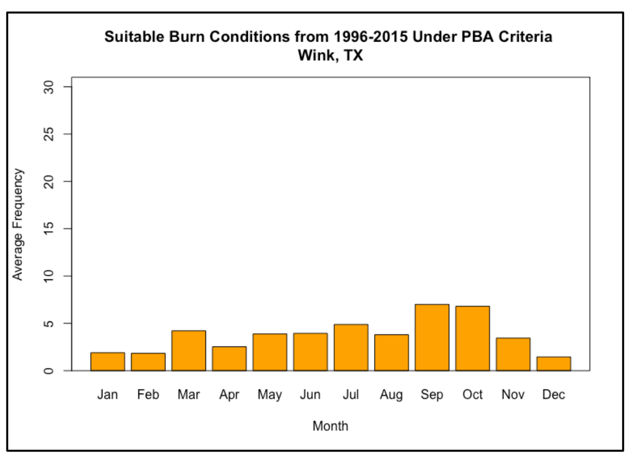
A45. Abilene, TX – West Central Texas



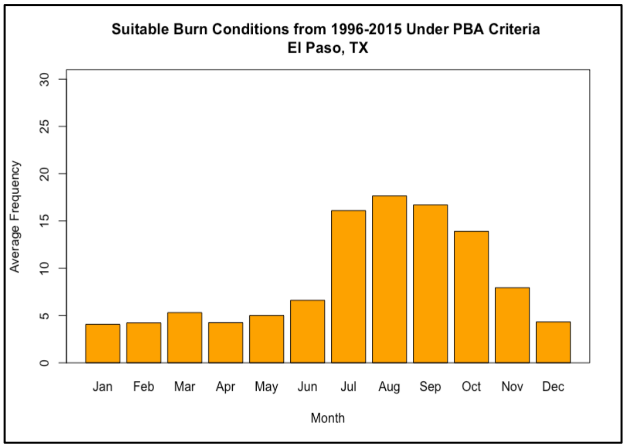
A46. Lubbock, TX – West Central Texas



A47. Amarillo, TX – West Central Texas

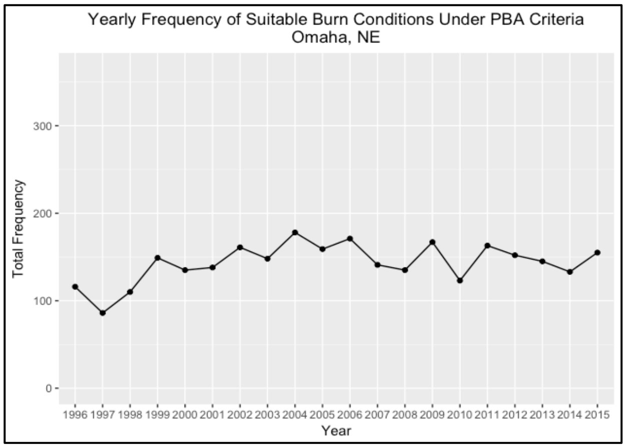


A48. Wink, TX – Southwest Texas

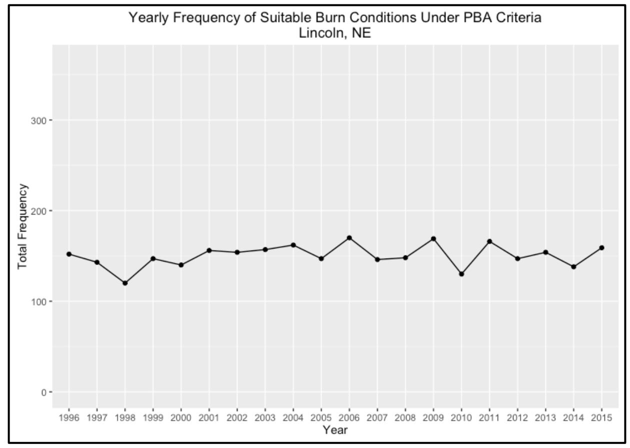


A49. El Paso, TX – Southwest Texas

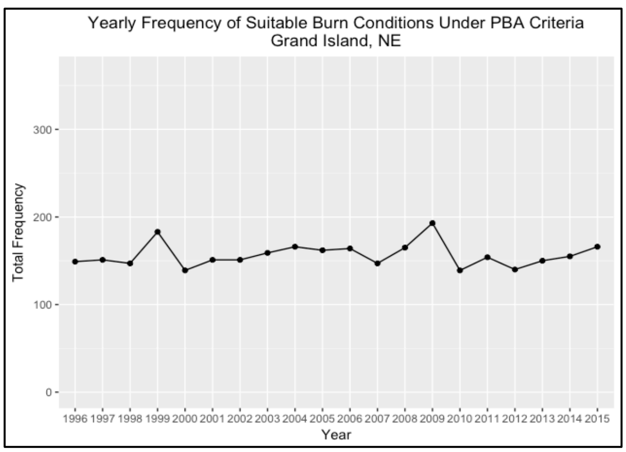
Appendix B: Yearly Frequency of Suitable Burn Days; ordered by Prescribed Burn Association region



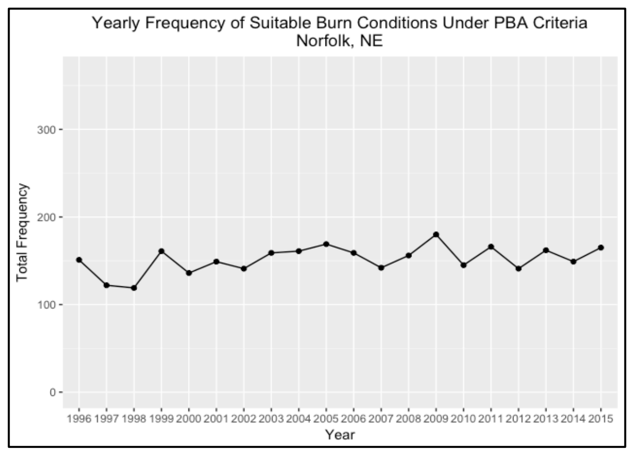
B1. Omaha, NE – All thresholds are constant throughout the state



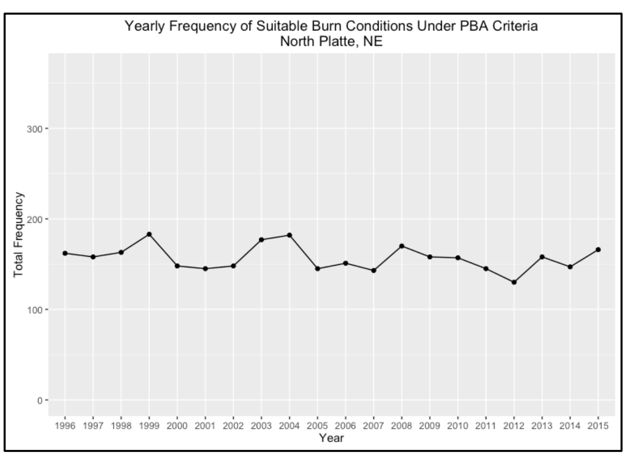
B2. Lincoln, NE



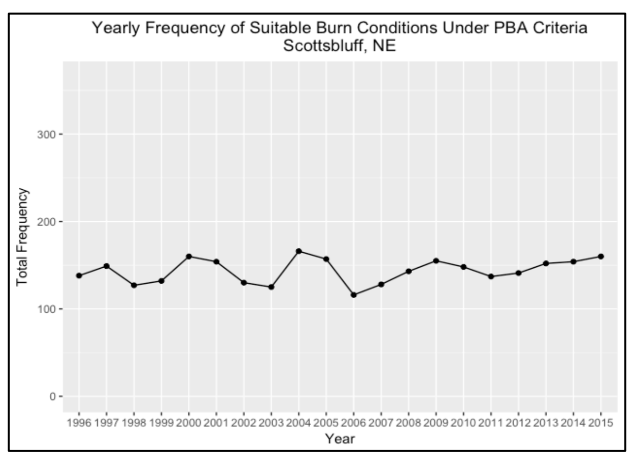
B3. Grand Island, NE



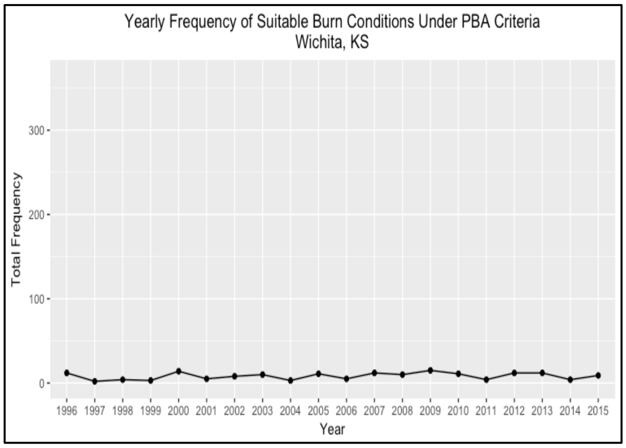
B4. Norfolk, NE



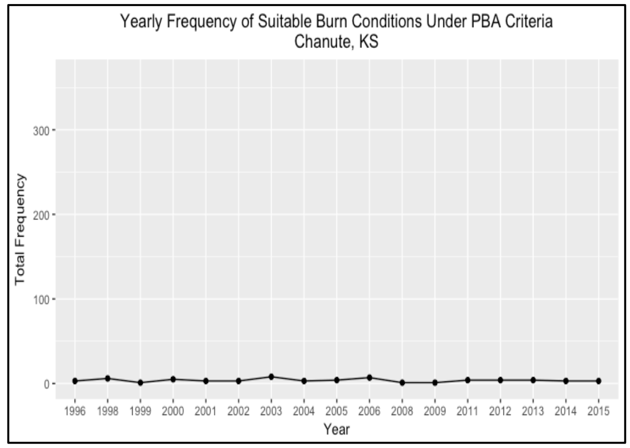
B5. North Platte, NE



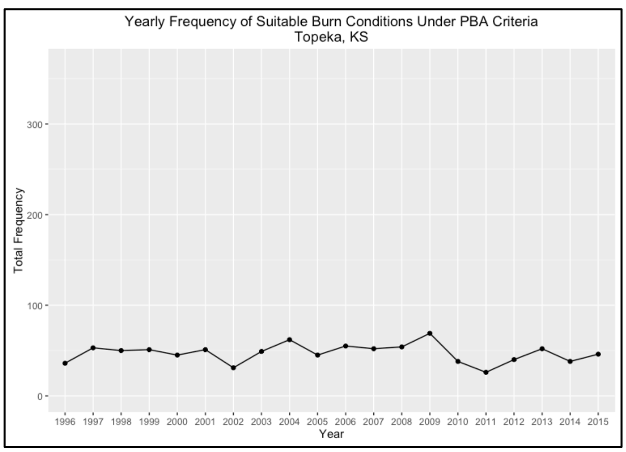
B6. Scottsbluff, NE



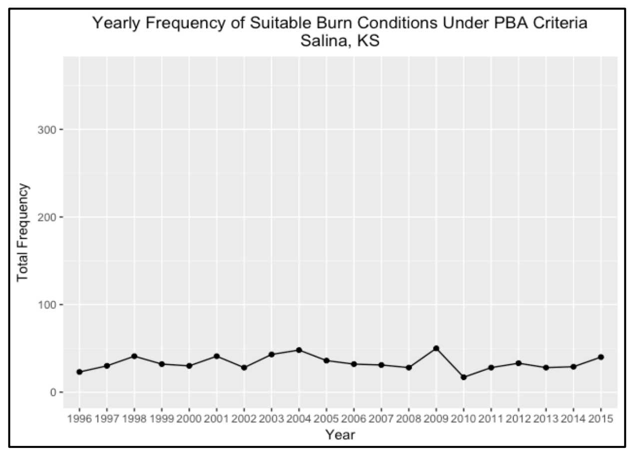
B7. Wichita, KS – Eastern Kansas



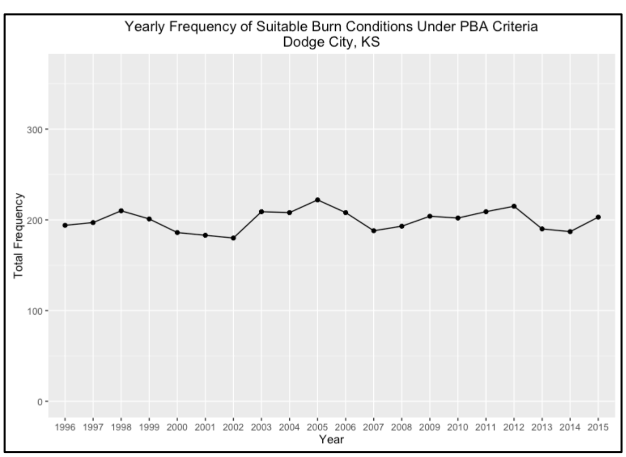
B8. Chanute, KS – Eastern Kansas



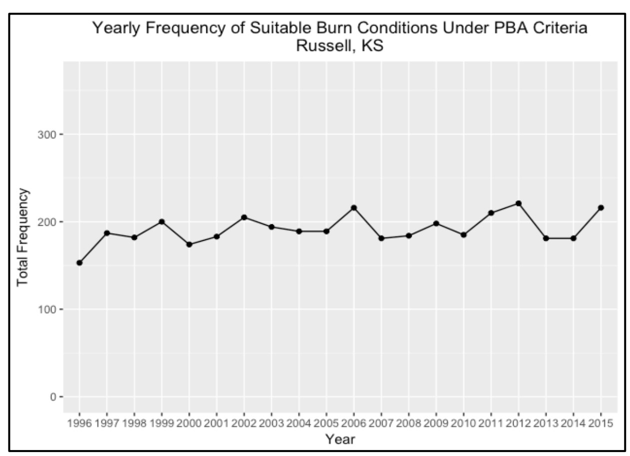
B9. Topeka, KS – Eastern Kansas



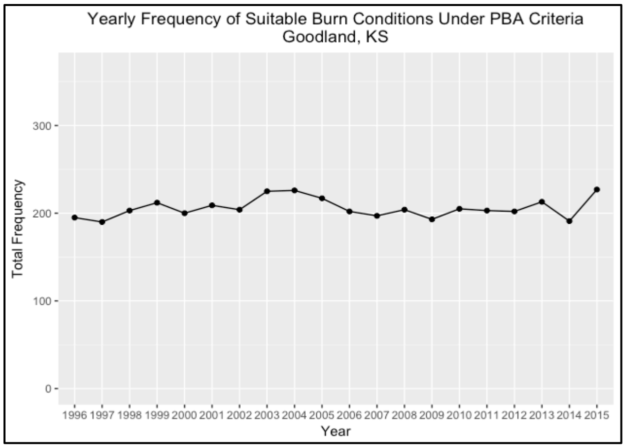
B10. Salina, KS – Eastern Kansas



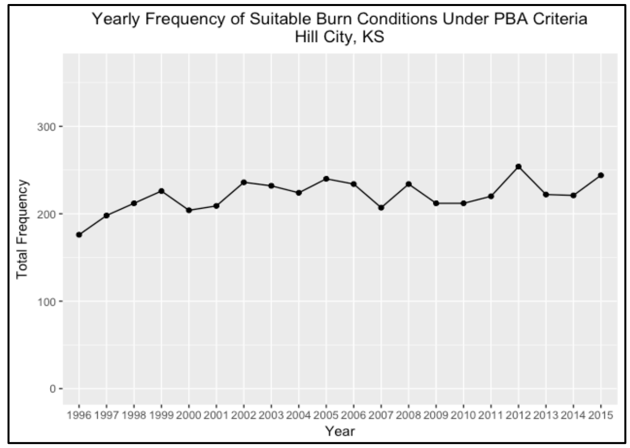
B11. Dodge City, KS – Western Kansas



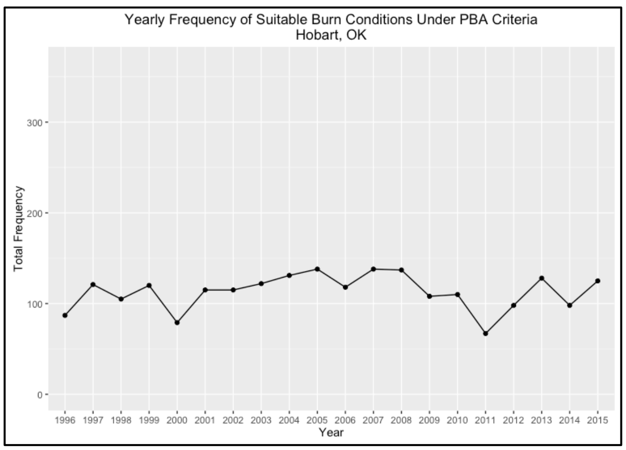
B12. Russell, KS – Western Kansas



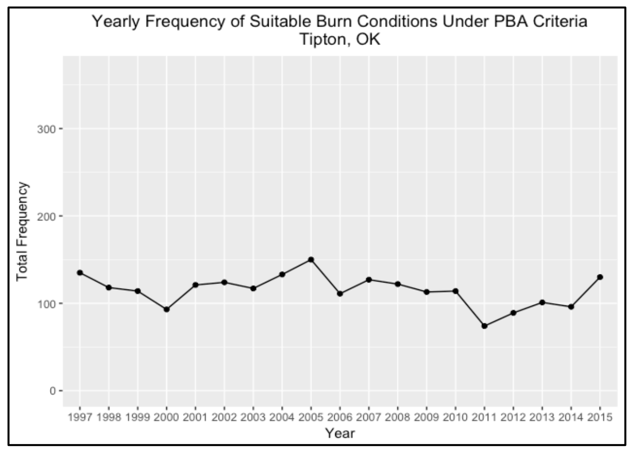
B13. Goodland, KS Western Kansas



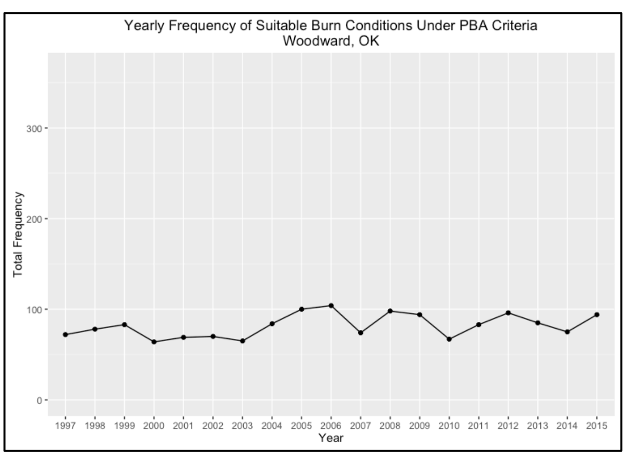
B14. Hill City, KS – Western Kansas



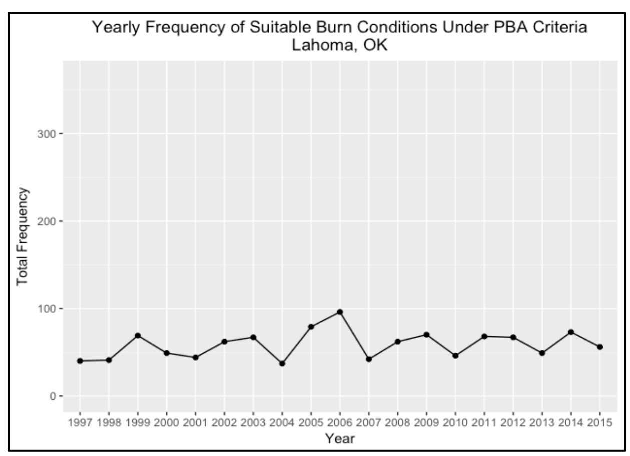
B15. Hobart, OK – Southwest Oklahoma



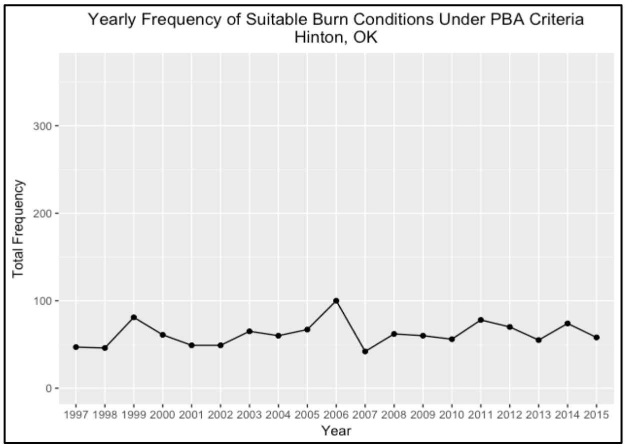
B16. Tipton, OK (Mesonet station) – Southwest Oklahoma



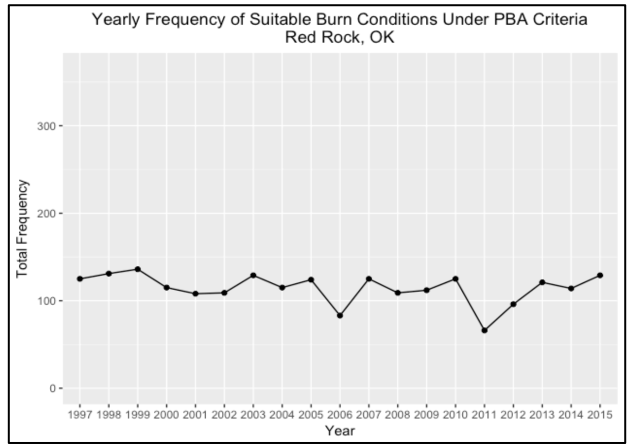
B17. Woodward, OK (Mesonet station) – Northwest OK



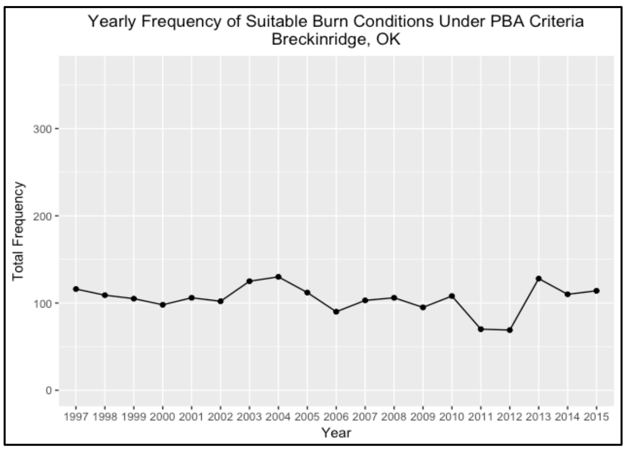
B18. Lahoma, OK (Mesonet station) – Northwest OK



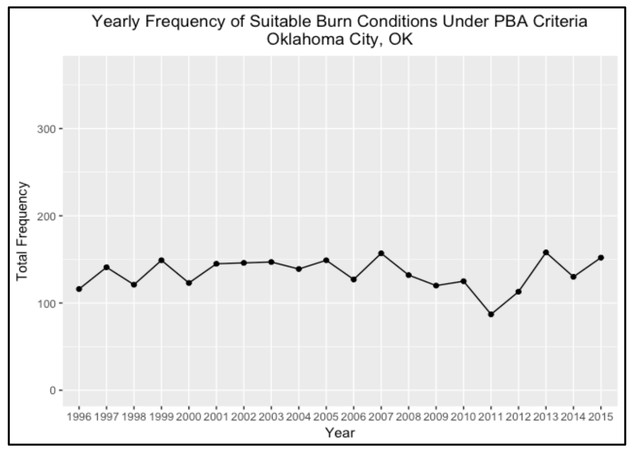
B19. Hinton, OK (Mesonet station) – Northwest Oklahoma



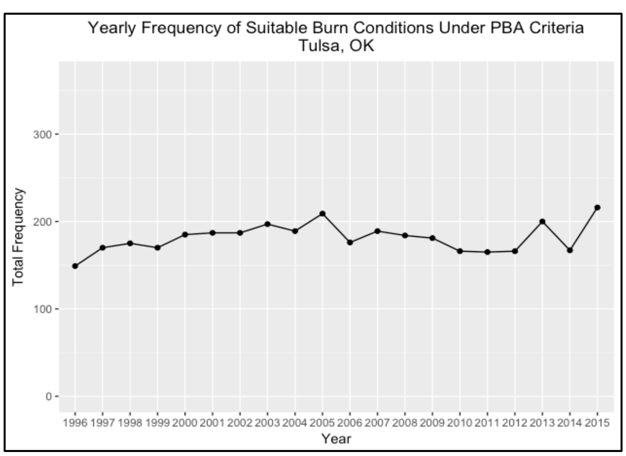
B20. Red Rock, OK (Mesonet station) – North Central Oklahoma



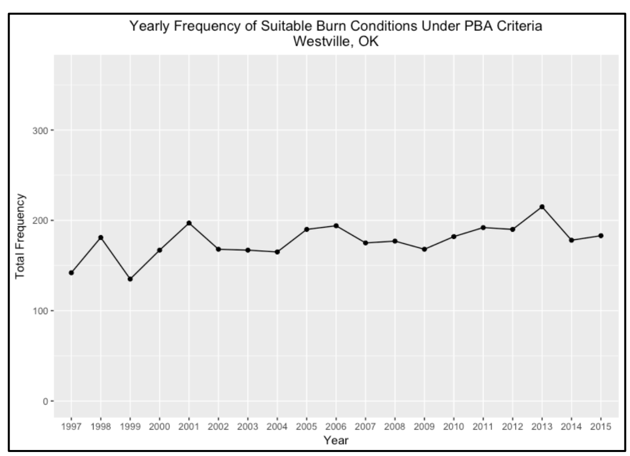
B21. Breckinridge, OK (Mesonet station) – North Central Oklahoma



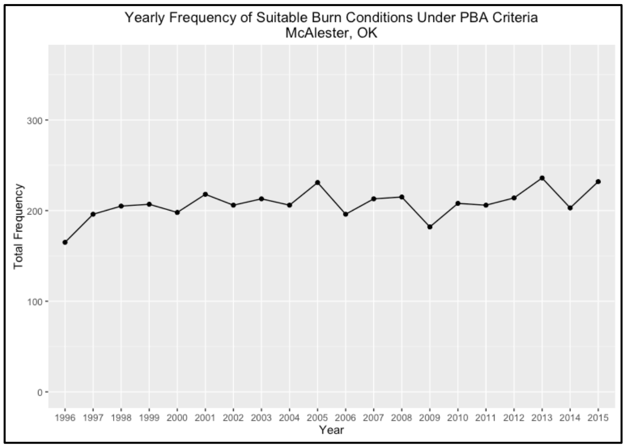
B22. Oklahoma City, OK – Central Oklahoma



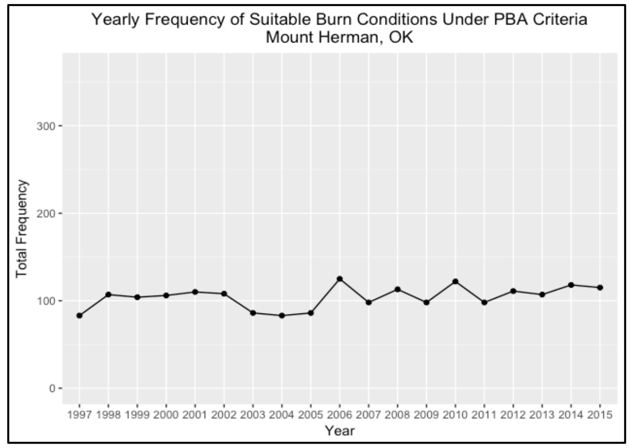
B23. Tulsa, OK – Northeast Oklahoma



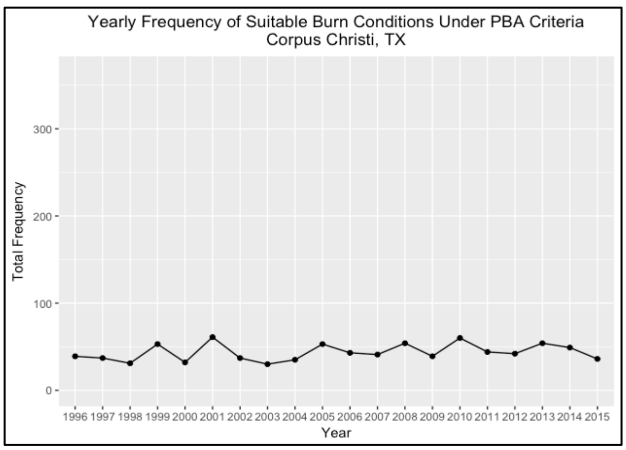
B24. Westville, OK (Mesonet station) – Northeast Oklahoma



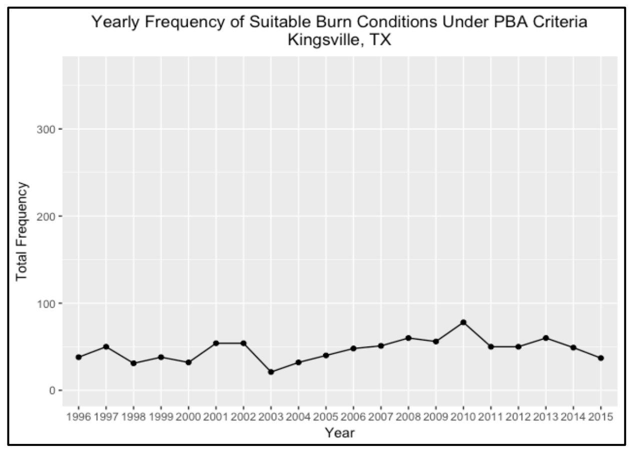
B25. McAlester, OK – Southeast Oklahoma



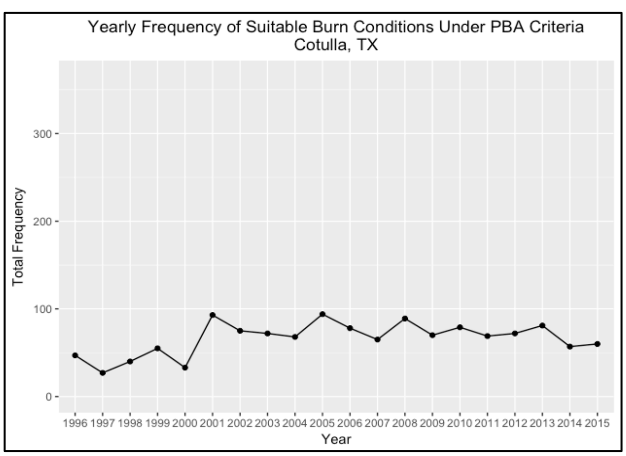
B26. Mount Herman, OK (Mesonet station) – Southeast Oklahoma



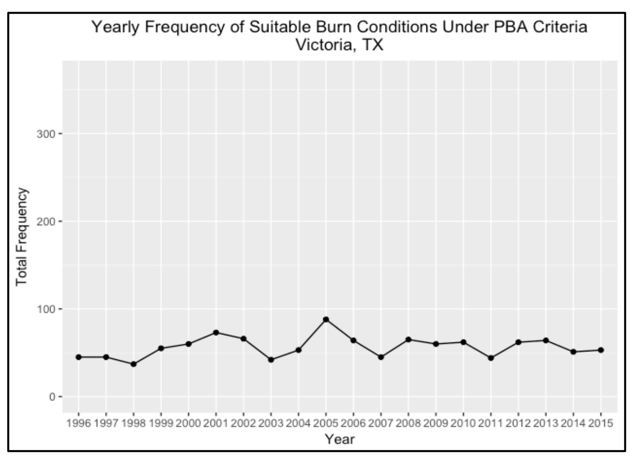
B27. Corpus Christi, TX – Southern Texas



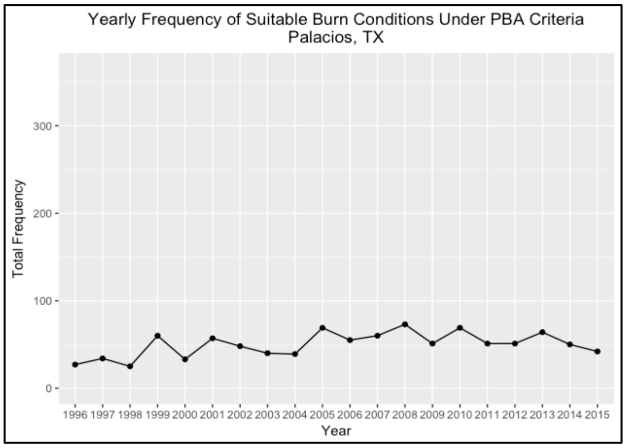
B28. Kingsville, TX – Southern Texas



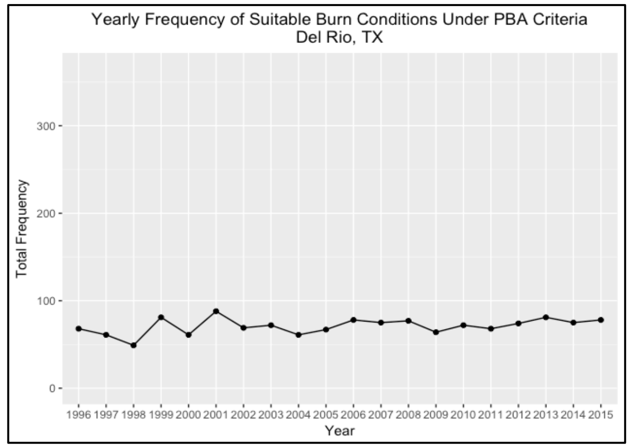
B29. Cotulla, TX – Southern Texas



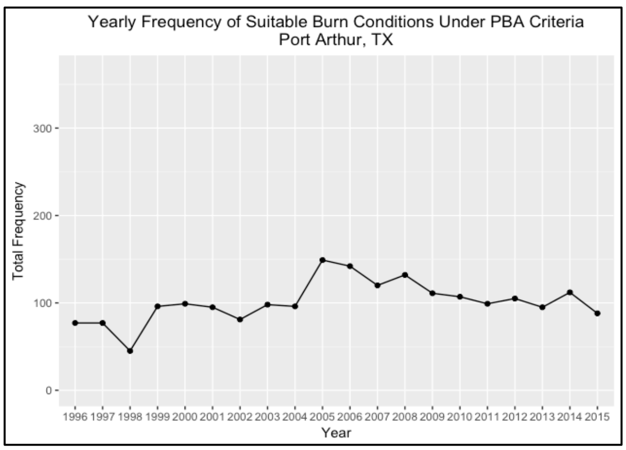
B30. Victoria, TX – Southern Texas



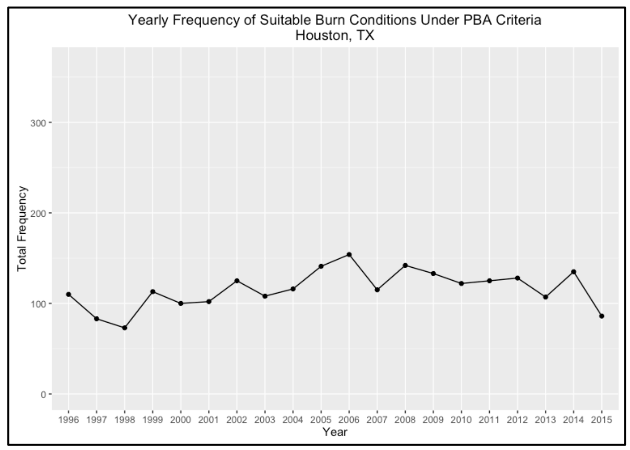
B31. Palacios, TX – Southern Texas



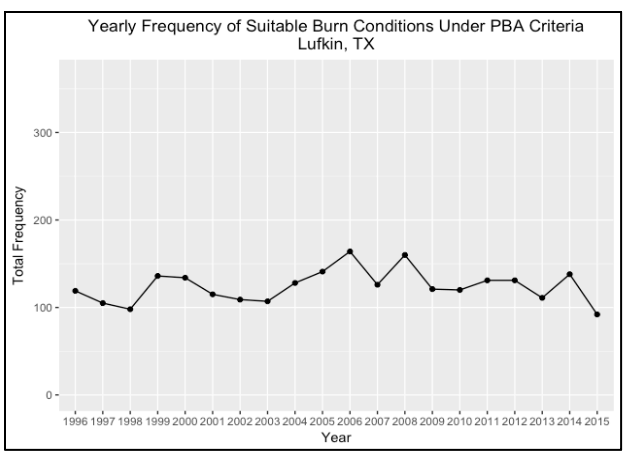
B32. Del Rio, TX – Southern Texas



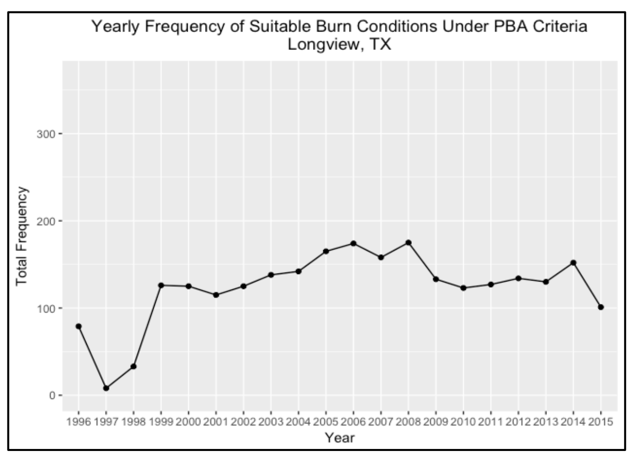
B33. Port Arthur, TX – South Central Texas



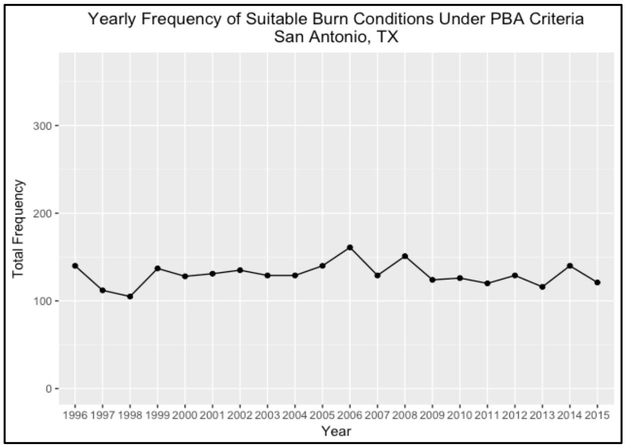
B34. Houston, TX – South Central Texas



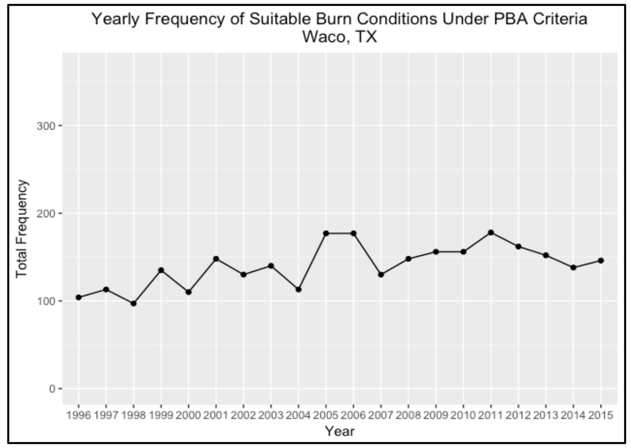
B35. Lufkin, TX – South Central Texas



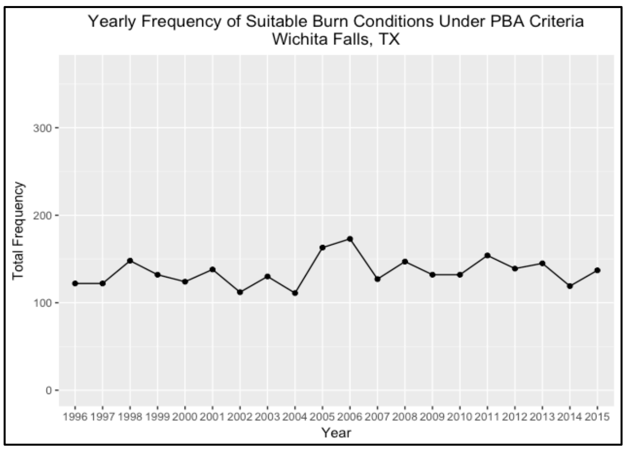
B36. Longview, TX – South Central Texas



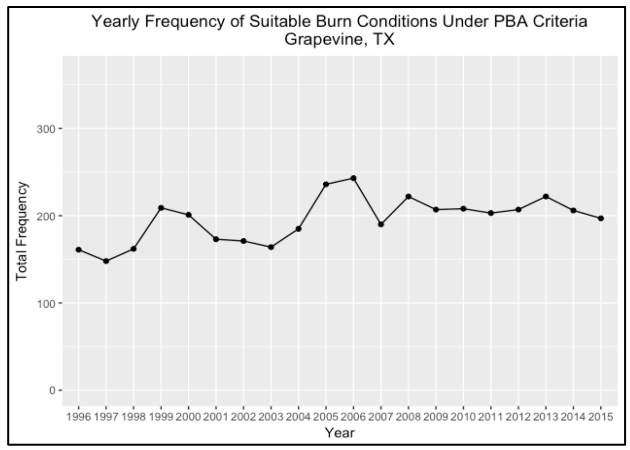
B37. San Antonio, TX – South Central Texas



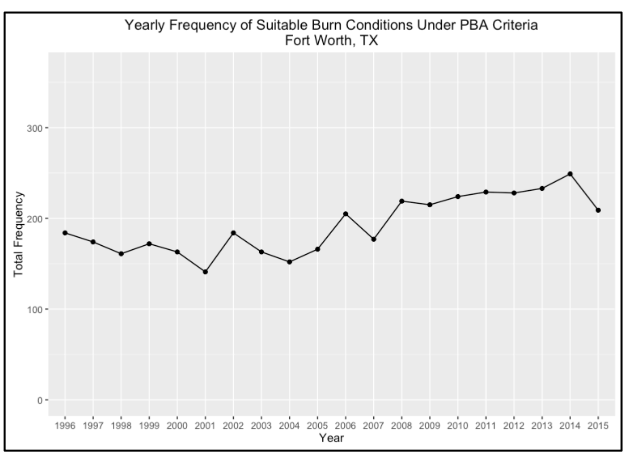
B38. Waco, TX – Central Texas



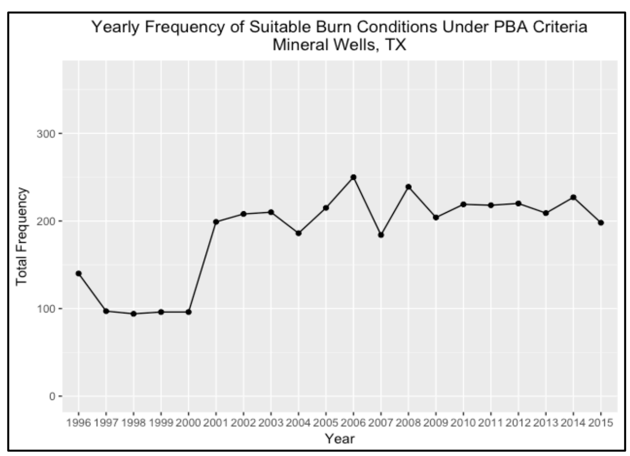
B39. Wichita Falls, TX – West Central Texas



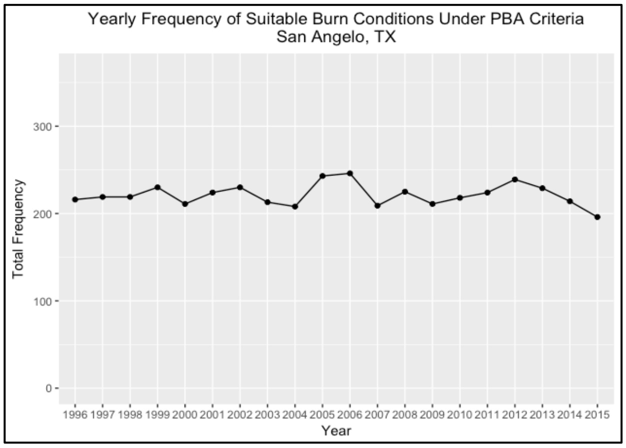
B40. Grapevine, TX – West Central Texas



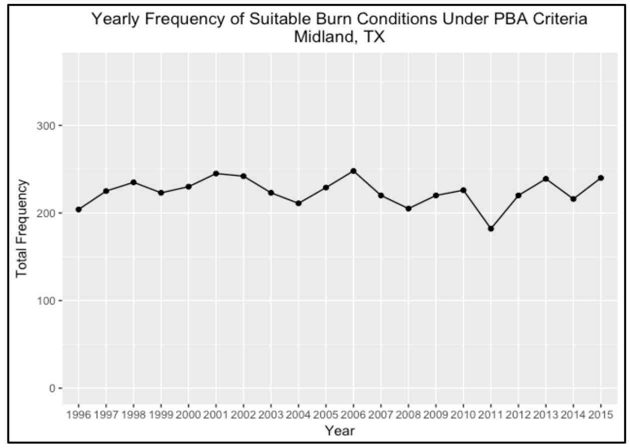
B41. Fort Worth, TX – West Central Texas



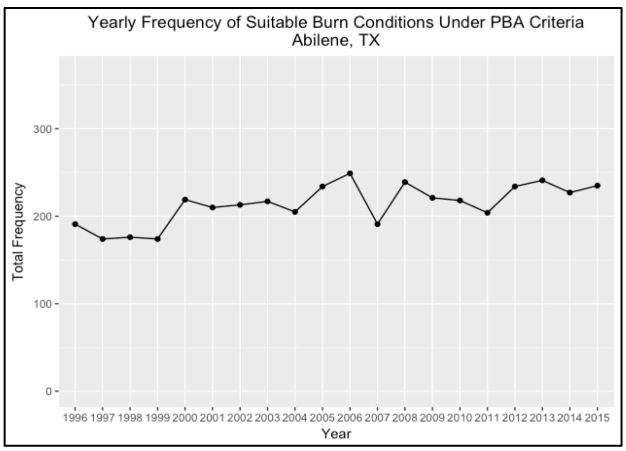
B42. Mineral Wells, TX – West Central Texas



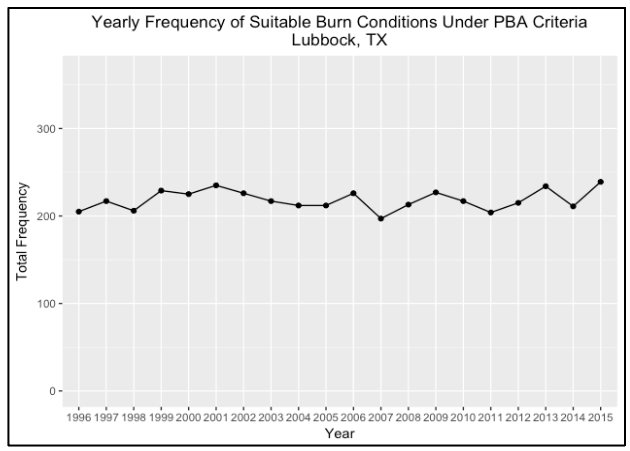
B43. San Angelo, TX – West Central Texas



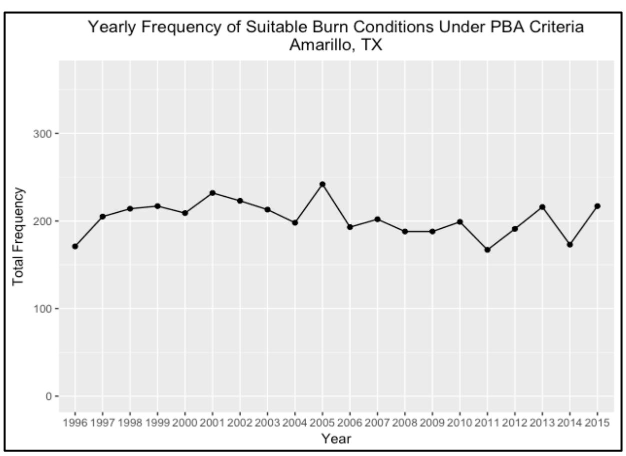
B44. Midland, TX – West Central Texas



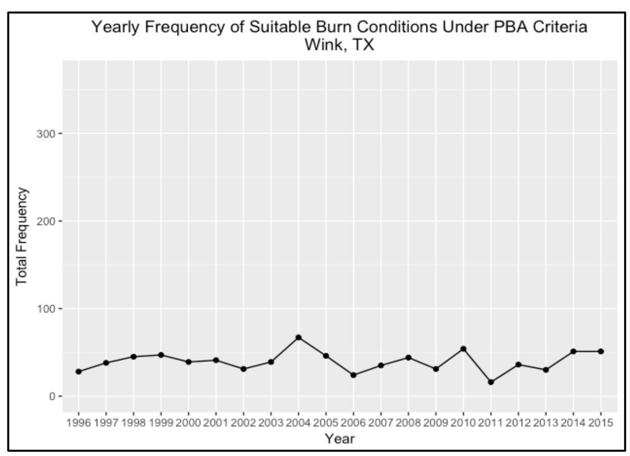
B45. Abilene, TX – West Central Texas



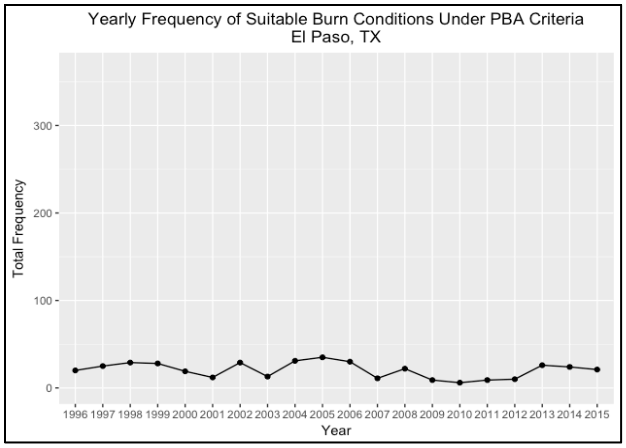
B46. Lubbock, TX – West Central Texas



B47. Amarillo, TX – West Central Texas

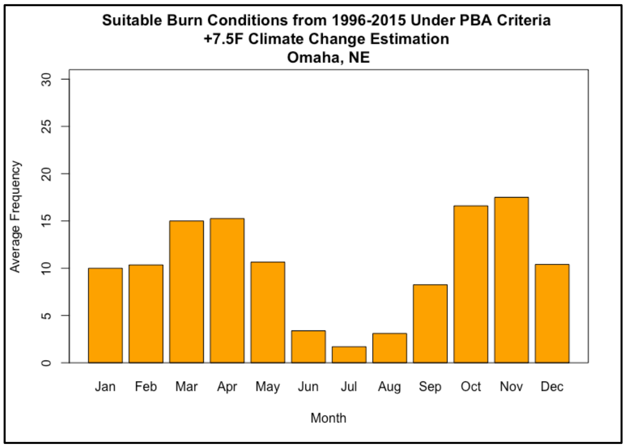


B48. Wink, TX – Southwest Texas

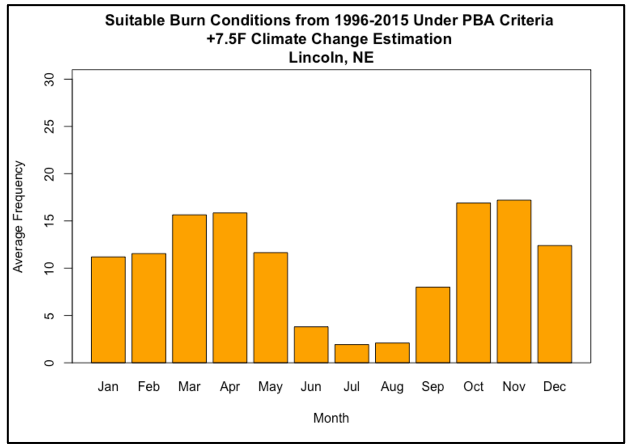


B49. El Paso, TX – Southwest Texas

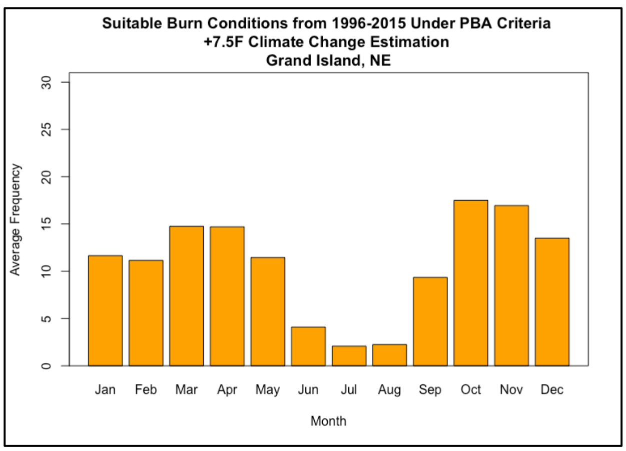
Appendix C: Average monthly frequency of suitable burn days under climate change conditions for end-of-century timeframe



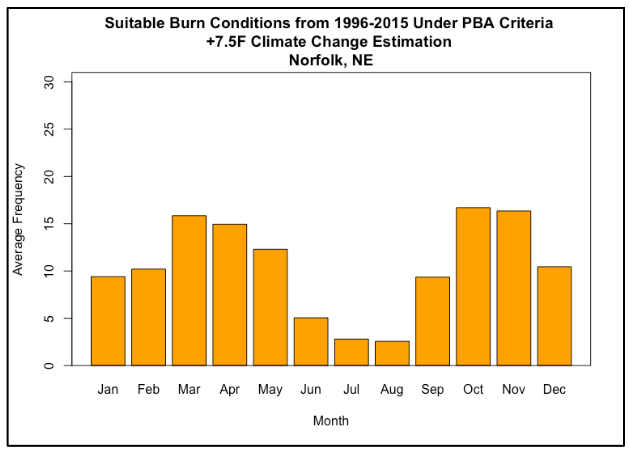
C1. Omaha, NE – All thresholds are constant throughout the state



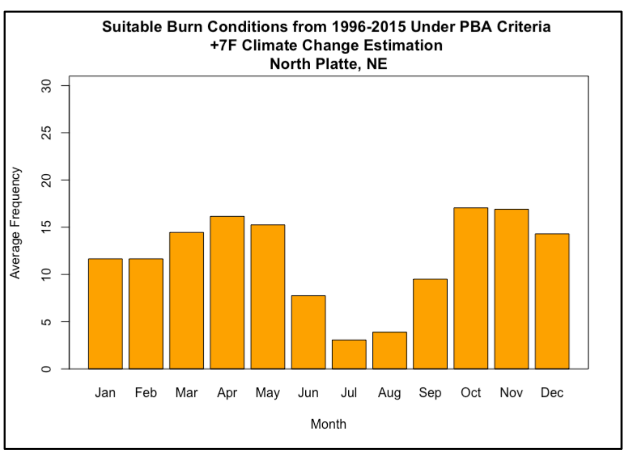
C2. Lincoln, NE



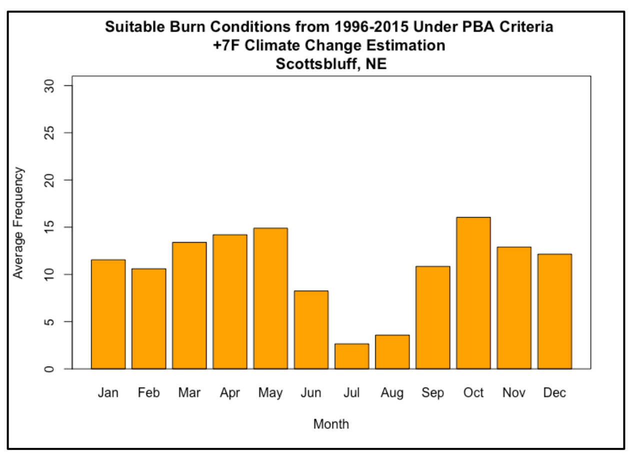
C3. Grand Island, NE



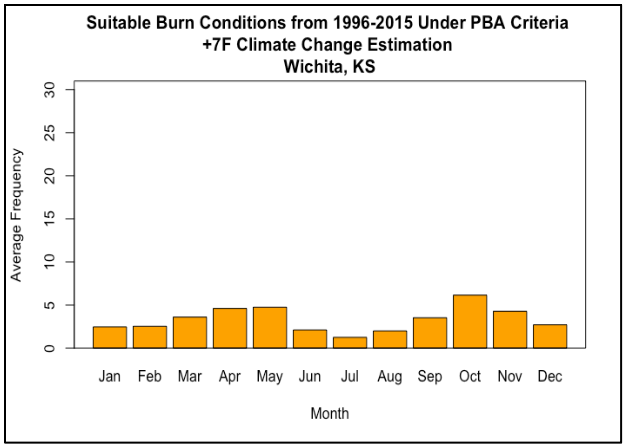
C4. Norfolk, NE



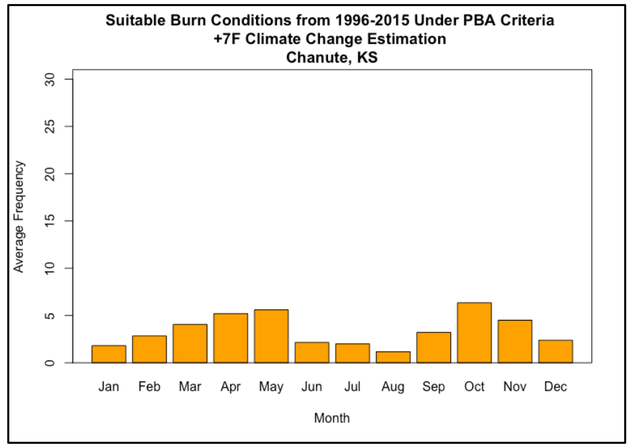
C5. North Platte, NE



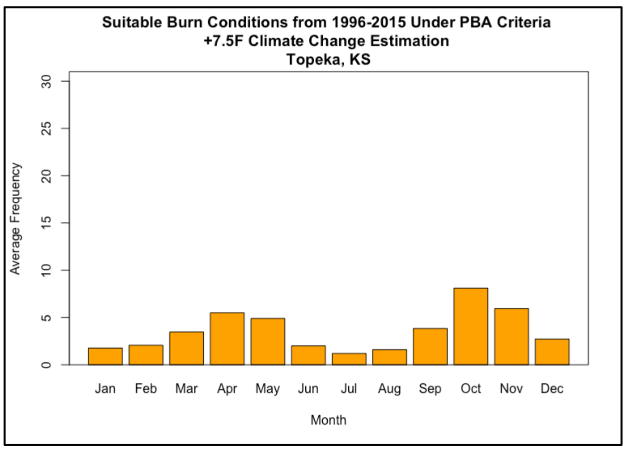
C6. Scottsbluff, NE



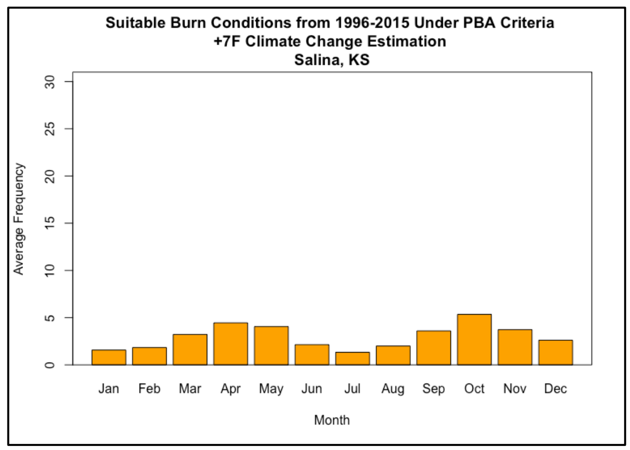
C7. Wichita, KS – Eastern Kansas



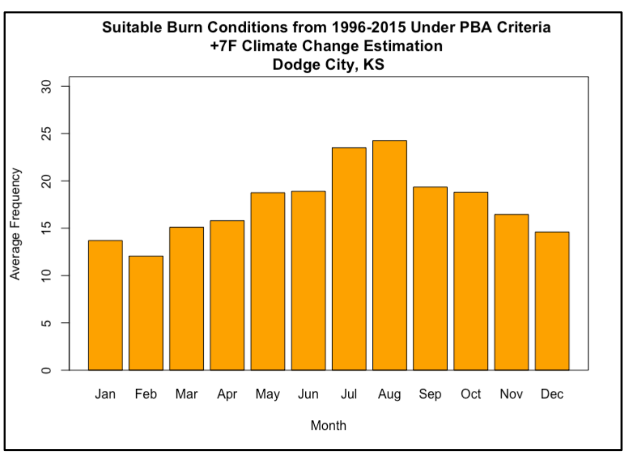
C8. Chanute, KS – Eastern Kansas



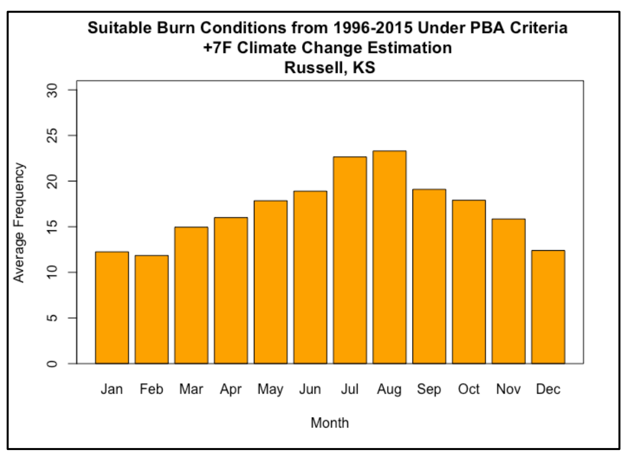
C9. Topeka, KS – Eastern Kansas



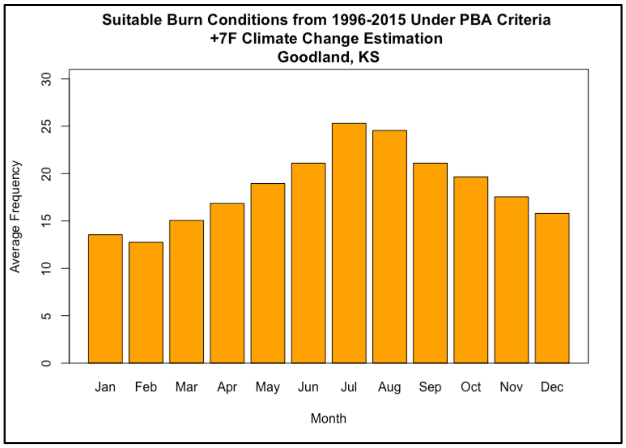
C10. Salina, KS – Eastern Kansas



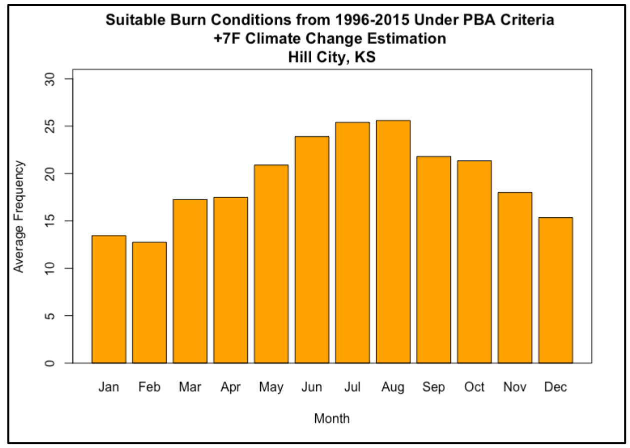
C11. Dodge City, KS – Western Kansas



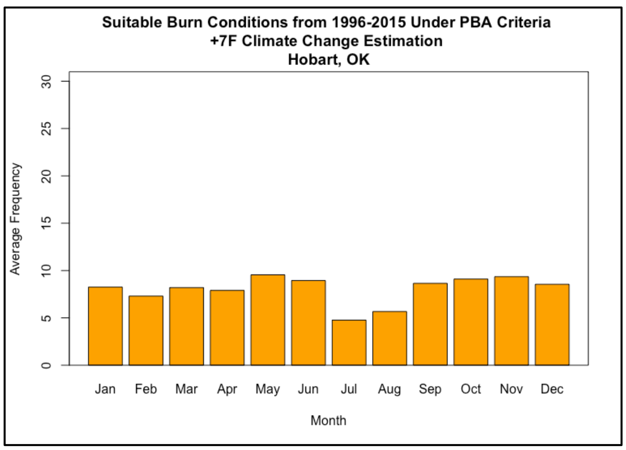
C12. Russell, KS – Western Kansas



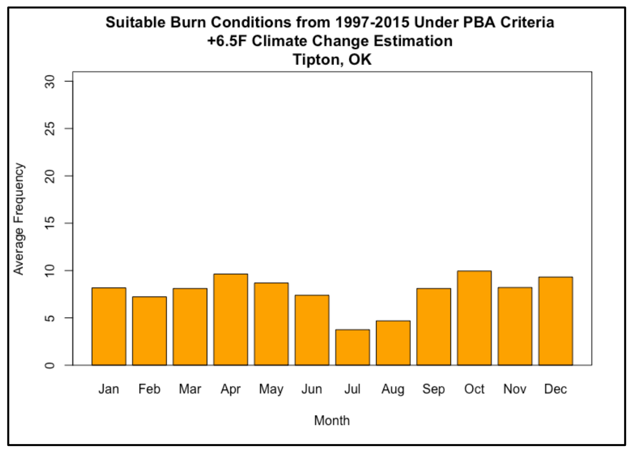
C13. Goodland, KS Western Kansas



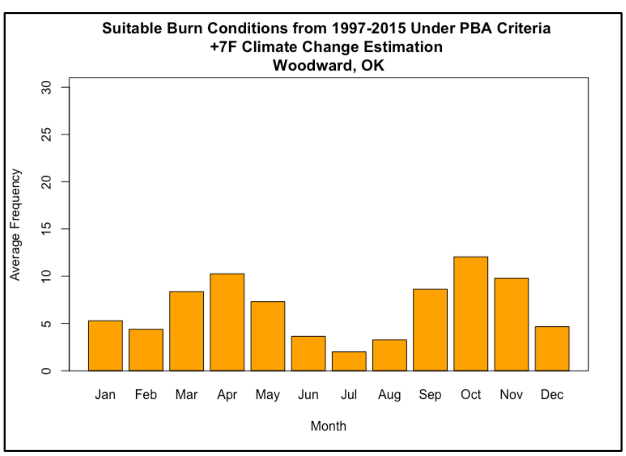
C14. Hill City, KS – Western Kansas



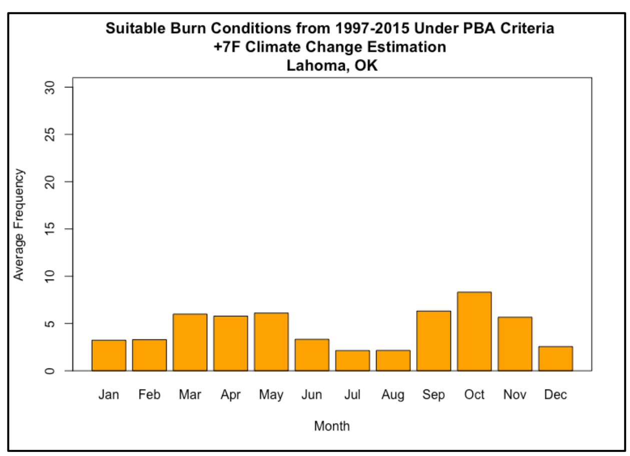
C15. Hobart, OK – Southwest Oklahoma



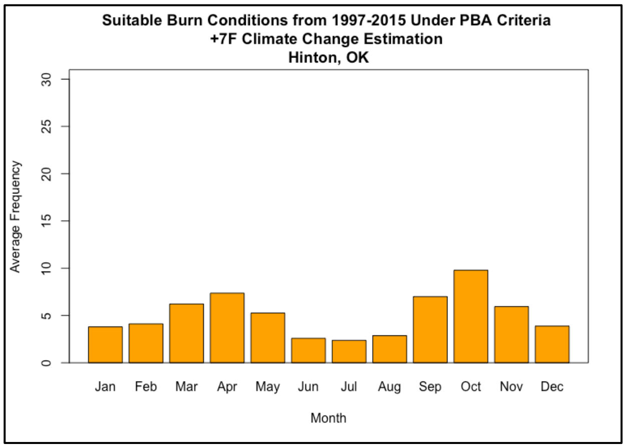
C16. Tipton, OK (Mesonet station) – Southwest Oklahoma



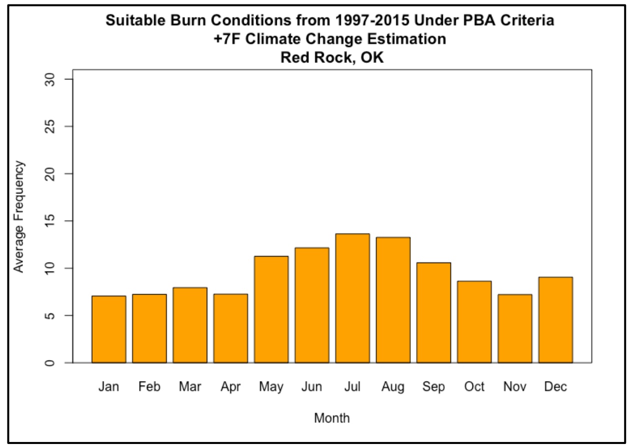
C17. Woodward, OK (Mesonet station) – Northwest OK



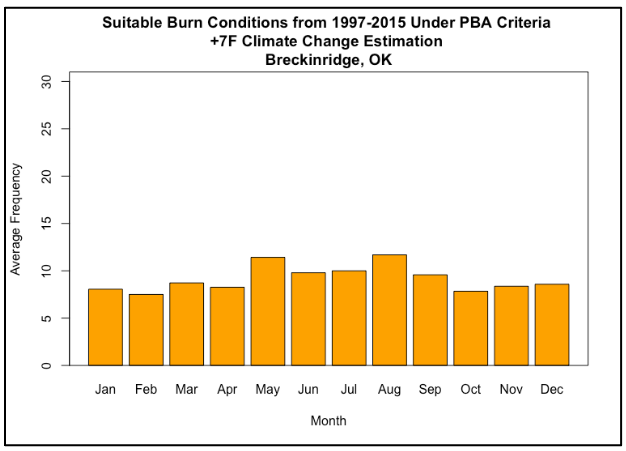
C18. Lahoma, OK (Mesonet station) – Northwest OK



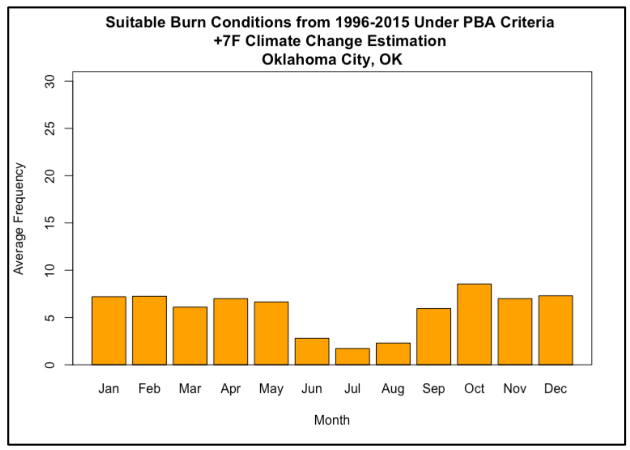
C19. Hinton, OK (Mesonet station) – Northwest Oklahoma



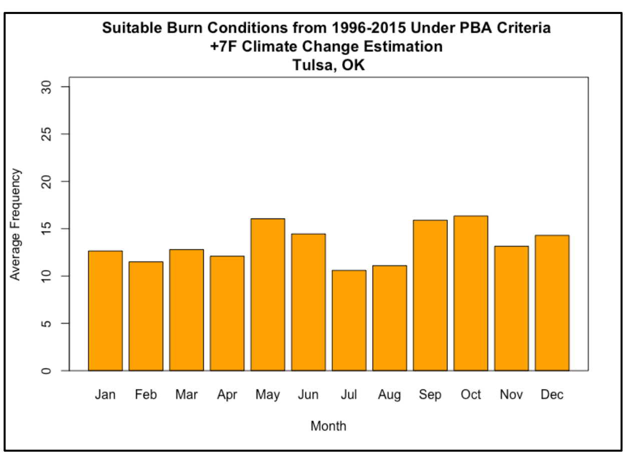
C20. Red Rock, OK (Mesonet station) – North Central Oklahoma



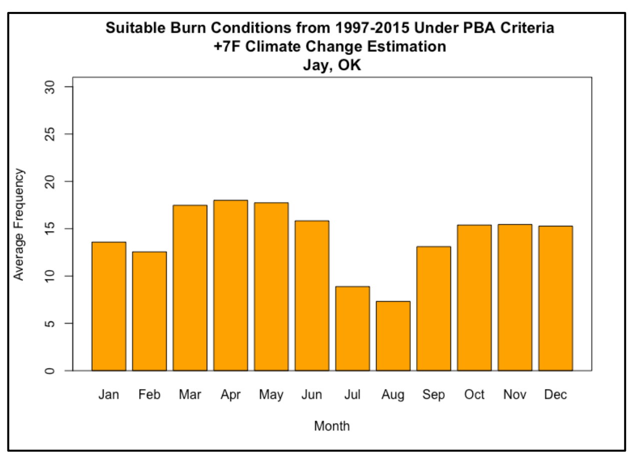
C21. Breckinridge, OK (Mesonet station) – North Central Oklahoma



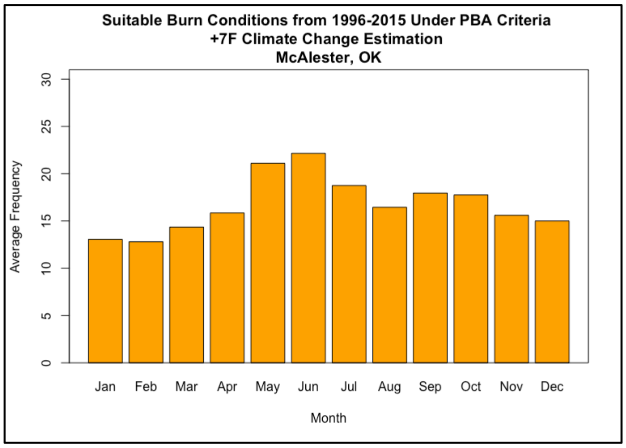
C22. Oklahoma City, OK – Central Oklahoma



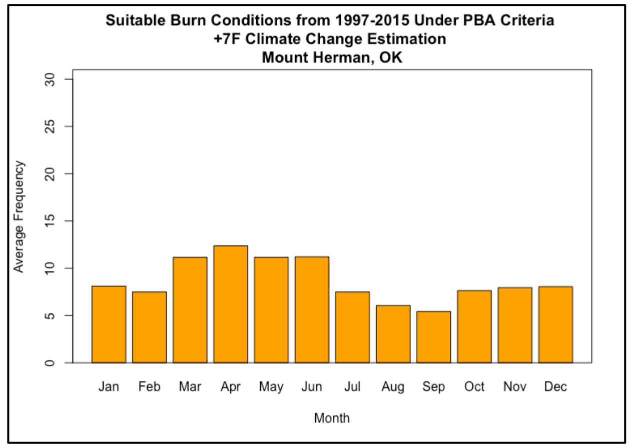
C23. Tulsa, OK – Northeast Oklahoma



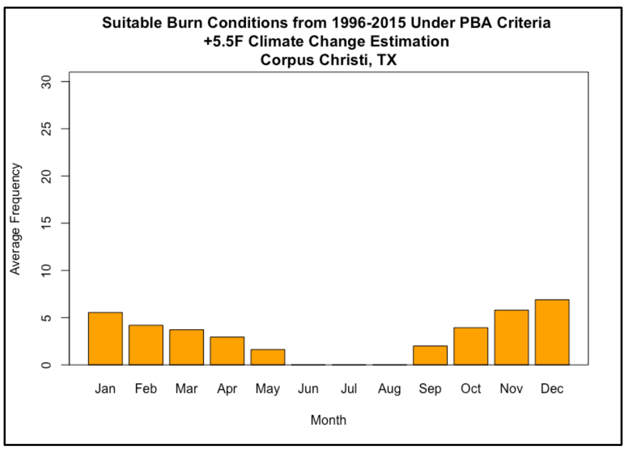
C24. Jay, OK (Mesonet station) – Northeast Oklahoma



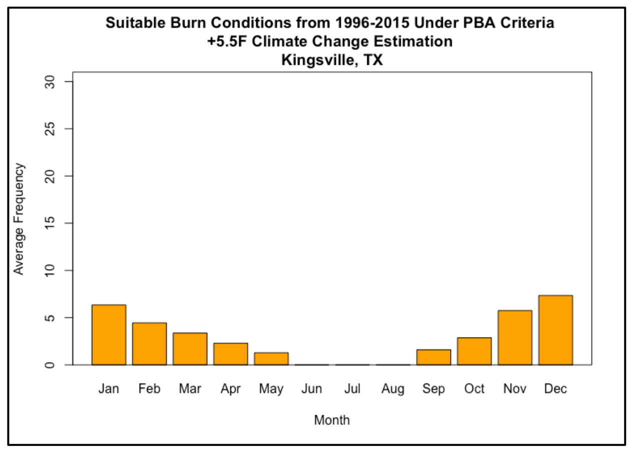
C25. McAlester, OK – Southeast Oklahoma



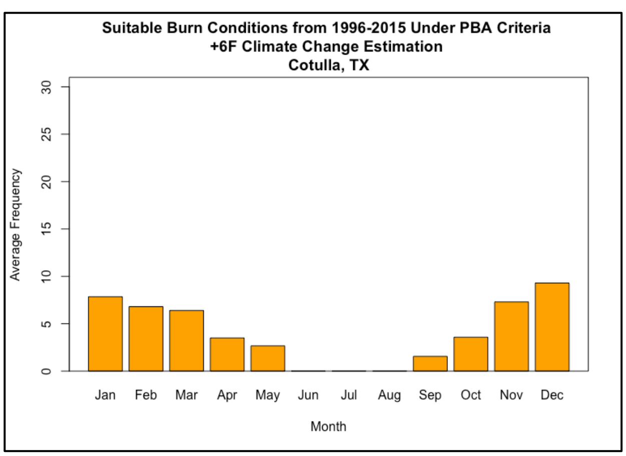
C26. Mount Herman, OK (Mesonet station) – Southeast Oklahoma



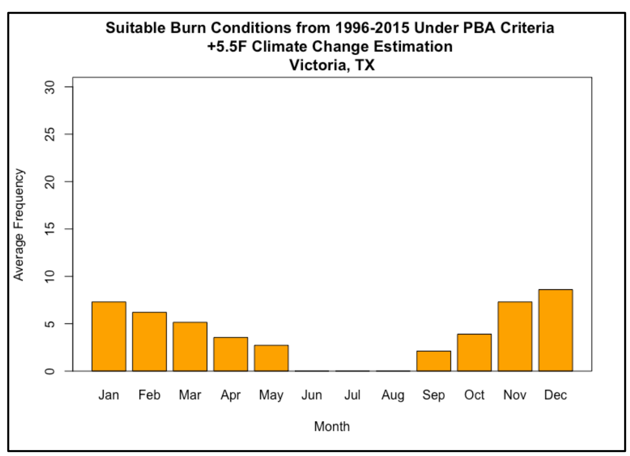
C27. Corpus Christi, TX – Southern Texas



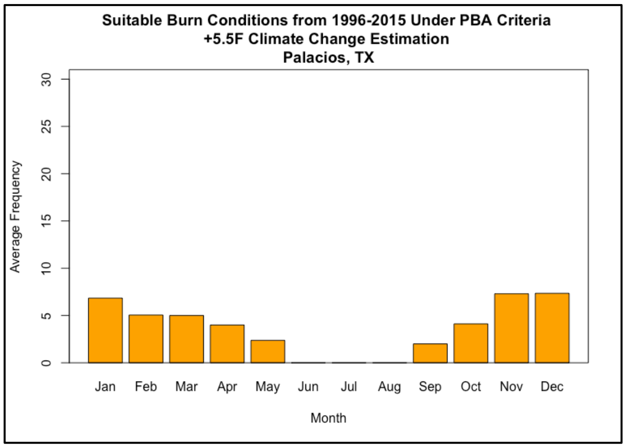
C28. Kingsville, TX – Southern Texas



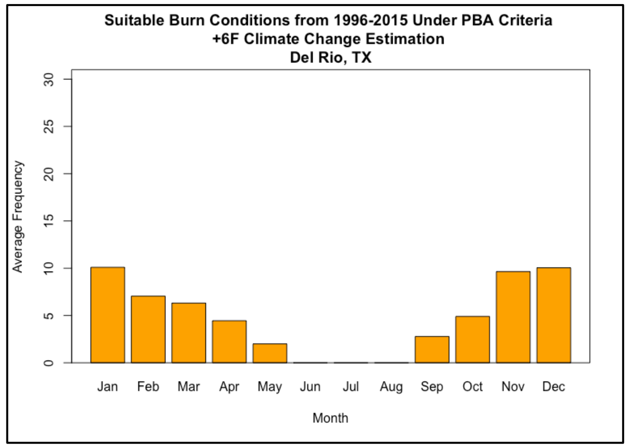
C29. Cotulla, TX – Southern Texas



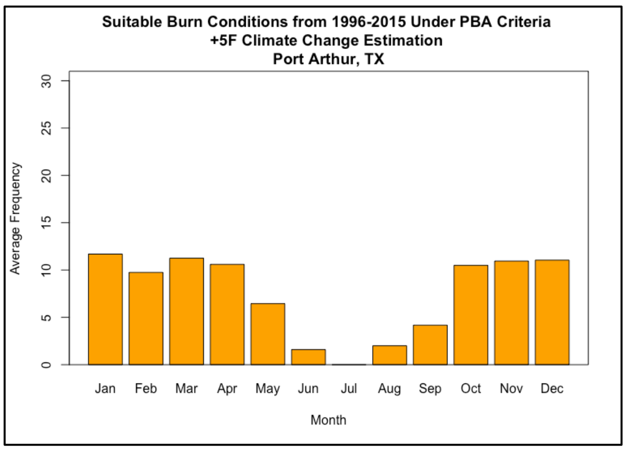
C30. Victoria, TX – Southern Texas



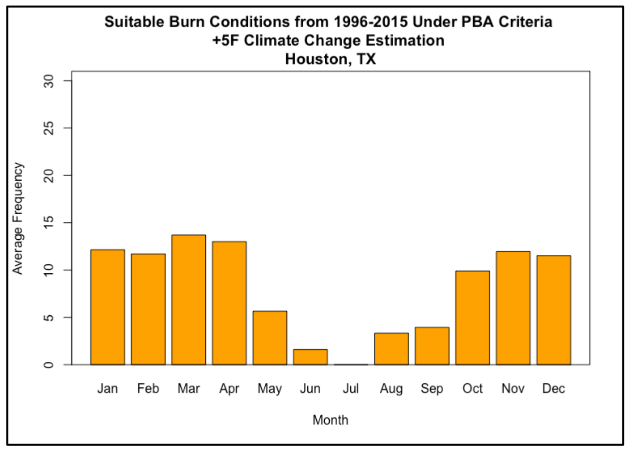
C31. Palacios, TX – Southern Texas



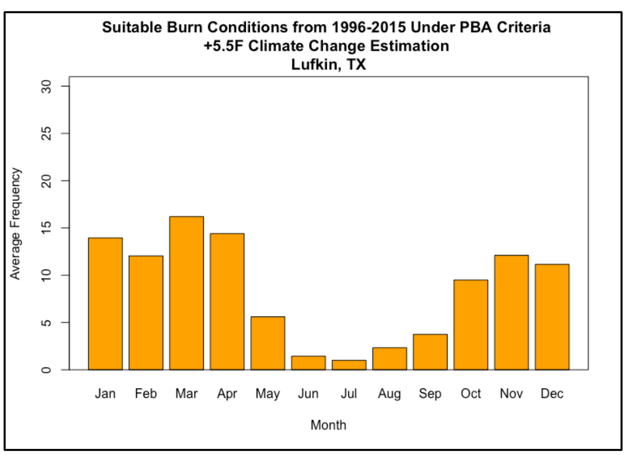
C32. Del Rio, TX – Southern Texas



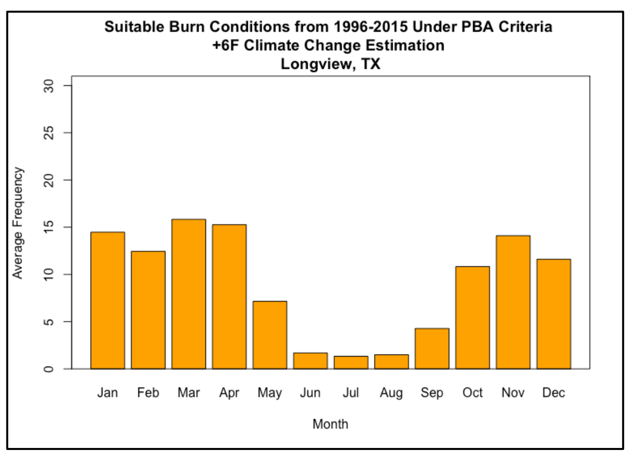
C33. Port Arthur, TX – South Central Texas



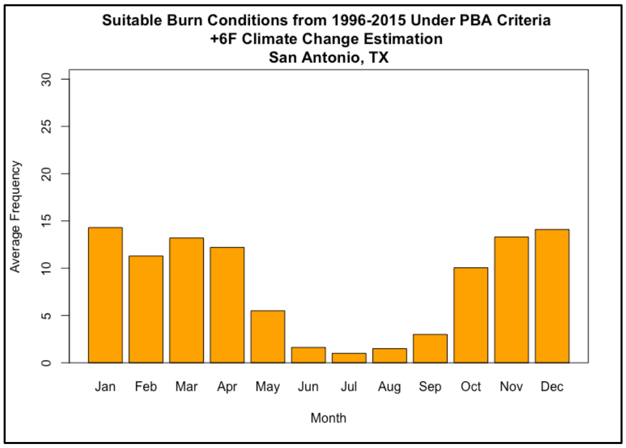
C34. Houston, TX – South Central Texas



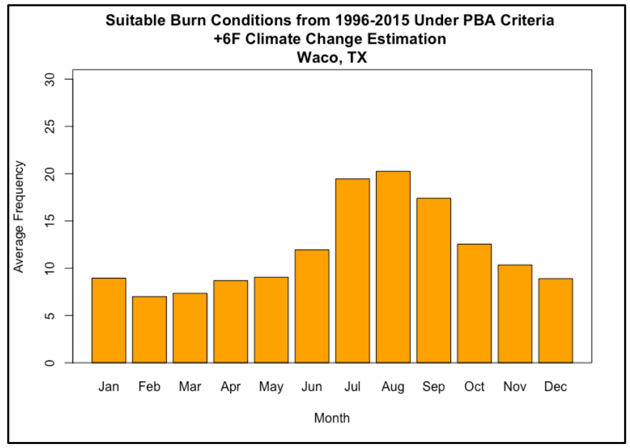
C35. Lufkin, TX – South Central Texas



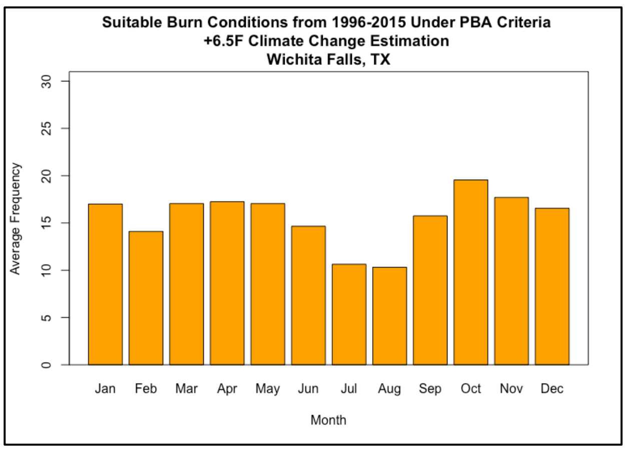
C36. Longview, TX – South Central Texas



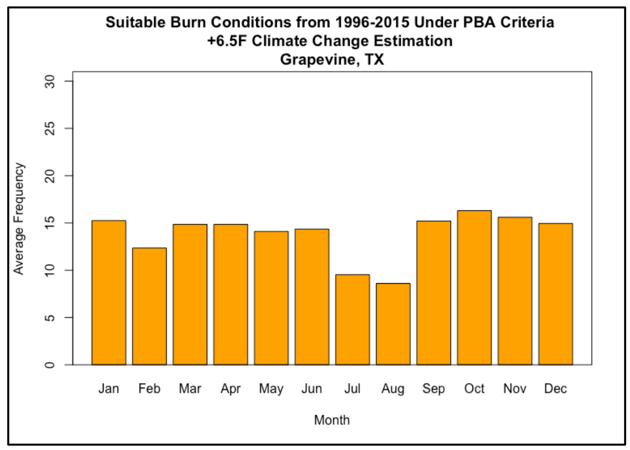
C37. San Antonio, TX – South Central Texas



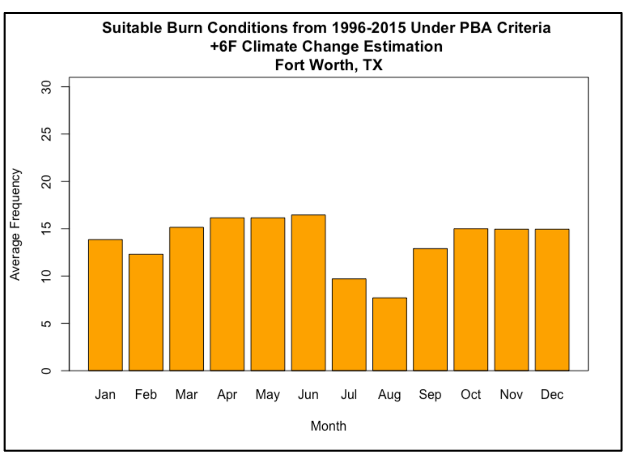
C38. Waco, TX – Central Texas



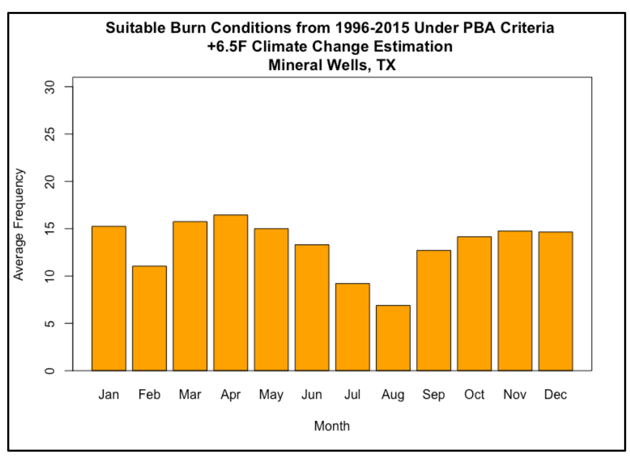
C39. Wichita Falls, TX – West Central Texas



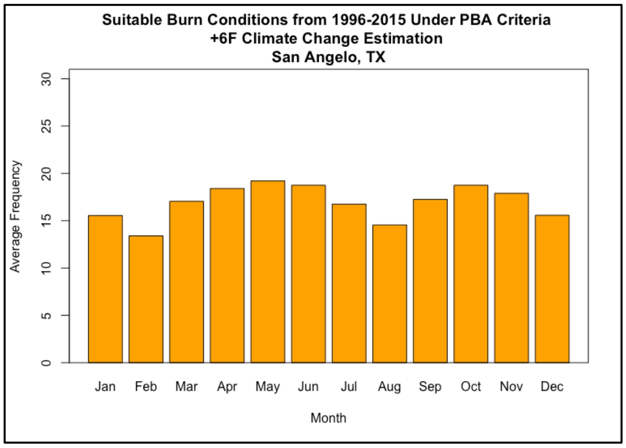
C40. Grapevine, TX – West Central Texas



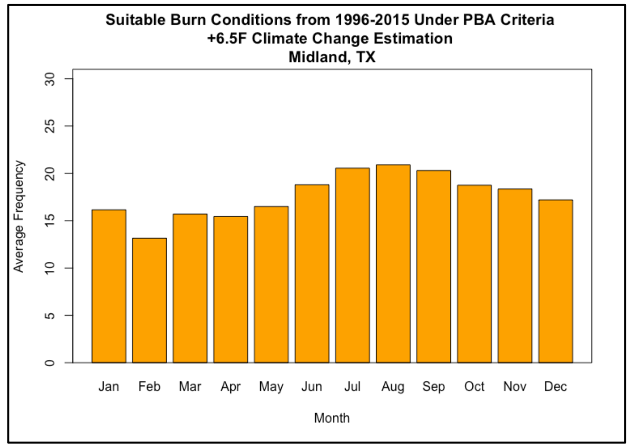
C41. Fort Worth, TX – West Central Texas



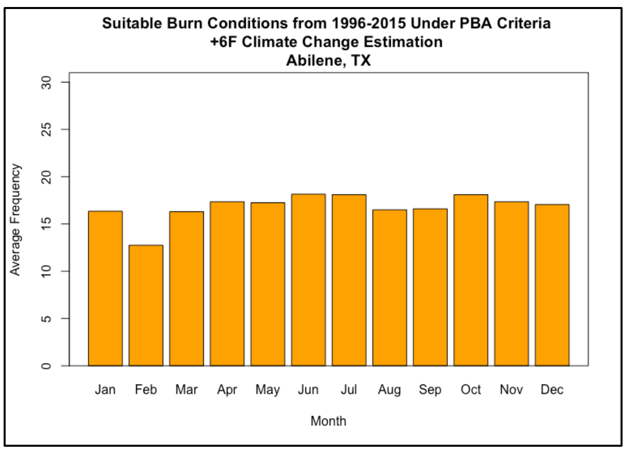
C42. Mineral Wells, TX – West Central Texas



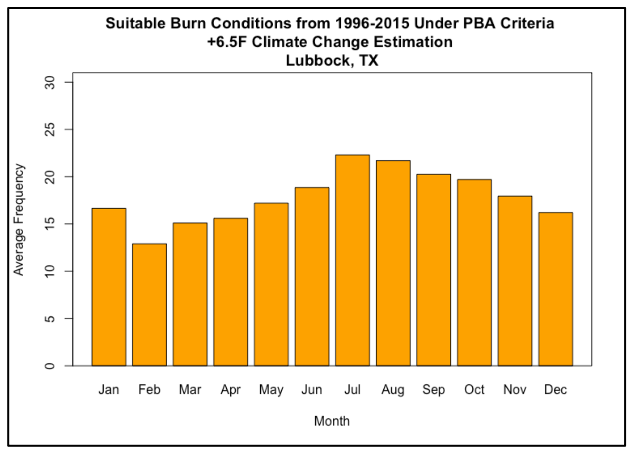
C43. San Angelo, TX – West Central Texas



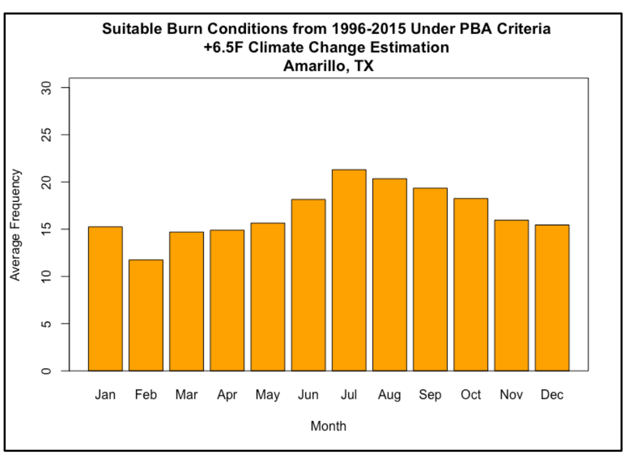
C44. Midland, TX – West Central Texas



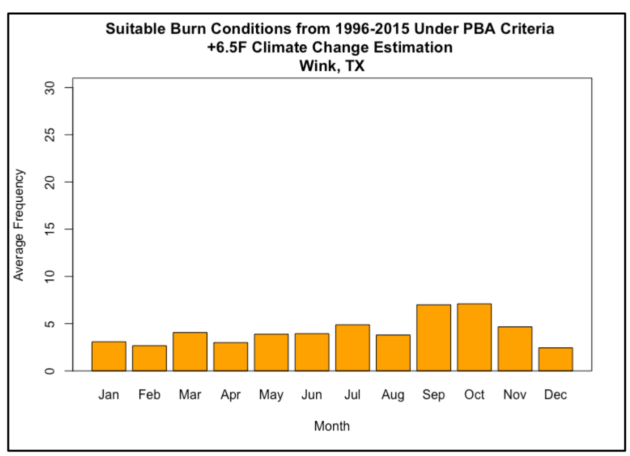
C45. Abilene, TX – West Central Texas



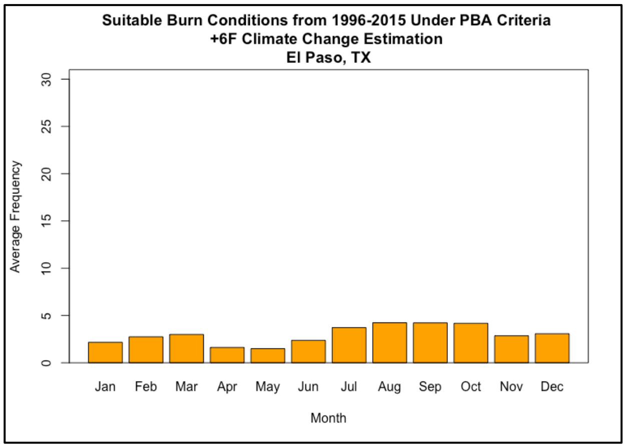
C46. Lubbock, TX – West Central Texas



C47. Amarillo, TX – West Central Texas

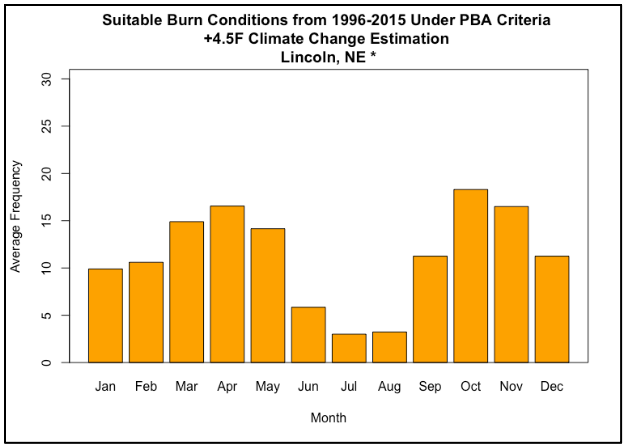


C48. Wink, TX – Southwest Texas

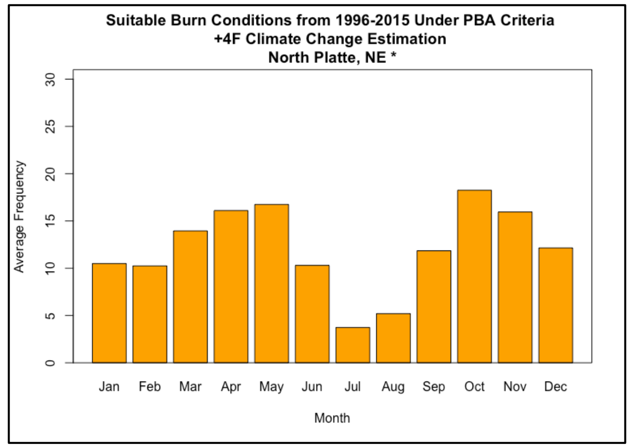


C49. El Paso, TX – Southwest Texas

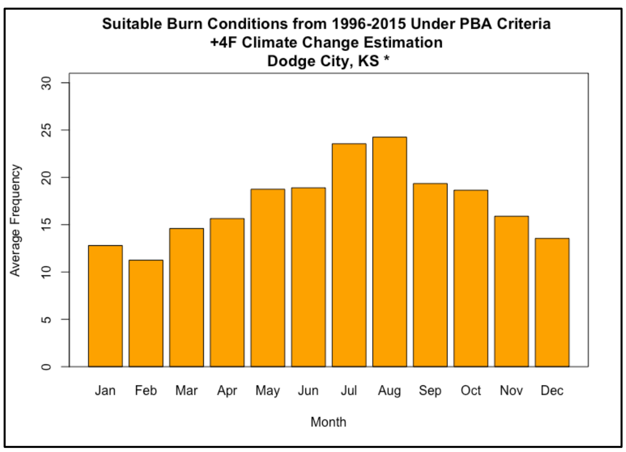
Appendix D: Average monthly frequency of suitable burn days under climate change conditions (* depicts a mid-century estimation)



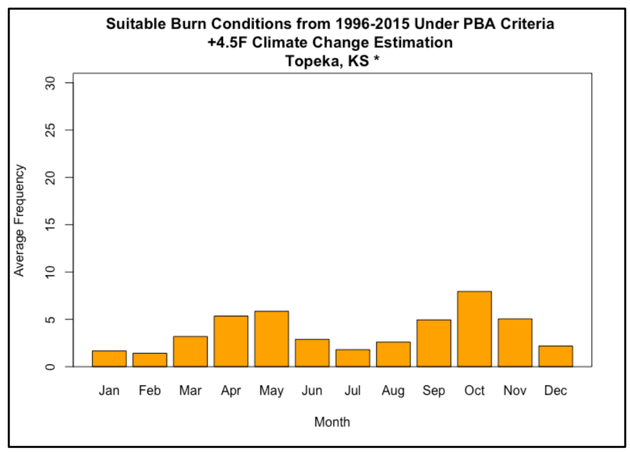
D1. Lincoln, NE



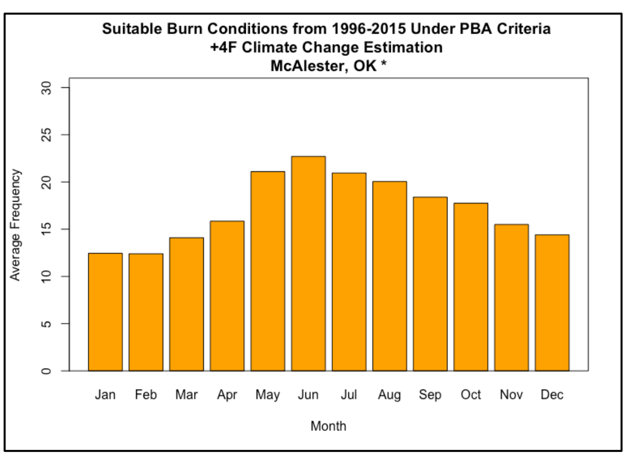
D2. North Platte, NE



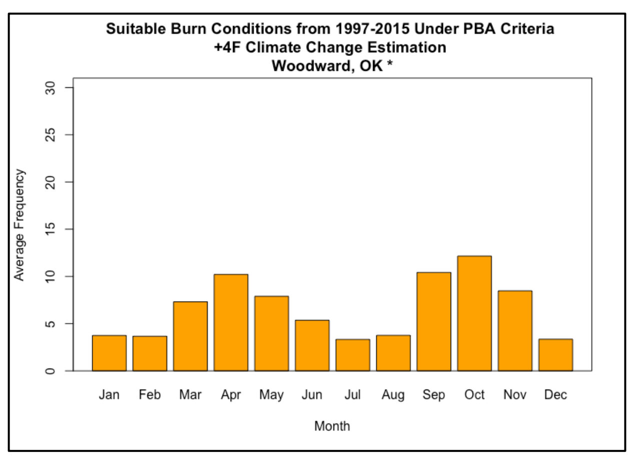
D3. Dodge City, KS



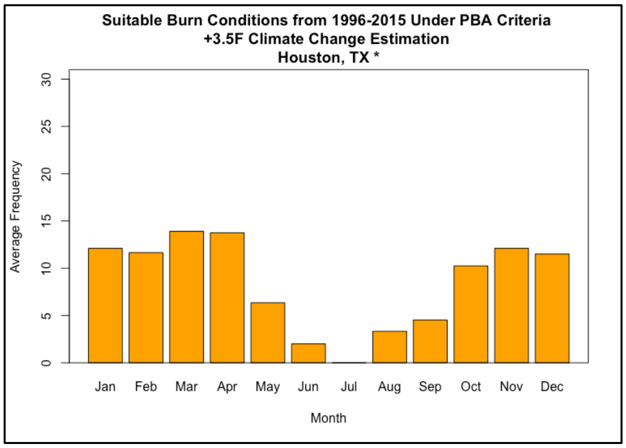
D4. Topeka, KS



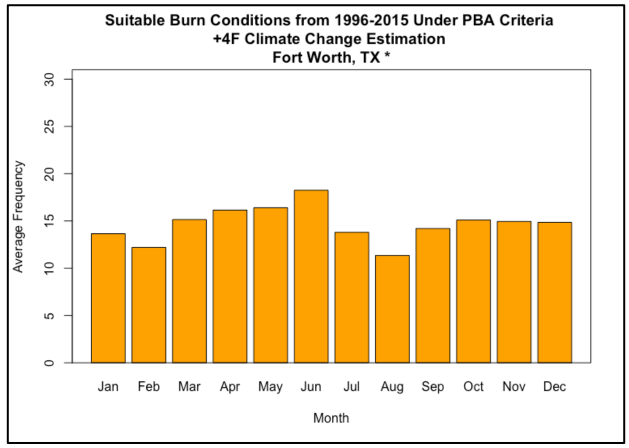
D5. McAlester, OK



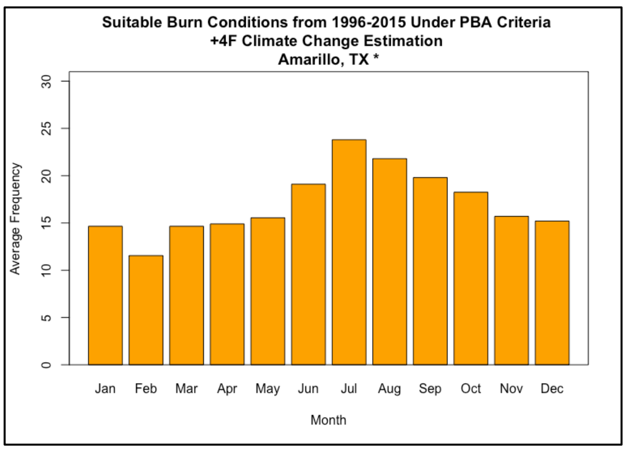
D6. Woodward, OK (Mesonet station)



D7. Houston, TX



D8. Fort Worth, TX



D9. Amarillo, TX

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