FIRE HISTORY IN THE OHIO RIVER VALLEY AND ITS RELATION TO CLIMATE[1]

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ABSTRACT: Annual wildfire records (1926-77) from the national forests in states bordering the Ohio River (Illinois, Indiana, Kentucky, Missouri, Ohio, and West Virginia) were compared to climate records to assess relationships. Summaries of spring and fall fire seasons obtained for the Daniel Boone National Forest in Kentucky (1970-92) and for the State of Ohio (1969-84, including national forest lands) allowed for more detailed analysis. A wet spring followed by the onset of drought conditions, as measured by Palmer's Drought Severity Index (PDSI), was significantly correlated to the area burned by wildfire the following year ($p < 0.0009$). We hypothesize this was caused by a buildup of fine fuel followed by fuel desiccation in the first stages of drought. Extremely severe fall fire seasons were weakly related to El Niños.

Keywords: ENSO, ignition source, southern oscillation, teleconnections, wildfire.

INTRODUCTION

Teleconnections between large-scale atmospheric circulation patterns and regional weather patterns might provide forest managers with an important planning tool. For example, in a broad, regionally based study, Simard and others (1985) found a high correlation with fires in the southern states and El Niños, but found little or no correlation in the northeastern or southwestern United States. Simard and Main (1987) then used about 50 years of data to develop a regression equation to predict severity of the fire season in the south using the El Niño/Southern Oscillation (ENSO) climate anomaly. Although these preliminary studies showed only a weak relation between the ENSO and wildfires in a region that includes the Southwest, Swetnam and Betancourt (1990) found significant teleconnections between the ENSO and the occurrence of wildfires in the National Forests of Arizona and New Mexico in 200 years of data. We investigated these relationships for the Ohio River Valley (ORV), defined as the states of Illinois, Indiana, Kentucky, Missouri, Ohio, and West Virginia, and found little association between the ENSO events and Palmer Drought Severity Index (a measure of drought) in 93 years of data, but a significant correlation between spring and fall fire seasons from 1970 through 1992 in Kentucky and variables constructed from PDSI and ENSO (Yaussy and Sutherland, in press). In this paper, we have added data from Ohio and looked at variables constructed from PDSI to capture the drought events.

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DATA and METHODS

Annual National Forest fire records (1925-77) for the ORV show that fires in these states are a cultural artifact (figure 1). Although humans are the primary ignition source for fires in the east (99%) and cultural factors should determine the number of fires, the area burned by these fires should respond to climatic influences. For example, many fires set during wet periods would burn only small areas; however, several fires set during dry periods could quickly cover large areas. Therefore, we chose to study the area burned by wildfires, which is indicative of the severity of a fire season as opposed to the number of fires reported.

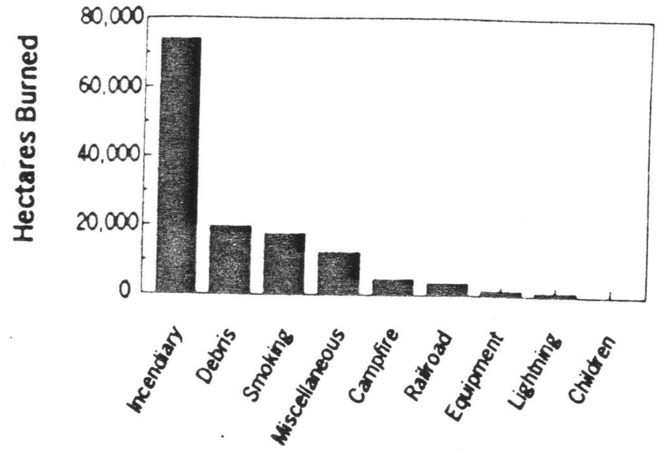

Figure 1. Area burned by cause of fire for the national forests in the ORV (1940-77).

We chose the PDSI to measure drought intensity (Palmer 1965). PDSI is based on climate factors (temperature, season, region), water supply (precipitation, stored soil moisture), and water demand (evapotranspiration, runoff, percolation). PDSI is slow to respond to sudden changes in the weather, so the value from one month is highly correlated to the value of the previous month. PDSI is a standardized index, so negative numbers indicate a drought condition and positive values are wet periods. A PDSI of -1 indicates a slight drought while a -4 signifies a severe drought. We are using PDSI as an indicator of fuel moisture, which determines the intensity of the fire seasons. Monthly PDSI measurements were obtained from data supplied by the National Climatic Data Center for 1925 through 1992 for hydrologic regions of the states in the ORV .

The Southern Oscillation Index (SOI) is the calibrated difference between atmospheric sea-level pressure at Tahiti, French Polynesia, and Darwin, Australia. When the SOI is low, the atmospheric sea-level pressure is low in Tahiti and high in Darwin. This is called an El Niño event and corresponds to wet weather in the southwestern United States (Swetnam and Betancourt 1990). When the SOI is high, it is termed a La Niña event and is typically associated with droughts in the Southwest. Monthly SOI measurements used in this study are those developed and standardized by Wright (1989) for 1925 through 1988. We used a 3-month moving average to smooth the SOI time series to eliminate noise without masking trends, such that:

$$SOIAV_t = (SOI_t + SOI_{t-1} + SOI_{t-2})/3.$$

Transformations of PDSI and SOIAV also were used in this analysis.

Several types of fire data were used for this analysis: annual records of area burned by wildfire for the National Forests in the ORV (1925-77); records of individual fire events (1970-92) for the Daniel Boone National Forest (DBNF) in Kentucky; annual fire records (1942-92) for the regions of Ohio protected by the Ohio Department of Natural Resources (ODNR); and records of spring and fall fire seasons for Ohio (1969-84).

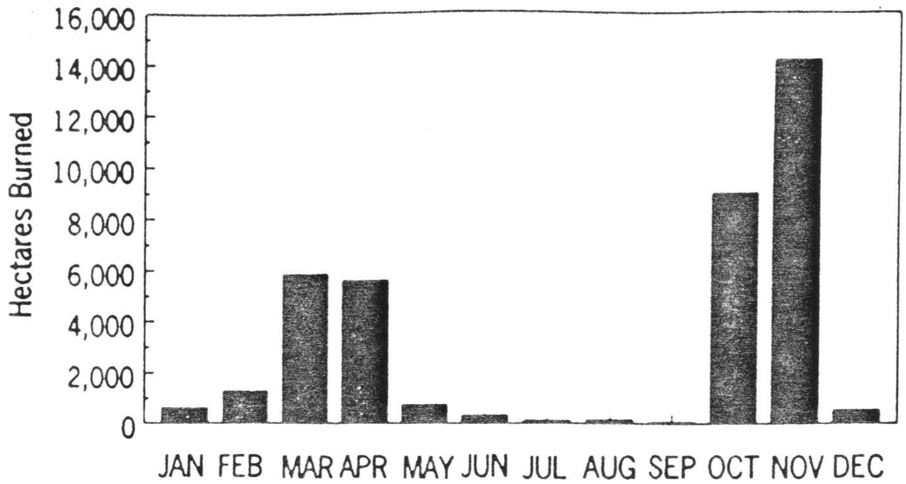

Figure 2. Area burned by wildfire on the DBNF accumulated by month from 1970 to 1992.

When the DBNF data are summarized by month, the two fire seasons of the ORV, spring and fall, are apparent (figure 2). From figure 2 it appears that the fall season is more severe than the spring, but figure 3 demonstrates that 1981, 1987, and 1991 were exceptional fall fire seasons. To combine the DBNF and ODNR seasonal data sets, we summarized the individual event data from the DBNF into spring (January through June) and fall (July through December) observations to coincide with the ODNR data. The DBNF and ODNR seasonal observations of area burned (AB) were then divided by the area under fire protection, scaled by 1,000, to obtain AB per 1,000 ha protected. A log transformation was taken of these values to normalize the variables, LAB:

$$LAB = \ln((AB / (\text{area protected})) * 1000).$$

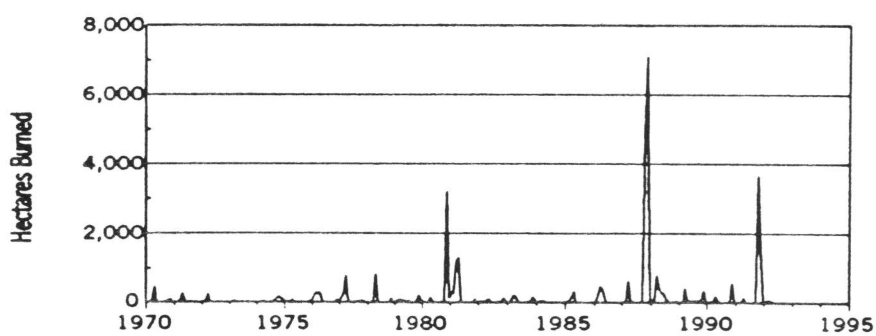

Figure 3. Timeline of area burned by month on the DBNF.

Because the resulting data sets were too small to analyze with the standard tests of ascertaining whether the variables were indeed normal, we interpreted normal probability plots (figure 4) of the data. These give no indication that the variables are not distributed normally.

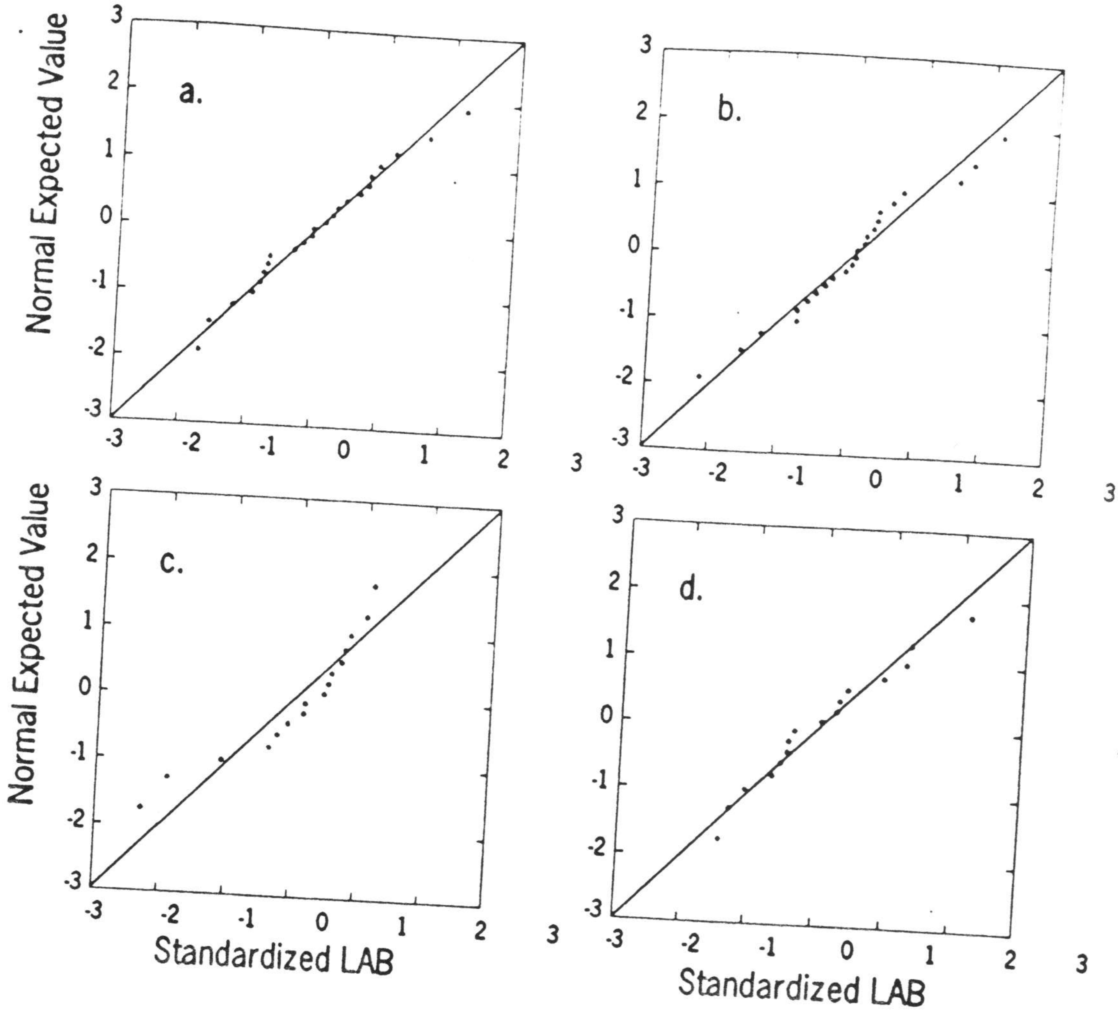

Figure 4. Probability plots of standardized LAB for (a.) DBNF spring, (b.) DBNF fall, (c.) ODNR spring, (d.) ODNR fall.

Since we were trying to find variables that would predict severity of fire season, we analyzed values of SOIAV, PDSI, and transformations of these variables from 1 to 12 months preceding the spring or fall fire seasons. Relationships between LAB and these lagged values were quantified with Pearson correlation statistics.

RESULTS

Prior to World War II, the value of wood products as war materials prompted the initiation of national fire campaigns on prevention (Pyne 1982). Figure 5 demonstrates the effect of fire suppression during and following World War II on the area burned in national forests of the ORV. Yet the years with the most severe fires coincide with or precede droughts that follow wet periods. This can be explained by lush growth of fine fuels during the wet periods and a rapid drying of these fuels at the onset of drought.

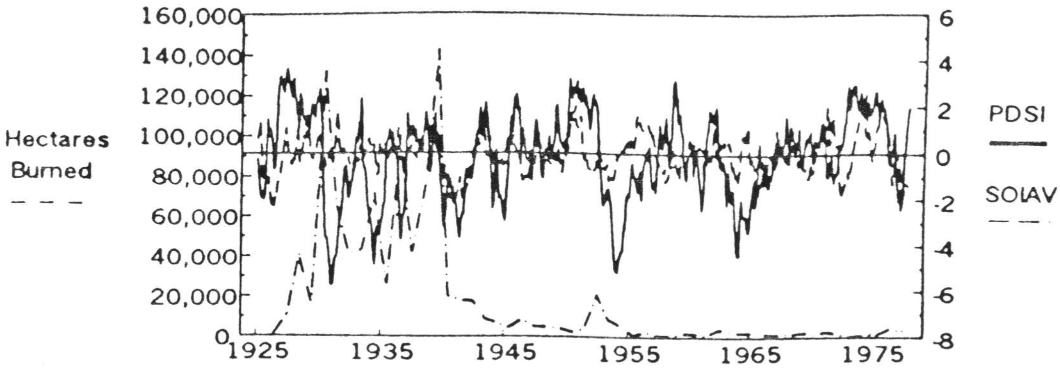

Figure 5. Timeline of the SOI, PDSI averaged for all hydrologic regions in the ORV, and area burned by wildfire in the national forests of the ORV.

The DBNF data show the same relationship as found for the annual records of the ORV large fire years preceding the worst periods of drought, evident for 1988 and 1991 when plotted against the PDSI for the climatological region containing the DBNF (figure 6). Ginger Brudevold, a member of the Fire and Aviation staff of the Forest Service's Southern Region, assured us that these were severe fire seasons and not a change in fire suppression policy which would allow manageable fires to burn to lessen the fuel load.

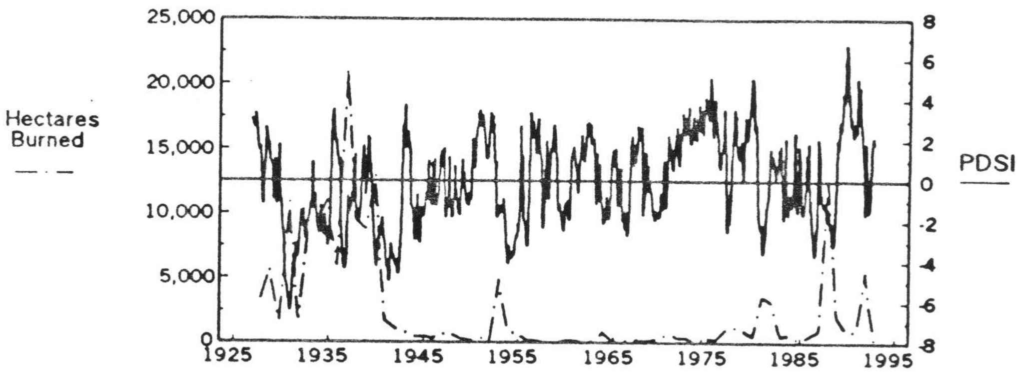

Figure 6. Timeline of the PDSI Kentucky hydrologic region 4 and area burned by wildfire in the DBNF.

The ODNR records do not begin before WWII nor show the increased fire suppression indicated for the national forests (figures 7-8) while still showing a relationship with fluctuating PDSI averaged for the 10 hydrologic regions in Ohio. Figure 9 demonstrates that the ODNR and DBNF data sets are from different distributions and must be analyzed separately; however, they do appear synchronous. The difference may be attributable to differences in land use and ownerships.

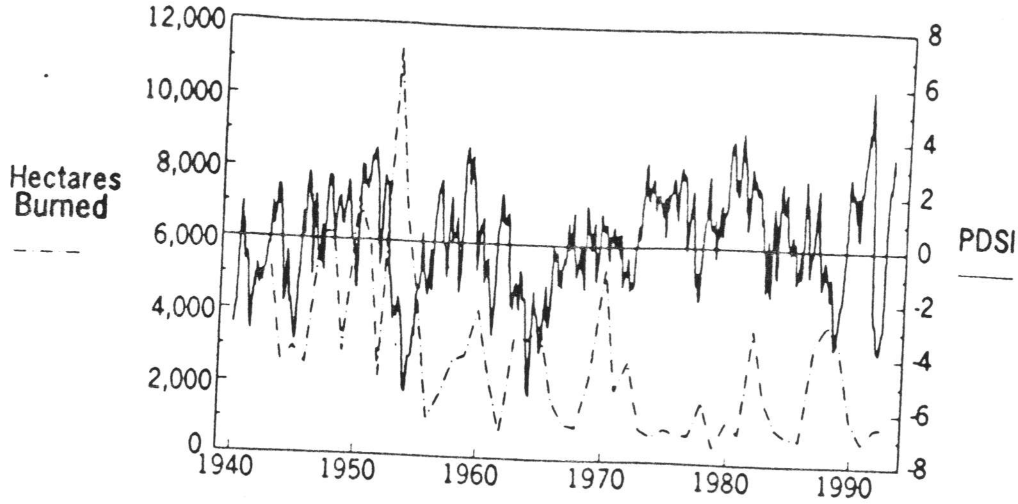

Figure 7. Timeline of the PDSI averaged for all hydrologic regions in Ohio, and area burned by wildfire in lands protected by the ODNR.

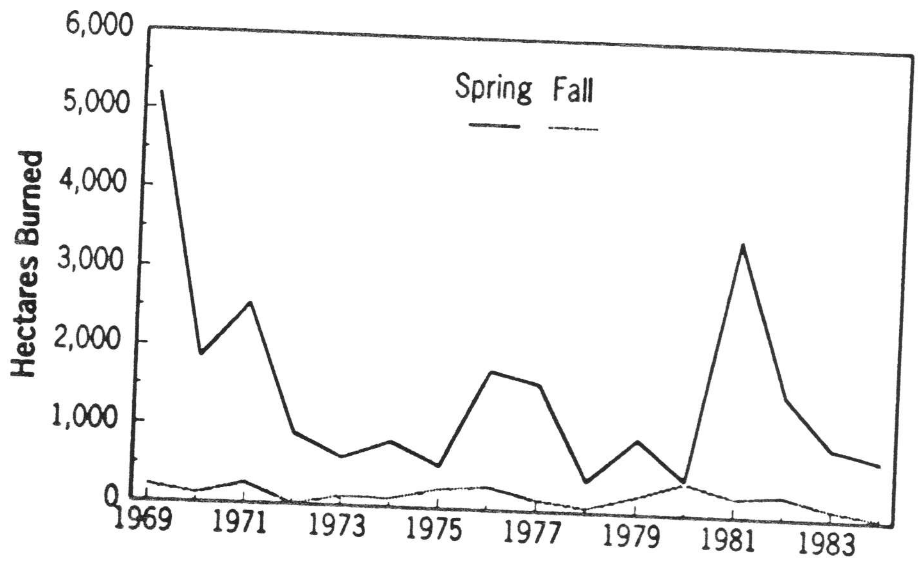

Figure 8. Comparison of area burned by wildfire in areas protected by the ODNR.

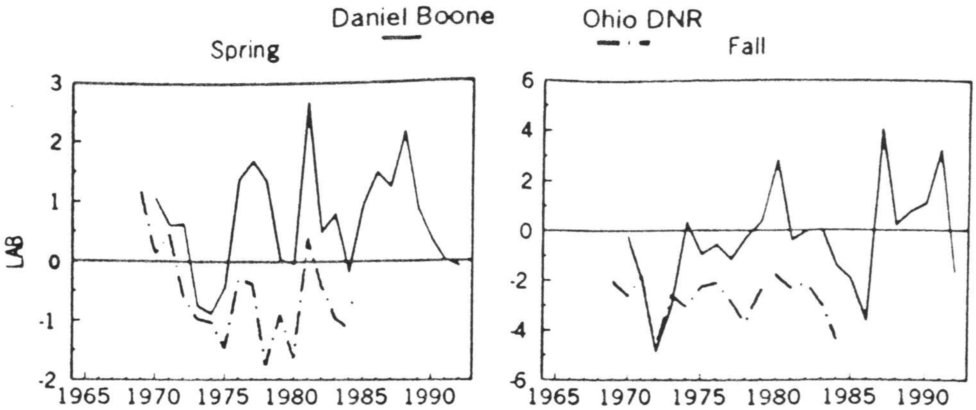

Figure 9. Comparison of transformed fire-season variables for the DBNF and the ODNR.

The most significant transformation, PDDIF, was devised to reflect the buildup of fine fuels in wet periods which is then followed by drought (figure 10):

$$PDDIF_{t-k} = Max_{(t-k)..(t-k-12)}(PDSI) - PDSI_{t-k}$$

where:

$PDSI_{t-k}$ = the lagged value of PDSI
t = index of month beginning the fire season (t = January for spring, t = July for fall)
k = index of lagged month (k = 1,..,12)
$Max_{(t-k)..(t-k-12)}(PDSI)$ = the maximum PDSI measurement contained within the preceding 12 months of $PDSI_{t-k}$.

For example, when $Max_{(t-k)..(t-k-12)}(PDSI)$ is 3 (a wet period) and $PDSI_{t-k}$ is -3 (drought conditions) then $PDDIF_{t-k}$ is 6. Thus, $PDDIF_{t-k}$ should be positively correlated to LAB.

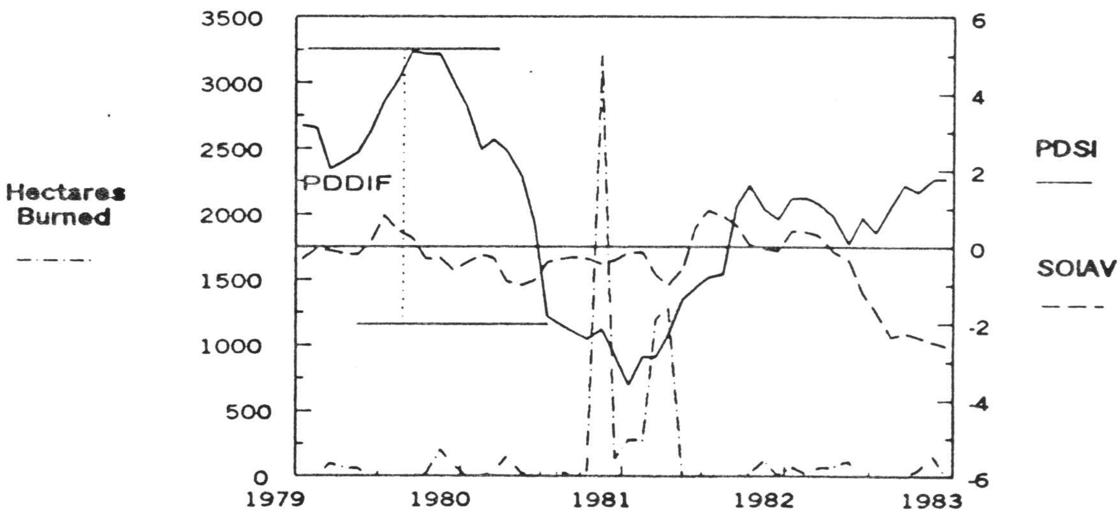

Figure 10. Calculation of PDDIF.

PDDIF of the preceding July (t = January, k = 6) was the most significant variable tested in predicting the spring LAB on the DBNF (figure 11). July PDDIF explains about 41% of the variation in spring LAB ($r = 0.64$, $p < 0.0009$, $n = 23$). While not statistically significant, SOIAV of the preceding April explained 12% of the variation in fall LAB on the DBNF ($r = -0.32$, $p < 0.1370$, $n = 19$) and was the most significant variable tested for the fall fire seaon.

Explaining 32% of the variation in the spring LAB for the ODNR data, PDDIF of the previous July was the most significantly correlated variable tested ($r = -0.57$, $p < 0.0222$, $n = 16$). However, figure 12 shows that the trend is opposite that of PDDIF on the DBNF (figure 11) and the hypothesized positive correlation. The PDSI of the previous August accounts for 41% of the variation in fall LAB of the ODNR data ($r = 0.61$, $p < 0.0082$, $n = 16$). Since these are small data sets, a few points such as the lowest three of the fall graph in figure 11 are highly influential in determining correlation.

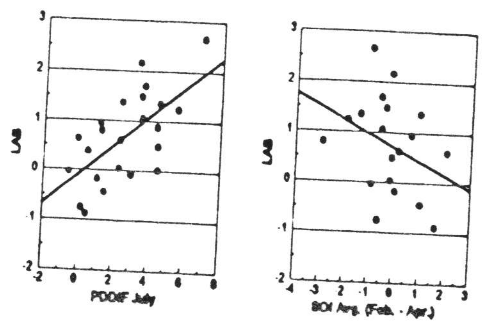

Figure 11. Correlations of the most significant variables with spring and fall LAB on the DBNF.

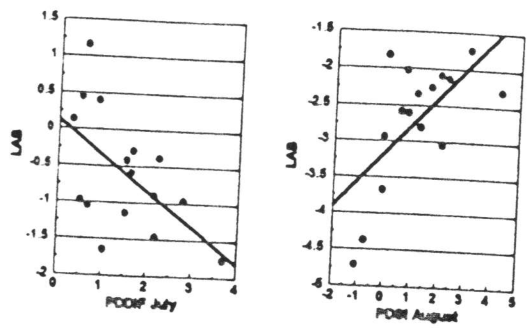

Figure 12. Correlation of the most significant variables with spring and fall LAB of the ODNR data.

The relationships between the annual totals of LAB for the DBNF and climate were investigated. We chose the period 1940 to 1992 to eliminate differences in area burned due to suppression during and after WWII. Again, PDDIF of the previous July was the most significant variable tested ($r = 0.363$, $p < 0.0076$, $n = 53$), accounting for 13% of the variation in LAB (figure 13).

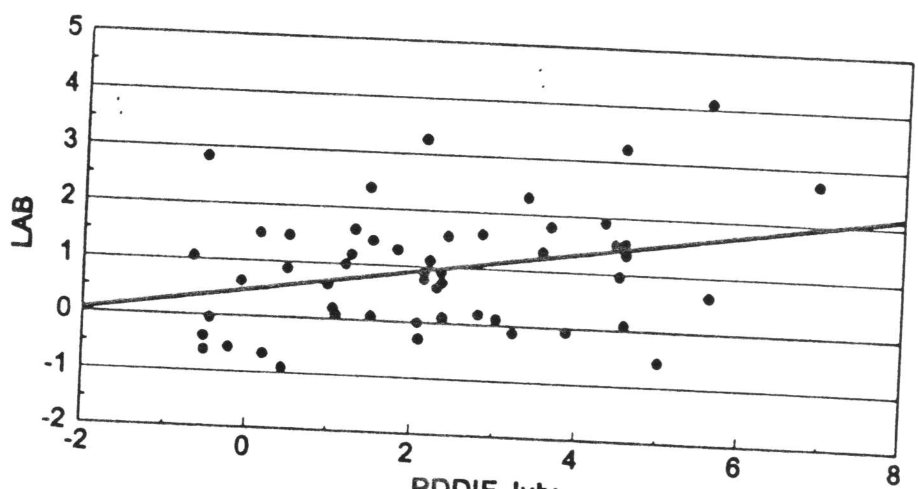

Figure 13. Relationship of annual total LAB of the DBNF from 1940 to 1992 and PDDIF of the previous July.

From these results, PDDIF of the previous July appears to be a variable associated with LAB. We analyzed the correlation of this variable with the LAB observations of all the national forests in the ORV from 1940 to 1977. The results in table 1 indicate that PDDIF is not correlated to LAB for states in the ORV with the possible exception of Kentucky.

Table 1.– Pearson correlation statistics for LAB of the national forests in the ORV and PDDIF of the preceding July from 1940 to 1977 (1940-92 for Kentucky).

State	r	p-level	Number
Illinois	0.060	0.719	38
Indiana	-0.016	0.926	38
Kentucky	0.363	0.008	53
Missouri	0.015	0.93	38
Ohio	-0.039	0.815	38
West Virginia	-0.131	0.435	38

CONCLUSIONS

Visually and logically, there should be a sound relationship between area burned and climatic factors such as drought. The most severe fire seasons on the DBNF were in the fall of 1981, 1987, and 1991. These are the types of events we would like to be able to predict. With the methods used in this study, these seasons were the least correlated with the variables we chose to depict climate.

The reason for the lack of correlation may be that the relationships in climate data look good for a short time but tend to degenerate when the time frame is extended. We have been ignoring interference from other sources, such as the North Atlantic Oscillation, and that may explain this degeneration; or the apparent relationships may well be spurious (Burroughs 1992).

As any statistician would say, "We need more data." We are in the process of obtaining records of individual events from the national forest-fire data base and from state agencies. However, much of these data cover the 1970's and 1980's, which had few extreme fire events. We also will extend the SOI data through 1992 to include the most recent El Niño events. Since climate in the ORV is driven by a combination of the prevailing westerlies, influenced by El Niños, and moisture from the Gulf of Mexico, we will to explore the effects of the North Atlantic Oscillation.

The effect of drought following a period of growth on fire season severity warrents further attempts to quantify and investigate the relationship.

LITERATURE CITED

BURROUGHS, W.J. 1992. Weather Cycles: Real or Imaginary. Cambridge University Press, New York, NY 10011-4211, 201 pp.

PALMER, W.C. 1965. Meteorological drought. Res. Pap. No. 65. U.S. Weather Bureau, Office of Climatology, Washington, DC, 58 pp.

PYNE, S.J. 1982. Fire in America: A Cultural History of Wildland Fire. Princeton University Press, Princeton, NJ, 654 pp.

SIMARD, A.J.; and MAIN, W.A. 1987. Global climate change, the potential for changes in wildland fire activity in the southeast. Proceedings of the symposium on climate change in the southern United States: future impacts and present policy issues, May 28-29, 1987, New Orleans, LA. U.S. Environmental Protection Agency, Washington, DC, p. 280-308.

SIMARD, A.J.; HAINES, D.A.; and MAIN, W.A. 1985. Relations between El Niño/Southern Oscillation anomalies and wildland fire activity in the United States. Agricultural and Forest Meteorology 36:93-104.

SWETNAM, T.W.; and BETANCOURT, J.L. 1990. El Niño-Southern Oscillation (ENSO) phenomena and forest fires in the southwestern United States. In Proceedings of the sixth annual pacific climate (PACLIM) workshop, March 5-8, 1989, Asilomar, CA. Edited by Betancourt, J.L. and MacKay, A.M. California Department of Water Resources, Interagency Ecological Studies Program Technical Report 23, p.129-134.

SWETNAM, T.W.; and BETANCOURT, J.L. 1992. Temporal patterns of El Niño/Southern Oscillation--wildfire teleconnections in the southwestern United States. In El Niño: historical and paleoclimatic aspects of the Southern Oscillation. Edited by Diaz, H.F. and Markgraf, V. Cambridge University Press, p. 259- 270.

WRIGHT, P.B. 1989. Homogenized long-period southern-oscillation indices. International Journal of Climatology. 9:33-54.

YAUSSY, D.A.; and SUTHERLAND, E.K. (in press). Relationships of the Southern Oscillation of the Pacific Ocean and droughts and wildfires in the Ohio River Valley. In Inventory and management in the context of catastrophic events. Edited by Meyers, W. and Fairweather, S. University of Pennsylvania, (in press).

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