Fire-Climate Interactions in the Selway-Bitterroot Wilderness Area

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Abstract—Tree-ring reconstructed summer drought was examined in relation to the occurrence of 15 fires in the Selway-Bitterroot Wilderness Area (SBW). The ten largest fire years between 1880 and 1995 were selected from historical fire atlas data; five additional fire years were selected from a fire history completed in a subalpine forest within the SBW. Results of the analysis indicate summers during the fire year were significantly ($p<0.001$) drier than average conditions. The summer preceding the fire year tended to be drier than average, but results were not statistically significant ($p>0.05$). A significant ($p<0.05$) wet year occurred four years prior to fire occurrence in the SBW. Further research which examines fire-climate interactions differentiated by forest type may provide an improved understanding of the dynamics between fire and climate.

In remote mountain areas where pre-20th century human occupation was limited and transient, climate variability was the dominant influence on interannual to centennial-scale fire and forest dynamics. Although the short-term weather (i.e., daily to monthly) patterns associated with large fire events in western forests have been well studied, longer-term climate patterns (i.e., seasonal to centennial) are less well understood. Interest in understanding the longer-term associations between climate and fire has increased in recent years due to concern over current and future changes in climate and fire regimes. An understanding of the interannual relationships between fire and climate could provide resource managers advance information to plan and implement mitigation efforts such as prescribed fire or could be used to guide decisions on the allowance of fires to burn under certain climate and weather conditions.

In some areas of the western U.S., the interannual relationships relating fire to interannual climate characteristics are well established. For example, it is well known that years in which large areas burn are often drier than normal. However, wetter than average winter-spring conditions are often present several years in advance of large fire years in ponderosa pine (*Pinus ponderosa* Law.) forests of the Southwestern United States (Baisan and Swetnam 1990; Swetnam and Betancourt 1998), and in the grasslands of the Great Basin (Knapp 1995). Wetter than average antecedent conditions result in an increase in fine fuels which readily burn during subsequent dry years (Baisan and Swetnam 1990; Swetnam and Betancourt 1998). In the coniferous forests of the Northern Rocky Mountains these interannual relationships have not been intensively explored. Intuitively, large fire occurrence (often examined through the use of historical data and modern records) in the Northern Rockies is related to short-term (seasonal or monthly) intervals of drier than average conditions (Barrett and others 1997). Low elevation forests in the Northern Rocky Mountains may have similar antecedent climate relationships to forests in the southwestern United States. In addition, upper elevation forests in the Northern Rocky Mountains may require longer periods of dry weather to dry accumulated fuels sufficiently to support spreading fires. For example, upper elevation forests might be expected to burn primarily during relatively drier years than lower elevation forests, or during a sequence of two or more drier than average seasons and years.

This research explores the relationship of interannual climate variability on fire occurrence in the Selway-Bitterroot Wilderness Area (SBW) on the border of Idaho and Montana (fig. 1). The effect of summer drought, using a

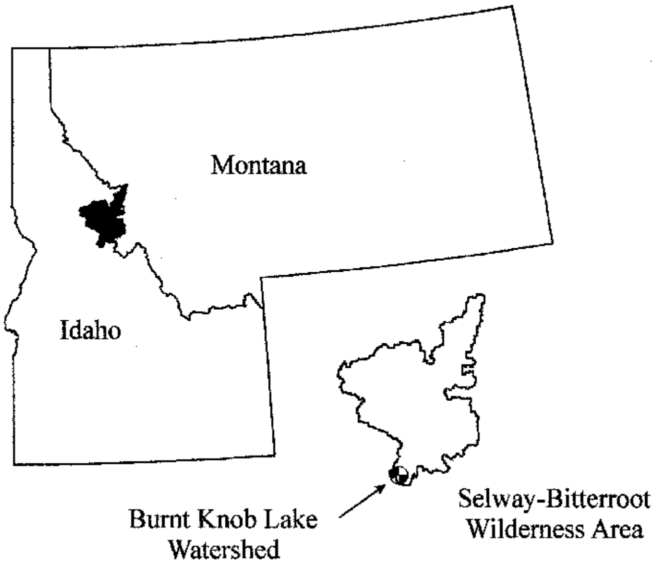

Figure 1—The location of the Selway-Bitterroot Wilderness Area on the border of Idaho and Montana in the northern Rocky Mountains. Burnt Knob Lake watershed is located in the southern portion of the Selway-Bitterroot Wilderness Area and is representative of subalpine forests of the region.

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tree-ring reconstructed summer Palmer Drought Severity Index (Cook and others 1999) is examined using superposed epoch analysis to identify important relationships between climate during the year of fire occurrence and interactions between fire and antecedent climate conditions. Fire-climate relationships are examined using fire years selected from the modern record as well as fire years identified in a crossdated fire history from a subalpine watershed in the SBW.

Study Area

The SBW, located on the border of Montana and Idaho (fig. 1), is composed of complex topography and a diversity of forest habitat types. At 547,370 ha (1,352,000 acres), the SBW is the third largest wilderness in the coterminous United States. Ponderosa pine-Douglas-fir (*Pinus Ponderosa* Laws.-*Pseudotsuga menziesii* Mirb.) habitats characterize xeric lower forest zones, with relatively mesic sites occupied by western redcedar (*Thuja plicata* Donn.) communities. Middle elevations of the SBW are composed of mixed-conifer forests with varying compositions of lodgepole pine (*Pinus contorta* var. latifolia Dougl.), western larch (*Larix occidentalis* Nutt.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), grand fir (*Abies grandis* (Dougl.) Lindl.), and Engelmann spruce (*Picea engelmannii* Parry). Long-lived whitebark pine (*Pinus albicaulis* Engelm.) and subalpine larch (*Larix lyallii* Parl.) persist at the highest elevations and on more extreme sites (Arno and Habeck 1972). Wildfires were consistently and effectively suppressed for most of the 20th century in and around the SBW. Since 1979, however, lightning-ignited fires have been allowed to burn within prescribed conditions in the SBW (Barrett and Arno 1991; Brown and others 1994).

The climate of the SBW varies from an inland-maritime climate in its northwestern areas to a somewhat drier continental climate in the southeast (Finklin 1983). The warmest and driest months are July and August. The fire season lasts from mid-June through late September, with peak lightning activity occurring in July and August (Finklin 1983). Fires ignite in the SBW throughout the summer, but historical records indicate most land area is burned later in the summer months when fuel conditions are driest.

Methods

A total of fifteen fire years were selected in the SBW area to examine fire-climate relationships (table 1). Ten fire years representing the largest areas burned in the 20th century were selected using historical fire atlas data (1880-1995). Five additional fire years (1709, 1719, 1729, 1741 & 1883) were selected from a crossdated fire history of a subalpine forest in the Burnt Knob Lake watershed (fig. 1) to obtain a longer time series of fire occurrence. These fire years were selected based on sample replication and the existence of associated forest stands based on age-class analysis.

A 279-year timeseries (1700-1978) of Palmer Drought Severity Indices (PDSI) reconstructed from tree-ring records was obtained from the NOAA Paleoclimatology Program (Cook and others 1999; data available on the world wide web at http://ngdc.noaa.gov/paleo/drought.html) to investigate relationships between large fire events and drought. PDSI is an estimate of the departure of soil moisture relative to average conditions (Palmer 1965). PDSI incorporates temperature and precipitation parameters as well as evapotranspiration and soil characteristics. Cook and others (1999) developed a systematic grid of tree-ring reconstructed PDSI to investigate the spatial characteristics of summer drought in the United States. Their grid consists of 155 grid points at a resolution of 2° x 3°. Station data used to reconstruct PDSI was selected using a 150 km search radius around each grid point. Tree-ring chronologies (consisting primarily of moisture sensitive ponderosa pine and Douglas-fir) were selected using a rule set developed to collect a minimum number of suitable chronologies at a minimal distance (see Cook and others, 1999 for more detail). Using regression techniques,

Table 1—Fire years selected for fire-climate analysis and reconstructed summer PDSI values during the fire year, and at one and four year lags. Reconstructed summer PDSI from Cook et al. 1999. Fire years with (*) are years selected from the crossdated fire history in Burnt Knob Lake watershed.

Fire event year	PDSI during fire year	PDSI Lag 1	PDSI Lag 4
1709*	0.84	–2.60	0.00
1719*	–0.58	–3.51	2.97
1729*	–2.31	–0.53	0.64
1741*	–1.99	–0.31	1.60
1883*	–0.44	–0.21	2.67
1889	–3.29	0.53	2.83
1890	–2.20	–3.29	–0.28
1895	–2.06	2.41	0.84
1910	–0.37	0.71	0.63
1919	–1.97	–2.38	1.80
1929	–1.28	–0.07	0.55
1934	–3.08	–2.30	–1.15
1979	–1.43	3.14	0.91
1987	–2.2	–0.86	3.11
1988	–3.54	–2.2	3.98

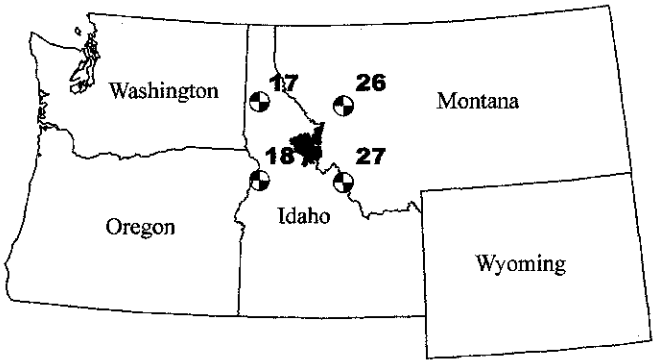

Figure 2—The location of the four grid points used to develop a regional index of tree-ring reconstructed summer PDSI (reconstructions from Cook and others, 1999, available online at http://www.ngdc.noaa.gov/paleo/drought.html).

Cook and others (1999) reconstructed summer (June-July-August) PDSI values back to at least A.D. 1700 in all cases, and in some instances to A.D. 1650. PDSI was not reconstructed beyond 1977, so PDSI values derived using instrumental data were used to extend the record to the present. For our analysis, we selected four grid points bracketing the SBW (fig. 2). PDSI values from these grid points were averaged to create a regional time series of summer PDSI from 1700-1995.

Superposed epoch analysis (SEA; Grissino-Mayer 1995; Lough and Fritts 1987; Swetnam 1993) was used to determine the relationship between fire occurrence and antecedent climate conditions. SEA computes the mean PDSI from the tree-ring reconstructed PDSI for the fifteen fire years selected. Mean PDSI was also calculated for each of the five years (years –1 to –5) prior to the selected fire years. Superposed epoch analysis is a technique that characterizes one parameter (i.e., the fire year) in relation to another (i.e., reconstructed summer PDSI) (Grissino-Mayer 1995). SEA uses Monte Carlo simulations to estimate confidence intervals around the observed mean values.

Results

Reconstructed summer PDSI values indicate 14 of 15 fire years occurred during moderate drought (PDSI <–1.0), though three years were very close to average conditions (fig. 3, table 1). Of the 15 fire events examined, 9 occurred during years when reconstructed summer PDSI was characterized as being an extreme drought (<–1.5). The frequency of reconstructed PDSI values less than –1.5 examined over 100 year intervals (e.g., 1700-1799, 1800-1899, and 1900-1995) exhibited some minor long-term differences between 1700-1995. Eighteen years between 1700 and 1799 exhibit reconstructed summer PDSI less than –1.5; the 1800-1899 period contained 13 years of reconstructed summer PDSI values less than –1.5 (table 2). Although covering the shortest time period, 19 years have PDSI values less than –1.5 between 1900 and 1995. Moderate drought (PDSI <–1.0) indicated a similar pattern, with a higher frequency of drought during 1900 and 1995 (table 2).

The time series of regional summer PDSI in the SBW graphically illustrates the variability in drought from 1700-1995 (fig. 3). The minimum reconstructed value of summer PDSI was –4.52 which occurred in 1721. The wettest summer recorded by this data set occurred in 1750 (4.34). Palmer (1965) arbitrarily defines moderate drought conditions to occur when PDSI values fall below –1.0. Extreme drought conditions exist when PDSI values are <–1.5.

The results of superposed epoch analysis suggests that summer drought conditions, as measured by reconstructed summer PDSI are significantly ($p< 0.001$) related to the

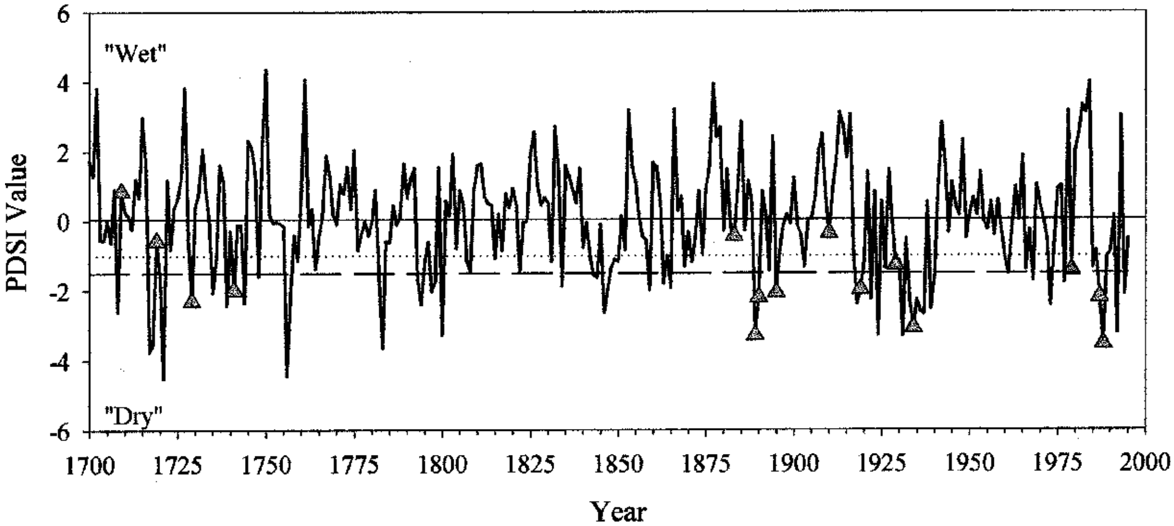

Figure 3—Time series of regional summer PDSI reconstructed from tree-rings. Fire years used in this analysis are plotted as triangles. The mean (near 0) is plotted as a solid line. Moderate drought (PDSI value <–1.0) is plotted as a dotted line, and severe drought (<–1.5) is plotted as a dashed line. Drought definitions are as in Palmer (1965).

Table 2—Frequency of drought conditions by century in the SBW based on reconstructed July PDSI (Cook et al. 1999). Moderate and extreme drought values are based on Palmer (1965) drought classification.

	Time period		
	1700-1799	1800-1899	1900-1995
No. Moderate Drought Events (<–1.0)	23	25	30
No. Extreme Drought Events (<–1.5)	18	13	19

occurrence of large fires in the SBW (fig. 4). The year preceding fire occurrence also appears to be drier than long-term average conditions, but this result is not statistically significant (p>0.05). Statistically significant (p< 0.05) wet conditions occur four years prior to the year of a fire event in the SBW (fig. 4).

Discussion

There are important relationships between inter-annual climate variability and large fire years in the SBW. Although emphasis has been placed on the importance of climate and short term weather conditions during the year of fire occurrence (e.g., Barrett and others 1997; Johnson and Larsen 1991; Johnson 1992), antecedent conditions up to four years preceding fire events may also be important. Statistically significant dry years during the fire years selected in the SBW (fig. 3) support the influence of seasonal (i.e., summer) drought leading to large areas burned. Drier-than-average conditions prior to the fire year, though not statistically significant, suggests extended drought might also play a role in the development of large fires in the SBW.

Although our results indicate important fire-climate relationships, other research in the Northern Rocky Mountains have not been conclusive. Barrett and others (1997) did not find a strong link between drought and fire occurrence in their analysis of fire-climate relations in the Interior Columbia River Basin. However, their comparisons with drought and fire events are hampered by a lack of annual precision, precluding the analysis of interannual fire-climate interactions. Moreover, the tree-ring reconstructed climate parameters used by Barrett and others (1997) are geographically much further from the majority of their fire history sites than the fire history and summer drought data used here.

Dry summers preceding the fire event, though not statistically significant, were present before almost all fire event years selected from the Burnt Knob Lake watershed (table 1). However, fire years during the modern period (years 1895-1988) sometimes had wetter than average conditions one year prior to fire occurrence (table 1). The fire years selected from the modern record probably include areas of lower elevation forests containing ponderosa pine with grass as an understory component similar to southwestern ponderosa pine forests. Ponderosa pine forests in the SBW may respond similarly to wetter than average conditions, with buildups of fine fuels acting as an important mechanism to large fire occurrence during succeeding dry years. In contrast, upper elevation forests, such as those represented by Burnt Knob Lake (fire years 1709-1883), may require a longer period of dry weather for fuels to dry out appreciably to support large fires.

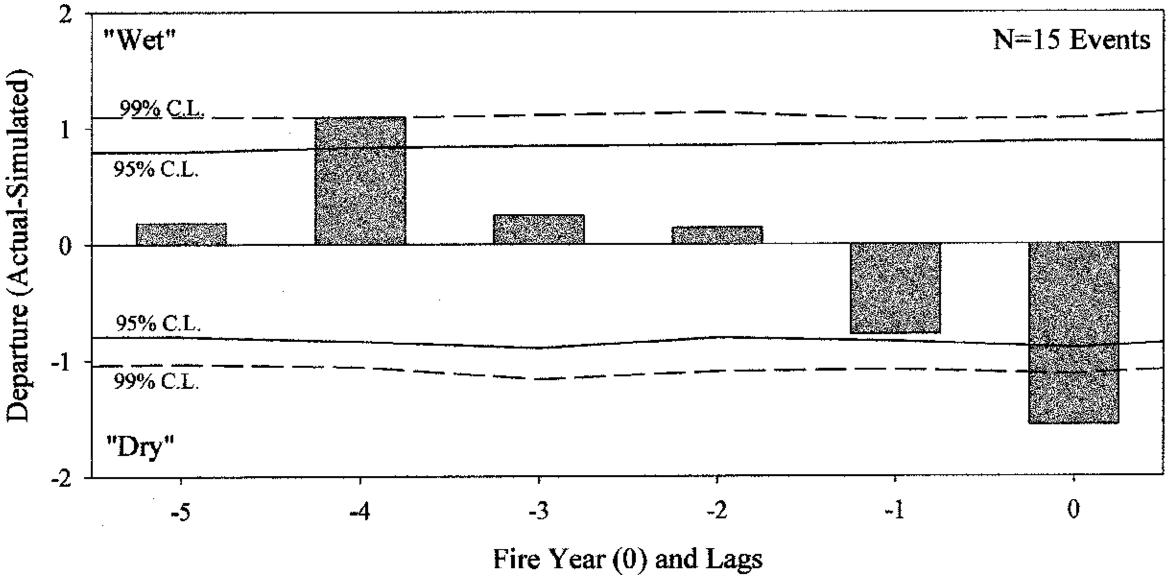

Figure 4—Results of superposed epoch analysis. Bars represent deviation from normal conditions based on 1000 simulations. The 99% and 95% confidence limits are also indicated.

The statistically significant wet year four years prior to fire occurrence may also be partially explained by the production of fuel (fig. 4). A subtle relationship exists between needle persistence and production with wet years. A wetter than average year may produce abundant needles, which are then shed during drought years, providing an important fuel source (Reich and others 1994; Swetnam and Baisan 1996). Thus, a wet year four years prior to fire occurrence may be related to the production of fine fuels, in a manner similar to the earlier discussion concerning the one year lag. The incorporation of additional fire events in the analyses may help to highlight these important lag effects. In addition, analyses which focus on fires occurring in specific vegetation types may highlight different fire-climate relationships between forest types.

The frequency of drought may have important impacts on fire regimes at long time scales. Several studies in the boreal forests of northern Canada suggest the frequency of drought has diminished following the end of the Little Ice Age, resulting in a decrease in area burned over the 20th century (Bergeron and Archambault 1993; Johnson 1992). However, Balling and others (1992) have found a 20th century trend of increasing drought conditions related to increasing temperatures during the fire season, coupled with a reduction of precipitation prior to the fire year have occurred in Yellowstone National Park. The frequency of drought, as measured by reconstructed summer PDSI, appears to have increased during the 20th century as compared to earlier time periods (table 2). The number of summers experiencing moderate drought (PDSI values <–1.0) has remained relatively constant from 1700 to 1899, but increases somewhat between 1900 and 1995. Increases in the frequency of drought occurrence, coupled with unnatural fuel buildups due to fire suppression, may lead to more severe stand replacement fire events in the future.

There are several important limitations of this analysis. First, there is a mismatch in scales of our fire history data collected in a small area from the Burnt Knob lake watershed, and the broad scale data from the 20th century. The large fire events observed in the Burnt Knob Lake area may be more influenced by local scale factors such as localized fuel characteristics, topography, human set fires, or short-term, local weather patterns. These fires may have occurred during a short period (one month) of dry weather which is not accurately portrayed by PDSI reconstructed over an entire summer season.

Although this analysis suggests there are important fire-climate relationships for the SBW, these results could be further strengthened if forest types were delimited for study. For example, there is a moderate amount of ponderosa pine-Douglas-fir forest in the SBW which has a very different fire regime than that of higher elevation forests of the area (Arno 1980). It is plausible that the relationship between PDSI and large fire years would be different in these two habitat types. We suspect that ponderosa pine-Douglas-fir forests in the SBW may have similar PDSI-fire relationships to ponderosa pine forests in the Southwest. That is, prior wet years may be important to large fire occurrence due to the production of fine fuels which contribute to fire spread during subsequent dry years. However, consecutive dry years may prove to be more important in subalpine forest environments where fuel conditions rather than abundance may be important mechanisms of large fire events (Agee 1993). To more effectively evaluate the relationship between drought conditions and fire, long high resolution data sets of fire history need to be developed over a broad region.

Monthly values of PDSI often contain high levels of autocorrelation (0.6-0.8). Because the calculation of PDSI uses prior values of PDSI to determine a current PDSI value, low values are often related to low values from a prior month (Alley 1984). Therefore, even if a summer is very dry, a wet spring prior to the fire season may have the effect of masking the dry summer PDSI somewhat. This limitation may be overcome using the Palmer Hydrologic Drought Index (PHDI) which removes the effect of prior values and is often thought of as a “real time” measure of drought (Alley 1984).

One problem identified by Cook and others (1999), which affects the strength of the fire-climate relationships identified here, is the quality of the PDSI reconstruction in mountainous landscapes. They concede that a lack of meteorological station data in many of these areas, coupled with a limited number of crossdated tree-ring chronologies in the northern Rockies, results in weaker reconstructions of PDSI for these areas. In fact, the weakest PDSI reconstructions, as identified by Cook and others (1999), occur in the mountains of Montana and along the front range of the Rockies from about central Colorado northward. In addition, a large search area was often necessary to locate a suitable number of tree-ring chronologies fitting the criteria and rule set for the reconstruction. This search radius sometimes exceeds 350 km. For this reason regional correlations among grid point reconstructions will be enhanced because the same tree-ring sites are being used to reconstruct PDSI for several grid points. Though the relationship between PDSI and large fire occurrence may not be perfect, it does identify important interannual and antecedent climate relationships with fire that can only be resolved using data with annual resolution.

Conclusions

This research suggests important relationships exist between fire and the onset of drought conditions during large fire years. Antecedent conditions may also play an important role in large fire occurrence in the forests of the SBW. Antecedent wet conditions may increase the production of fine fuels necessary to support large fires in low elevation forests. Although not statistically significant, drier than average conditions one year prior to fire occurrence may be important to the development of large fires in subalpine forests of the SBW. Further research which examines the relationship fire and climate needs to focus on individual forest types. In addition, annually resolved regional scale fire histories spanning multiple centuries will help better understand the role of climate on the fire regime of forests in the SBW.

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