Fire Suppression Effectiveness for Simultaneous Fires: An Examination of Fire Histories

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ABSTRACT. We examined fire and weather records for areas of the western United States for the period 1970–1984 to determine the effects of simultaneous wildfire occurrence on fire suppression efforts. Burning conditions were accounted for by use of short strings of fires which involved simultaneous suppression efforts. These strings were matched with closely preceding isolated fires to form matched sets, which were used to examine the relative effects of simultaneous fire occurrence. Fires were predominantly lightning-caused, and within matched sets they showed little difference in burning conditions. The first-occurring fires in the strings showed significantly longer suppression times than the preceding isolated fires, and travel times to the sixth-occurring fires were significantly greater than times to the first-occurring fire. These effects are not entirely consistent with expectations of fire personnel, perhaps because of shortcomings in the fire history records, which are particularly deficient in reporting force allocation, fire progress, and fire location.

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During the fire season, clusters of fires on national forests in the western United States often require simultaneous suppression. Storm and lightning patterns can be so widespread that multiple fires within a national forest coincide with similar incidents on other forests. In some areas the majority of fires occur under such conditions, yet detailed studies of historical occurrence (such as those of Hornsby 1936, Barrows 1977a, 1977b, 1978, Bevins 1983, and Haines et al. 1973) have not considered the effects of simultaneous occurrence. Simultaneous occurrence of fires often places extraordinary demands on control forces and requires deployment of shared resources from greater distances. It seems natural that fire-fighting effectiveness would suffer during such periods, due to dilution of forces and fatigue. Such declines in efficiency could be of great importance in fire-fighting efforts, but only anecdotal evidence has been available previously.

This paper reports a study of Forest Service fire history records undertaken to determine the effect of simultaneous wildfire occurrence on suppression effectiveness.

METHODS

Computerized versions of the Forest Service 5100–29 fire report forms for the years 1970–1984 (Yancik and Roussopoulos 1982), and records from Forest Service fire weather stations for the years 1975 through 1984 were used. Data from several national forests in four study areas were examined in detail. These included the Malheur, Ochoco, Umatilla, and Wallowa-Whitman National Forests in northeast Oregon; the Colville, Okanogan, and Wenatchee in Washington; the Deschutes, Fremont, and Winema in central Oregon; and the San Bernardino and Cleveland in southern California. The forests within each study area are close to each other and show strong similarities in fuel types, climate, and fire cause patterns. The following variables were considered: burned area (AREA), suppression time (ST), travel time (TRAV), maximum number of personnel (MAXP), lightning activity level (LAL), and the reported burning index (RBI).

After editing to remove gross errors, the data included 6130 fires from northeast Oregon, 2691 from central Oregon, 2949 from Washington, and 3178 from southern California. For each reported fire with corresponding fire weather records, burning index was also calculated directly from weather records. Several reliable weather stations located within each forest were chosen. A single fuel model was assumed to hold throughout each forest, and values of the burning index were calculated for each selected weather station. NFDRS fuel model C was used for all forests located in Oregon, as advised by fire personnel from that area. Burning index values were averaged to obtain a single value for each day and for each forest studied. This measure was called the *calculated burning index* (CBI).

To measure fire clustering we used the starting multiplicity (SM). The SM assumes one value for each fire and is defined as the number of fires undergoing suppression on the same forest at first suppression of this fire. Isolated fires are assigned a value of zero Several multiplicity measures were examined in attempts to find the most sensitive and meaningful, including some based on regional (multiple-forest grouping) and forest district areas. SM showed the strongest associations with time required for suppression.

The data were first examined using exploratory techniques to determine general trends and to develop an awareness of data characteristics that might affect the choice of statistical techniques. The techniques used included scatterplots, boxplots, and Pearson and Kendall correlations.

Because of possible spurious correlation of fire-fighting effectiveness measures (like suppression time) and SM through the influence of weather conditions, attempts were made to control for variation of conditions. Exploratory analyses showed that pairwise relationships among available variables were too weak to supply such control. The observed variable distributions and the presence of data errors argued against using standard regression techniques. Instead, we used matched sets of fires, each set including a fire string plus a preceding isolated fire (Figure 1). A string is a group of fires within which, at every time from first suppression to last containment, at least one fire is uncontained. If these strings are short in duration, comparisons made within the sets should involve reasonably consistent burning conditions.

Strings used in construction of matched fire sets were required to consist of at least six fires, have an SM greater than 3 for the sixth fire, and an isolated fire immediately preceding the string. Each matched set of fires therefore yields information on isolated fires and fires with low and moderate SM values. The number of fire sets fulfilling these requirements was

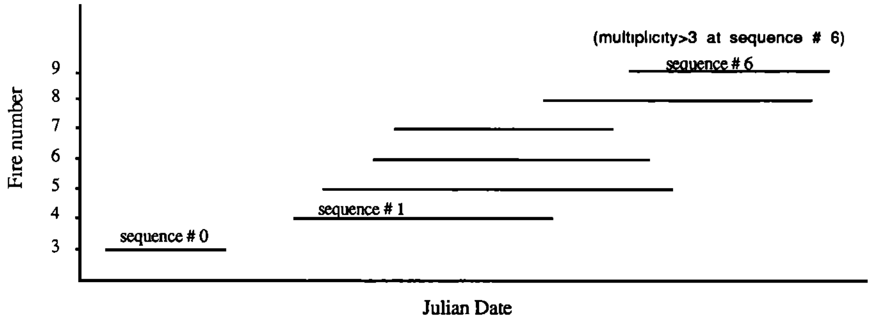

Fig. 1. Representation of a matched set of fires used in investigating multiplicity effects. Left end of line segments represent arrival time, right end represents containment time. Each matched set is composed of an isolated fire closely followed by six fires with overlapping suppression periods. Sequence numbers refer to chronological ordering of fire starts within a matched set.

36 in northeast Oregon, 30 in central Oregon, and 18 in Washington. This technique was not used with southern California data.

Wilcoxon's matched pairs test (Mendenhall 1983) was used to test for differences between positions in matched sets. This test offers much greater power and reliability than parametric analogs such as the paired t-test when parametric assumptions cannot be supported. Pairwise differences between the first, second, and last-occurring fires in these sets were tested. Because of prior expectations for direction of changes, the attained significance levels were calculated relative to one-sided hypotheses.

All analyses were first attempted on data from northeast Oregon, then repeated with data from central Oregon and Washington. Exploratory techniques were also used with data from southern California.

RESULTS

Scatterplots and boxplots generally revealed weak pairwise relationships among variables, with the exception of the burned area-suppression time association. Several variables not discussed above were also examined with similar results. These included the energy release component and ignition component of the NFDRS (Deeming et al. 1977), and other damage measures from the fire reports. The observed associations are summarized with Kendall correlation coefficients in Table 1. These statistics are based on analysis of data from northeast Oregon for the period 1980–1984 and are representative of associations seen for other time periods and study areas. Although many of these correlations are statistically significant ($P < 0.05$), only the correlations between burned area and suppression time and LAL and SM are even moderate in magnitude. In northeast Oregon, where the great majority of fires are lightning-caused, the correlation of daily values of LAL and SM was only 0.196. The correlation of LAL with the following day's SM was also weak. Strong associations of burning conditions, fire-fighting effectiveness, lightning, and simultaneous wildfires were not in evidence. Despite different fire cause patterns, associations in southern California and the Northwest were similar.

Wilcoxon's test, in application to matched fire sets, is sensitive to differences associated with chronological ordering of fires (sequence). Because of the structure of matched sets, changes in sequence also imply changes in SM. The variables often have equal values, resulting in many zero differences. Because of this, the significances obtained with Wilcoxon's test are conservative estimates of the true values. Only three comparisons revealed significant results (Table 2): (1) Positive differences in LAL between sequence 1 and sequence 0 fires were marginally significant ($0.05 < P < 0.1$). Sequence 6 fires showed a marginally significant increase in LAL relative to isolated fires. Higher lightning activity therefore seems to be associated with simultaneous fire occurrence. (2) Sequence 6 fires had significantly longer travel times than sequence 1 fires, indicating that forces reach fires occurring early in strings more quickly than later fires (3) A highly significant ($P < 0.01$) difference was manifest between suppression times of sequences 1 and 0. The median difference was 120 minutes; the mean difference was 233 minutes. Sequence 1 fires require longer suppression, indicating (in this sense) a decrease in fire-fighting efficiency. Although the mean difference between sequence 6 and 1 was 92 minutes, this value was heavily influenced by one extreme positive value. The median difference is −90 minutes, and the test result is not significant.

Differences of the CBI and RBI (Table 2) associated with sequence changes were not significant. Two other NFDRS indices (not shown) were calculated from weather records and compared: energy release component and ignition component (Deeming et al. 1977). No significant differences were seen. These results indicate that burning conditions within a set are relatively uniform. Differences associated with sequence therefore cannot be attributed to changes in burning conditions.

The results of tests on data from northern Washington and central Oregon closely paralleled those of northeast Oregon (Figure 2). Note that the lines joining points in Figure 2 are simply optical devices to aid in recognition of results from the same area. Data collected by the California Division of Forestry indicate fires with SM = 1 generally have longer suppression periods than fires with SM = 0 (Glen Lee, CDF, personal communication), further corroborating the results in Figure 2.

Matched fire sets for northeast Oregon were further investigated for possible confounding factors. Examination of fire causes showed that 79% of the sequence 0 fires were lightning-caused, compared to 95% for sequence 1, and 92% for sequence 6. Elapsed times between the start times of sequence 0 and sequence 1 fires were generally short, with 87% being less than 55 hours and 76% less than 25 hours. The strings in matched sets were required to include at least six fires, but no upper limit was placed on the total number of fires associated with these strings. This number varied from 6 to 56, with 84% of the strings involving less than 18 fires. The maximum SM in strings varied from 4 to 16, with 82% of the strings exhibiting maximums less than 10. Remember, that values of SM greater than 6 occur after sequence 6 and do not directly affect the statistical results presented here.

Table 1. Kendall tau *b* correlations between selected variables for northeast Oregon (1980–1984).

	LAL	RBI	CBI	ST	AREA	SM
LAL	1.000	0.057	0.011	0.052	−0.031	0.196
RBI	0.057	1.000	0.482	0.088	0.017	0.044
CBI	0.011	0.482	1.000	0.083	−0.009	0.071
ST	0.052	0.088	0.083	1.000	0.192	0.144
AREA	−0.031	0.017	−0.009	0.192	1.000	−0.004
SM	0.196	0.044	0.071	0.144	−0.004	1.000

Table 2. Results of Wilcoxon's signed rank test for paired differences within matched sets of fires from northeast Oregon (1975–1984). The reported significance levels are for one-tailed tests; for MAXP, the alternate hypothesis is that the true median difference is negative; for other variables, the alternate hypothesis is that the true median difference is positive.

Comparison	Variable	Attained significance	Mean difference	Median difference
seq 1 − seq 0	CBI	0.41	0	0
	RBI	0.31	3	0
	LAL	0.06	0.3	0
	TRAV	0.74	−45 min.	2 min.
	MAXP	0.47	6	0
	ST	0.0002	233 min.	120 min.
seq 6 − seq 0	CBI	0.53	−2	0
	RBI	0.77	−1	0
	LAL	0.06	0.2	0
	TRAV	0.45	−26 min.	3 min.
	MAXP	0.21	−0	0
	ST	0.13	325 min.	0 min.
seq 6 − seq 1	CBI	0.61	−1	0
	RBI	0.89	−4	0
	LAL	0.71	−0.1	0
	TRAVEL	0.04	20 min.	15 min.
	MAXP	0.08	−7	−1
	ST	0.81	92 min.	−90 min.

DISCUSSION

Simultaneous fires tend to require more suppression time than single fires, while retaining similar size distributions (Table 3). There are two possible explanations: (a) simultaneous fires strain fire-fighting resources, producing longer suppression times; or (b) multiple fires tend to occur under conditions that make suppression difficult. In the case of (b) the association between multiplicity and suppression time is spurious, and it cannot be said to indicate causation. Explanation (a), however, has clearer implications for fire management. The primary objective of this study was to assess the validity of explanation (a) above. To do this, variation in burning conditions must be accounted for. The use of matched sets of fires seemed to be the most reliable method available. Within such a set, conditions appear to be fairly constant, so that multiplicity effects can be directly assessed.

We restricted comparisons to the first six fires in a string to avoid using fires that burned for long periods without serious suppression efforts. In addition, this restriction limits the possibility of additional force allocations influencing the results. Because such allocations are poorly documented in the data, it is impossible to account for their influence. The researcher must instead strive to avoid them. The comparison of fires in matched sets is therefore primarily a comparison of responses on a local level.

We expected the first fires in a string to be less severe than later fires of higher multiplicity since they strain management resources less. But the first fire in a string tended to burn more area and have longer suppression times. One explanation is that dispatchers may direct first efforts to the most dangerous fires; if true, this would bias our comparisons. Fire personnel consulted during this study did not indicate this as a common practice, however

Fire personnel suggested that the observed differences between sequence 0 (isolates) and sequence 1 fires (first fire in a string) might be due to differences in methods of force dispatch. With high lightning activity expected, forces are held in reserve for suppression of later fires. When isolated fires occur with no further fire starts expected, fewer (or no) forces are held in reserve, so these fires usually receive larger suppression forces. This implies that force size may explain the greater suppression times of sequence 1 fires relative to sequence 0 fires. But since Wilcoxon's test indicates no significant differences in MAXP within matched fire sets, differences in dispatch systems seems an inadequate explanation.

Another possible explanation is the sometimes common practice of holding the best fire-fighting personnel in reserve during early fires in an expected string. This results in the least experienced forces being dispatched to early string fires. Fire records are too incomplete to allow this suggestion to be well investigated, but the data in Table 2 are consistent with this explanation.

Although significant suppression time differences were shown between fires of differing multiplicities, the difficulty of demonstrating these differences conflicts with accounts of fire personnel, which usually indicate strong associations with suppression difficulty. The present study also shows that higher multiplicities are not always associated with decreased suppression effectiveness. These discrepancies may be partly explained by the fact that the accounts of fire personnel are surely affected by experiences with high multiplicity, while the present study examines only the milder effects associated with moderate multiplicity. Secondly, the fire report data have shortcomings that make it likely that even substantial differences would be difficult to demonstrate.

Some of the most serious shortcomings of the current fire history data are: (1) The methods of data collection can lead to data of questionable reliability. Reports are sometimes completed long after fires are controlled, for instance. (2) The reported values reflect a suppression system already in operation, and the treatment accorded fires varies greatly. Data detailing resource use is of poor quality, however, so inequities in suppression efforts cannot be accounted for. (3) Although a large fire may burn and undergo suppression for many days, the reports give only a single value for RBI and area burned. At present, re-

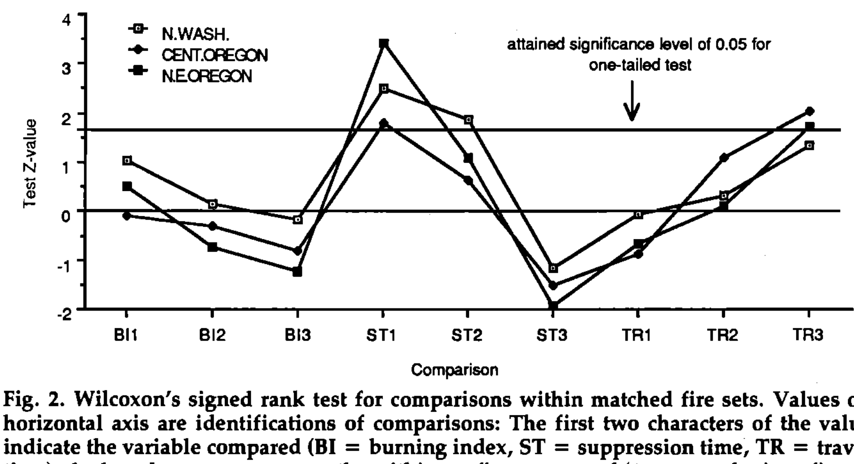

Fig. 2. Wilcoxon's signed rank test for comparisons within matched fire sets. Values on horizontal axis are identifications of comparisons: The first two characters of the value indicate the variable compared (BI = burning index, ST = suppression time, TR = travel time); the last character represents the within-set fires compared (1 = second minus first, 2 = last minus first, 3 = last minus second). Vertical axis represents the attained significance level for the specified test as the value of a standard normal random variable.

Table 3. Suppression time and number of fires occurring in national forests north of California, south of Canada, east of the Cascade Mountains, and west of the Rocky Mountains (1975–1984). Fires are classified by simultaneous fire occurrence within the same forest (single or multiple fire), simultaneous fire occurrrence in other forests (forest involvement), and fire size.

Final fire size (ac)	Average suppression time (hr) Single forest involvement		Multiple forest involvement	
	Single fire	Multiple fire	Single fires	Multiple fires
0.0–0.25	1	2	3	5
0.26–9.9	2	6	6	12
10.–99.9	8	12	15	58
100.–299.9	9	27	26	63
300.–999.9	25	39	47	253
1000.–4999.9	—	72	—	198
5000+	—	—	—	142
Final fire size (ac)	**Number of fires Single forest involvement**		**Multiple forest involvement**	
	Single fire	Multiple fire	Single fires	Multiple fires
0.0–0.25	1986	534	4056	7962
0.26–9.9	316	100	794	1246
10.–99.9	27	11	115	125
100.–299.9	4	2	24	27
300.–999.9	1	2	7	26
1000.–4999.9	—	—	4	14
5000+	—	—	—	3

searchers must adopt arbitrary rules for allocating damage and estimating burning conditions through the suppression period of a fire. (5) The current records indicate location by forest, district, township, and range. Conversion of this information to a more usable form is prohibitively time-consuming for researchers, discouraging attempts to use location information.

Because of these shortcomings, the effects of high multiplicity cannot be well evaluated with the present data. In such cases, unequal distribution of fire-fighting forces is probable, and because reliable data on force disposition are not available, fires in this circumstance cannot be meaningfully compared. Unfortunately, it is probable that multiplicity effects are most strongly manifested above threshold levels which cannot be meaningfully compared using current data. Those situations in which multiplicity effects might play the most important role are therefore the most inaccessible to study, and the use of short matched strings is only a crude approximation. Nonetheless, the present study does show that simultaneous occurrence of wildfires is sometimes associated with declines in suppression effectiveness. □

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