J11.3 A COMPARISON OF PRECIPITATION AND DROUGHT INDICES RELATED TO FIRE ACTIVITY AND POTENTIAL IN THE US

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1. INTRODUCTION

At least thirteen drought indices for the United States (US) have been developed since the early 1900s (Heim 2002). Four commonly used drought indices that may be most applicable to wildfire are the Palmer Drought Severity Index (PDSI), the Palmer-Z (a derivative of the PDSI), the Standardized Precipitation Index (SPI) and the Keetch-Byrum Drought Index (KBDI). The first three of these indices can represent monthly and longer time scales. KBDI, originally designed for fire control managers, represents a much finer temporal resolution (days). In this study, the longer time-scales are of most interest, so KBDI will not be considered further.

The PDSI, Palmer-Z and SPI all measure drought in different ways and for different purposes. An overview of each index is discussed and monthly correlations of these indices with the number of fire starts, acres burned, and Energy Release Component (ERC) values are examined. The ERC is a measure of how hot a fire might burn related to the available energy (BTU) per unit area (square foot) within the flaming front at the head of a fire (e.g., NWCG 2002). Because it reflects the contribution that all live and dead fuels have to potential fire intensity, it may also be considered a composite fuel moisture value.

The main objective of this study is to compute the correlations between drought indices and fire, particularly at monthly time scales. The study also explores if there are any spatial regions or temporal periods where certain drought indices correlate better to fire than others.

2. DROUGHT INDEX OVERVIEW

2.1 *Palmer Drought Severity Index (PDSI)*

Developed in 1965, the PDSI is a soil moisture algorithm calibrated for relatively homogenous regions. Though very popular for historic and analysis reasons, the PDSI has shown some weakness for mountainous terrain and areas of frequent climatic extremes (see http://enso.unl.edu/ndmc/enigma/indices.htm). The PDSI is spatially incomparable across the U.S., however, it is relatively effective for measuring impacts sensitive to soil moisture conditions such as for agricultural applications (Alley 1984; Guttman et al 1992; Guttman 1997). Soulé (1992) points out, however, that the PDSI tends to respond too slowly to be a useful measure of agricultural drought and too rapidly to assess conditions of hydrological drought, such as stream flow and ground water. In addition, the PDSI is not an easily computed index since it requires inputs that are often not readily available or difficult to acquire for quick computation and not spatially uniform. The PDSI is typically computed for a single month, but the algorithm provides for some memory over the most recent 12 months (Heim 2002). Westerling (et al 2002) describes predictability of PDSI correlated with fire occurrence in the western US.

2.2 *Palmer-Z*

The Palmer-Z is similar to the PDSI, but reflects the moisture anomaly of the soil water balance as opposed to the intensity of the drought represented in the PDSI. Often, the difference between the current moisture conditions and the average moisture conditions are desired. Some areas of the western US are normally dry on a seasonal basis. Hence, these normally dry regions can be said to have a climatological drought relative to other, wetter regions. However, if one analyzes the moisture anomaly for one of these typically dry regions, the magnitude of a single year's drought can be compared to what the climatological drought is for that same area. Therefore, the sensitivity of Palmer-Z to soil moisture anomalies is useful to depict anomalously dry events even in normally dry regions.

Similar concerns and benefits discussed for the PDSI also apply to the Palmer-Z since they are related to each other.

2.3 *Standardized Precipitation Index (SPI)*

The SPI is an index based on the probability of precipitation for a number of consecutive months. Though relatively new compared to the PDSI and the Palmer-Z, the SPI is gaining popularity because of its standardized nature. An SPI in one region can be directly compared to an SPI in a completely different climate zone. Another advantage is that the SPI can be computed for various time scales. The PDSI and the Palmer-Z are most commonly computed for single months. The SPI can be computed for any set of consecutive months (e.g., 1, 3, 6, 36, 72, etc.). For example, the 12-month SPI represents how the most recent twelve months of precipitation compares to that same twelve-month period historically. This allows for a cumulative depiction of precipitation deficits or excesses.

The SPI is based solely on amount of precipitation recorded at a location. It does not incorporate any soil moisture algorithm.

3. METHODOLOGY

Historical drought index data for this analysis was acquired from the Western Regional Climate Center's

(WRCC) database. This included monthly PDSI, Palmer-Z, and SPI for 1-, 3-, 6-, 12-, 24-, 36-, 48-, 60, and 72-month periods. The monthly historical drought data is stored by climate division. Seven climate divisions were chosen to highlight how well each of the indices correlated to fire starts, acres burned and ERC (Figure 1). These divisions were chosen based upon a significant number of years with fire activity and a sufficient number of Remote Automated Weather Station (RAWS) sites to be able to compute a divisionally representative ERC.

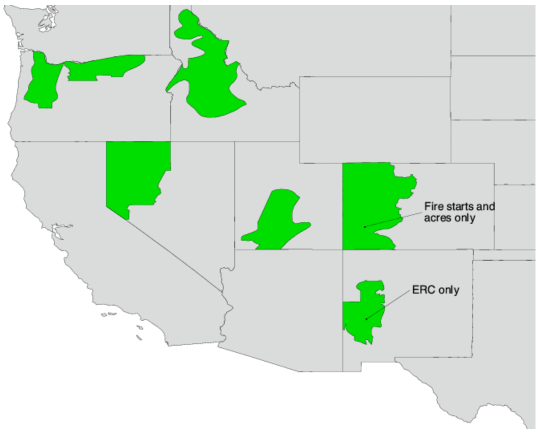

Figure 1. Climate division locations used in the analysis. For all divisions, the number of fire starts, area burned and ERC were analyzed except as noted in Colorado and New Mexico.

Figure 2 represents the average number of fire starts for each region by month. Clearly, the months of May through October have the most fire activity for all the regions. Therefore, this analysis examines drought indices between April and September to statistically describe the following months fire characteristics from May through October.

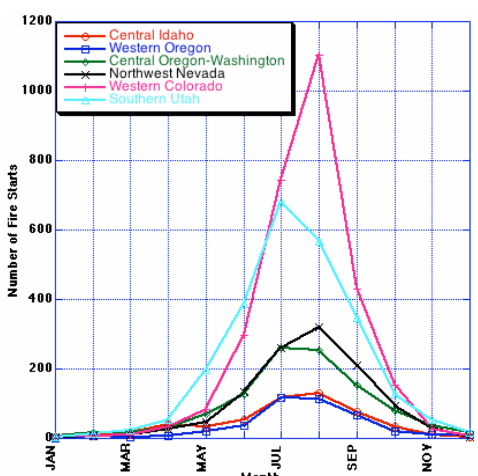

Figure 2. Average number of fire starts by month for each region examined.

RAWS records daily surface atmospheric elements that are used as inputs into the NFDRS algorithms. In order to compute the ERC index, additional RAWS site information was extracted from the Wildfire Information Management System (WIMS) database including slope, climate class and fuel model. In this case, a fuel model G (e.g., USFS 1983) was fixed for all sites. For each climate division, at least 11 years from the 22-year period 1980 through 2001 had to have both fire and ERC data to be considered for analysis (Table 1). For the primary months of interest, each location has at least 20 or more years of data.

Table 1. Total number of RAWS sites used in determining the median surface atmospheric conditions representative of each climate division analyzed.

Climate Division	Number of RAWS sites
Central Idaho	35
Western Oregon	10
Central OR-WA	12
Northwest Nevada	13
Western Colorado	36
Southern Utah	15
Western New Mexico	11

Due to the minimal number of years analyzed, the Spearman Rank correlation was chosen as a measure of how well years ranked by drought index value compared to years ranked by number of starts, acres burned or ERC. For example, Table 2 lists the July PDSI annual values and the August number of fire starts for the central Idaho climate division. The years are sorted by the PDSI value and the total number of fire starts separately, and each year given a rank value for the respective variable. The Spearman Rank equation correlates the two variables by comparing the difference of each set of rank values using the equation

$$r = 1 - 6\sum \frac{d^2}{N(N^2 - 1)},$$

where *d* is the difference in statistical rank of the corresponding variables and *N* is the number of values being compared (e.g., 21 years) (e.g., Lehmann and D'Abrera 1998). For a perfect positive correlation value of one, the years for each variable would have identical ranks with the difference in the ranks equal to zero for each year. In the case of Table 2, the Spearman correlation is –0.30.

For all drought indices, a positive index value indicates wetter than normal conditions and negative index values imply dryer than normal conditions. Correlations between the drought indices and either number of fire starts, number of acres, or ERC value can range between –1 and 1. A positive correlation indicates a direct relationship between two variables. In other words, when one variable shows a lower value than normal, the other variable will also show relatively lower values, and conversely, higher values of one variable will be associated with higher values of the other variable. A negative correlation indicates an inverse relationship. This means that a higher ranked value of one variable will be associated with a lower ranked value of the other variable.

Table 2. Annual July PDSI values and August number of fire starts along with their annual ranks and rank differences for the central Idaho climate division.

Year	PDSI value	PDSI Year Rank	Number of Fire Starts	Starts' Year Rank	Difference between ranks
1980	1.80	12	27	2	10
1981	1.92	13	52	8	5
1982	2.83	20	20	1	19
1983	2.52	19	53	9	10
1984	3.02	21	51	7	14
1985	-2.75	4	38	4	0
1986	-1.32	9	53	9	0
1987	-2.68	5	46	5	0
1988	-3.44	3	80	15	-12
1989	-2.66	7	102	17	-10
1990	-1.40	8	176	21	-13
1991	1.08	11	83	16	-5
1992	-3.68	1	77	13	-12
1993	2.35	17	77	13	4
1994	-3.48	2	171	20	-18
1995	2.05	15	124	18	-3
1996	1.93	14	62	11	3
1997	2.25	16	34	3	13
1998	2.48	18	63	12	6
1999	-0.85	10	134	19	-9
2000	-2.68	5	48	6	-1

4. RESULTS

The results from the analysis are illustrated through time series plots of monthly correlations between each variable (i.e., number of fire starts, number of acres, and ERC value) and drought index for the seven climate divisions for April through September. A table at the end of each section summarizes which drought index had the highest correlation (whether positive or negative) to fire starts, acres burned, and ERC value.

4. Fire Starts

All drought indices examined showed relatively low correlations to the number of fire starts occurring in the following month. Correlations ranged anywhere from –0.62 to 0.65. For western Oregon, most drought indices showed a positive correlation for most months with the exception of the PDSI that showed strong inverse correlations in April and May (Figure 3). The dominating positive correlations for most of the season in this region means that if one month had a positive drought index value (i.e., wet), then there would be a larger number of fire starts the following month. On the other hand, the positive correlations also mean that if the drought index for a particular month was negative (i.e., dry), the following month typically had fewer fire starts than normal.

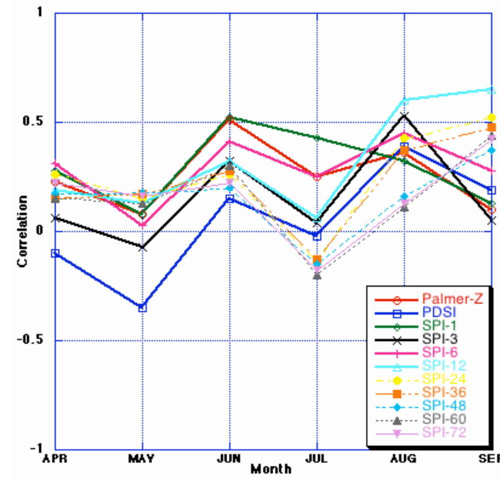

Figure 3. Monthly correlation between drought index and the number of fire starts the following month for the western Oregon region.

Southern Utah was the only region that showed not only similar correlations with each index, but started the fire season with an inverse relationship to fire starts and ended the season with a relatively strong, positive correlation (Figure 4). This means that for the first half of the fire season, wetter (dryer) months were typically followed by fewer (more) fire starts the next month. However, the last half of the season has a more direct relationship between drought and fire starts. If the early part of the season was wet, this could be keeping the fuel moistures too high to burn. On the other hand, if the early season were dryer than normal, less vegetation may be available at this time year. Western Colorado showed predominantly inverse correlations throughout the fire season, however, the PDSI stood out as the index with the strongest correlation compared to all others (Figure 5).

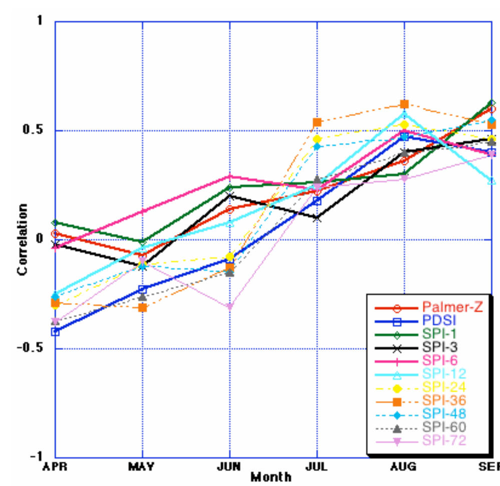

Figure 4. Same as Figure 3 but for Southern Utah.

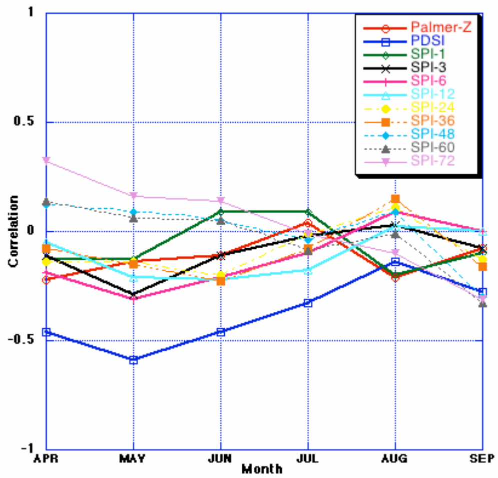

Figure 5. Same as Figure 4 but for Western Colorado.

A summary of the index with the best correlation to the number of fire starts the following month is summarized in Table 3.

Table 3. Drought index with the highest correlation to number of fire starts the following month by climate division and month.

Month	C. Idaho	W. Oregon	C. OR-WA	N.W. Nevada	W. Colorado	S. Utah
APR	0.39 (SPI-1)	0.31 (SPI-6)	0.40 (SPI-1)	0.35 (SPI-3)	-0.46 (PDSI)	-0.42 (PDSI)
MAY	-0.62 (PDSI)	-0.35 (PDSI)	0.20 (SPI-6)	0.40 (SPI-1)	-0.59 (PDSI)	-0.31 (SPI-36)
JUN	0.31 (SPI-60)	0.52 (SPI-1)	0.40 (SPI-3)	0.34 (SPI-3)	-0.46 (PDSI)	-0.31 (SPI-72)
JUL	-0.36 (SPI-36)	0.43 (SPI-1)	0.24 (SPI-3)	0.48 (SPI-3)	-0.33 (PDSI)	0.54 (SPI-36)
AUG	0.33 (SPI-6)	0.60 (SPI-12)	0.37 (Palm-Z)	-0.37 (SPI-1)	-0.21 (Palm-Z)	0.62 (SPI-36)
SEP	-0.20 (SPI-72)	0.65 (SPI-12)	0.47 (Palm-Z)	0.27 (SPI-6)	-0.33 (SPI-60)	0.63 (SPI-1)

As can be seen in Table 3, some regions correlate better with particular indices. For example, Western Colorado indicated that the Palmer derived indices, particularly the PDSI, had the highest correlation for nearly the entire fire season. Fire starts in southern Utah have the strongest correlations with the longer term SPI between May and August indicating that fire starts in this region are impacted more by longer periods of drought (i.e., 1.5 to 6 years) than periods of drought that last for a shorter period of time (i.e., a few months).

4.2 Acres burned

Correlations between drought index and number of acres burned the following month are quite varied from region to region. The overall range of correlations are greater for acres burned than for the number of fire starts (i.e., -0.56 to 0.85) and for more consecutive months. For example, correlations in western Oregon between drought index and acres burned are predominantly positive as they were for number of fire starts, however, the correlations are stronger and more consistent (e.g., June through September) (Figure 6). This means that wetter months were typically followed by fewer fire starts and dryer months were typically followed by more fire starts. It is unknown, without looking at the actual data, which of these two scenarios occurred more often. Wetter months could be increasing fuel moistures which would discourage ignition, and dryer months would have the opposite effect.

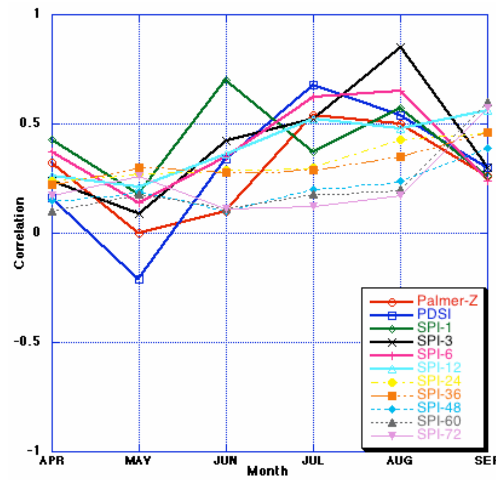

Figure 6. Same as Figure 4 but for Western Oregon correlations to number of acres burned.

Table 4. Same as Table 3 but for number of acres burned the following month.

Month	C. Idaho	W. Oregon	C. OR-WA	N.W. Nevada	W. Colorado	S. Utah
APR	0.51 (SPI-1)	0.43 (SPI-1)	0.43 (SPI-1)	0.20 (SPI-3)	0.31 (SPI-48)	-0.31 (PDSI)
MAY	-0.47 (PDSI)	0.30 (SPI-36)	-0.29 (SPI-48)	-0.48 (PDSI)	0.26 (SPI-72)	-0.46 (PDSI)
JUN	-0.37 (PDSI)	0.70 (SPI-1)	0.45 (SPI-3)	0.29 (SPI-3)	-0.43 (PDSI)	0.25 (SPI-1)
JUL	-0.23 (SPI-1)	0.68 (PDSI)	-0.27 (SPI-48)	0.32 (SPI-3)	-0.42 (PDSI)	-0.56 (PDSI)
AUG	0.45 (SPI-6)	0.85 (SPI-3)	0.24 (SPI-3)	0.20 (SPI-48)	0.32 (Palm-Z)	0.42 (SPI-1)
SEP	0.40 (SPI-12)	0.60 (SPI-60)	0.43 (SPI-6)	0.41 (SPI-24)	0.19 (SPI-6)	0.33 (SPI-36)

Table 4 indicates that there are no regions where a single drought index dominates for most of the season as the best correlation to number of acres burned. However, it should be highlighted that for the Great Basin regions, the shorter term SPI and PDSI seem to be the strongest in the first part of the fire season (i.e., April through July).

4.3 ERC

The stronger correlations between ERC and drought index were mostly negative with the exception of central Oregon-Washington. Figure 7 shows how this region not only had similar correlations among all the indices examined, but starts the fire season with a positive relationship and ends the season with a negative relationship. In other words, the beginning of the season had wetter (dryer) years followed by higher (lower) ERC values. The end of the season had wetter (dryer) years followed by lower (higher) ERC values. Again, without looking at the actual data, it is impossible to know which of the scenarios prevailed. An inverse relationship between moisture and ERC is logical given the strong impact precipitation has on lowering the ERC. The fact that there is a direct relationship between moisture and ERC in the beginning of the season could be due to the fact that the live fuel moisture have not yet been activated in the NFDRS algorithm. These are activated when green-up of the fuels has been determined. This may not occur in this region until May or June.

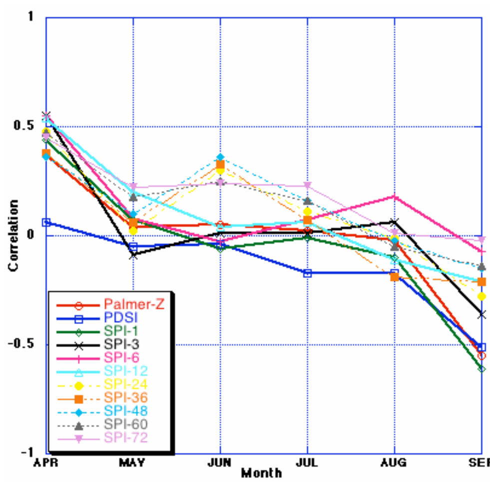

Figure 7. Same as Figure 5 but for the central Oregon-Washington region correlations with ERC.

All other regions that were examined with ERC exhibit an alternating correlation from month to month, whether it is a negative to positive or a strong to weak correlation from one month to the next. Figure 8 shows an example of this alternation for the southern Utah region. Not only does this figure show how PDSI is the strongest drought index to correlate with ERC for most months, but its correlation is strongest in May, July, and September, and weakest in April, June, and August.

The PDSI seemed to dominate as the drought index with the strongest correlation to the following month's ERC value for most cases. Though SPI appears often in Table 5, both the short term SPI (i.e., 12 months or less) and the long term SPI (i.e., greater than one year) appear to be fairly evenly distributed. Central Oregon-Washington was the only location that the SPI was the best correlation to ERC for all months. The middle months of May through August seemed to correlate best to the longer term SPI, whereas April and September correlated best with the 3- and 1-month SPI, respectively.

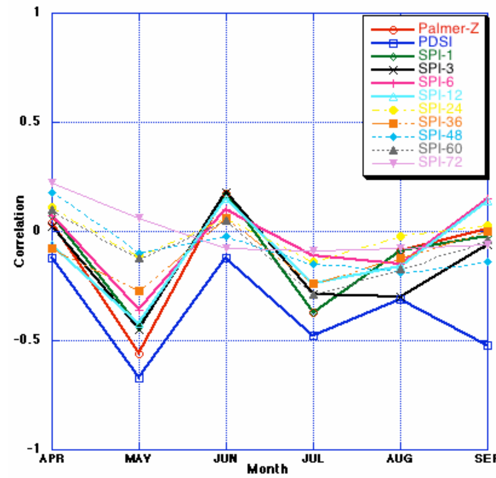

Figure 8. Same as figure 5, except for southern Utah drought index correlations with ERC.

Table 5. Same as Table 4 but for ERC.

Month	C. Idaho	W. Oregon	C. OR-WA	N.W. Nevada	S. Utah	W. New Mexico
APR	-0.20 (PDSI)	-0.48 (PDSI)	0.55 (SPI-3)	0.42 (SPI-12)	0.22 (SPI-72)	-0.56 (PDSI)
MAY	-0.42 (PDSI)	-0.43 (PDSI)	0.22 (SPI-72)	-0.59 (PDSI)	-0.67 (PDSI)	-0.55 (PDSI)
JUN	0.32 (SPI-24)	-0.33 (PDSI)	0.36 (SPI-48)	0.09 (SPI-12)	0.18 (SPI-3)	0.35 (SPI-60)
JUL	-0.40 (SPI-1)	-0.48 (PDSI)	0.23 (SPI-72)	-0.46 (PDSI)	-0.48 (PDSI)	-0.47 (SPI-24)
AUG	-0.42 (PDSI)	-0.29 (SPI-36)	-0.19 (SPI-36)	-0.42 (PDSI)	-0.31 (PDSI)	-0.38 (SPI-1)
SEP	-0.59 (PDSI)	-0.46 (PDSI)	-0.61 (SPI-1)	0.36 (SPI-6)	-0.52 (PDSI)	0.37 (SPI-60)

5. SUMMARY AND CONCLUSIONS

There was not a single drought index that was dominant throughout the fire season for any region. However, as Figure 9 shows, the PDSI was the index with the best correlation with ERC the following month. PDSI, SPI-1 and SPI-3 were the strongest index correlated to number of fire starts and acres burned. The longer-term SPI indices were rarely the index with the strongest correlation to any of the variables examined. It is interesting that the 36-month SPI and 48-month SPI were relatively stronger than other SPI indices between 12 and 72 months for number of fire starts and acres burned, respectively. This could offer some indication that there could be longer-term drought impacts on fire activity.

As Table 6 shows, no month appears to be partial to a particular drought index. With the exception of the 6-month SPI that shows the better correlation later in the season than earlier, the remaining SPI indices are spread relatively evenly throughout the season. PDSI correlates better with fire characteristics in the early part of the season, whereas the Palmer-Z shows better correlations in August and September.

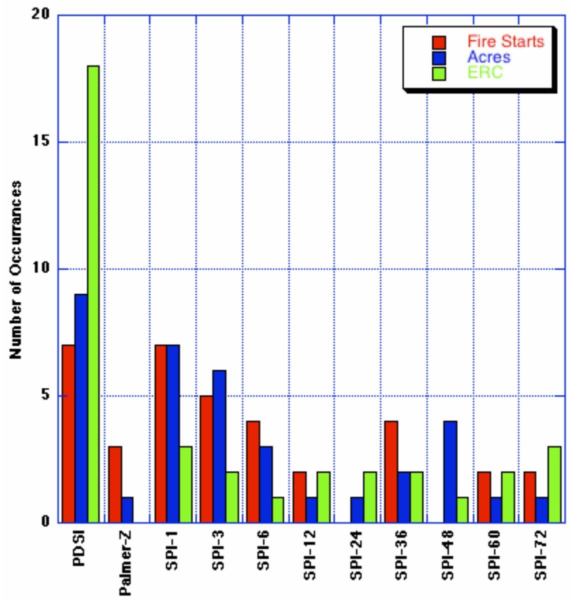

Figure 9. Number of times between April and September that each drought index had the best correlation to each fire characteristic.

Table 6. Number of times each drought index occurred by month.

Index	APR	MAY	JUN	JUL	AUG	SEP
PDSI	6	11	4	7	3	3
Palmer-Z	0	0	0	0	3	1
SPI-1	5	1	3	3	3	2
SPI-3	3	0	5	3	2	0
SPI-6	1	1	0	0	2	4
SPI-12	1	0	1	0	1	2
SPI-24	0	0	1	1	0	1
SPI-36	0	2	0	2	3	1
SPI-48	1	1	1	1	1	0
SPI-60	0	0	2	0	0	3
SPI-72	1	2	1	1	0	1

Though it would have been ideal to have indices consistently show strong correlations to fire starts, acres burned and ERC for particular locations or times of the year, the results still offer some guidance. The variability of the results could be due to the small datasets examined. Perhaps more years of fire data would show stronger consistency among the various indices. Future analysis should also examine the fire season as a seasonal (3-6 month) period in comparison to the typically higher variance monthly scale. This project compared drought indices to fire characteristics using the Spearman Rank correlation. Other methods and tools should be examined to provide additional support to these findings.

This analysis was useful in providing a better understanding of the complex relationship between ground moisture and fire characteristics such as number of starts, acres burned and ERC value. Additionally, there is a host of precipitation and drought related variables of potential value to researchers and fire management in the context of fire-precipitation-drought relationships that should be explored in detail.

5. ACKNOWLEDGEMENTS

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