FOREST FIRE HISTORY...

a computer method of data analysis

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In the continuing effort to control forest fires, the information gathered on the Individual Fire Reports (U.S. Forest Service Form 5100-29) is of great potential value. Its usefulness as a basis for control planning and for future research and development depends, however, on the degree to which it can be quickly summarized and clearly presented.

The data from these Reports for past years on a given National Forest, though not necessarily representative of current conditions, do provide some insight into potential problems. And they establish a basis for estimating probabilities of fire occurrence, detection time, initial attack time, and other related variables.

This report describes a series of digital computer programs designed to retrieve and present information from the Individual Fire Reports. Copies of the programs and a description of their mathematical derivation are available, upon request, from the Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701, Attention: Computer Services Librarian.

The programs are written in Fortran for operation on the IBM 360 computer. Two programs read and summarize data—one on fire occurrence and the other on fire detection and initial attack time. They are used in conjunction with a third program that computes the sample distribution and attempts to fit the data with a series of known continuous distributions. In the following description of the programs, sample distributions have been computed to illustrate the program output. Data used in the illustrations are drawn from several National Forests: the San Bernardino, Angeles, and Cleveland in California; the Clearwater in Idaho; and the Deschutes in Oregon.

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A series of computer programs is available to extract information from the Individual Fire Reports (U.S. Forest Service Form 5100-29). The programs use a statistical technique to fit a continuous distribution to a set of sampled data. The goodness-of-fit program is applicable to data other than the fire history. Data summaries illustrate analysis of fire occurrence, detection and initial attack time, and space and time relationships of multiple fires.

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FIRE OCCURRENCE PROGRAM

The fire occurrence program summarizes data on the number and size of fires and on the distribution of fires in time and space. By using this program, a cumulative sample distribution of fire occurrences over the 1960-69 period, projected on a 1-year time base, was produced for the San Bernardino and Clearwater National Forests *(fig. 1)*. The analysis shows that on the Clearwater 95 percent of the 1,056 lightning-caused fires occurred in a 3-month period. There were more man-caused fires on the San Bernardino National Forest, and they occurred throughout the year.

The cumulative lightning fire occurrence curves for both Forests are smooth S-shaped curves. Lightning-caused fires (a natural process) are seen to be normally distributed. For example, for the Clearwater National Forest, the mean, with respect to elapsed time from the beginning of the year, is about the 216th day, with a standard deviation of 24 days.

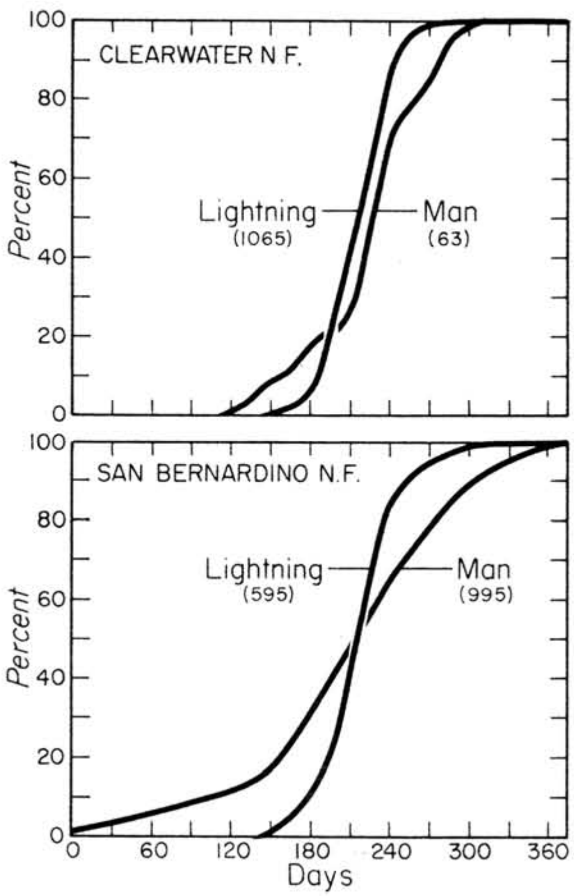

Figure 1—Sample distribution of man-caused and lightning fires, Clearwater National Forest, Idaho, and San Bernardino National Forest, California, 1960-69, projected over a 1-year period.

Man-caused fires are less easily predictable, and the methods presented here may or may not be applicable—depending on local conditions.

The data on fire size yield a useful comparison, based on reports from four National Forests *(table 1)*.

Table 1—*Acreage burned in fires from all causes, on four National Forests, 1960-1969*

National Forest and State	Total fires	Total acres burned	Total fires 0.25 acres or more	Fires burning 10,000 acres or more	
				Number	Acres burned
Cleveland (Calif.)	574	91,532	161	1	48,639
Angeles (Calif.)	774	215,000	262	6	146,332
San Bernardino (Calif.)	1,590	95,800	253	3	55,742
Clearwater (Idaho)	1,118	13,700	142	0	0

During the 90-day lightning season on the Clearwater National Forest, a large number of lightning-caused fires occur, with frequent multiple occurrences on a given day. The program yields the cumulative probability of this event, given that at least one lightning fire will occur:

Fires per day	*Cumulative probability*
1	0.48
2	.63
3	.70
4	.78
5	.81
6	.84
8	.89
10	.91
25	.996
36	1.00

All lightning fire occurrences during a given year may be set in increasing order of time while account is taken of the location of each one. During a single storm, lightning fire starts may cluster about an *initial* occurrence, which is defined according to specific time and space limits. An initial occurrence is a lightning fire start that (a) is outside a given radius measured from the location of a previous initial fire, (b) beyond a given maximum time span measured from the same previous initial fire, and (c) followed by one

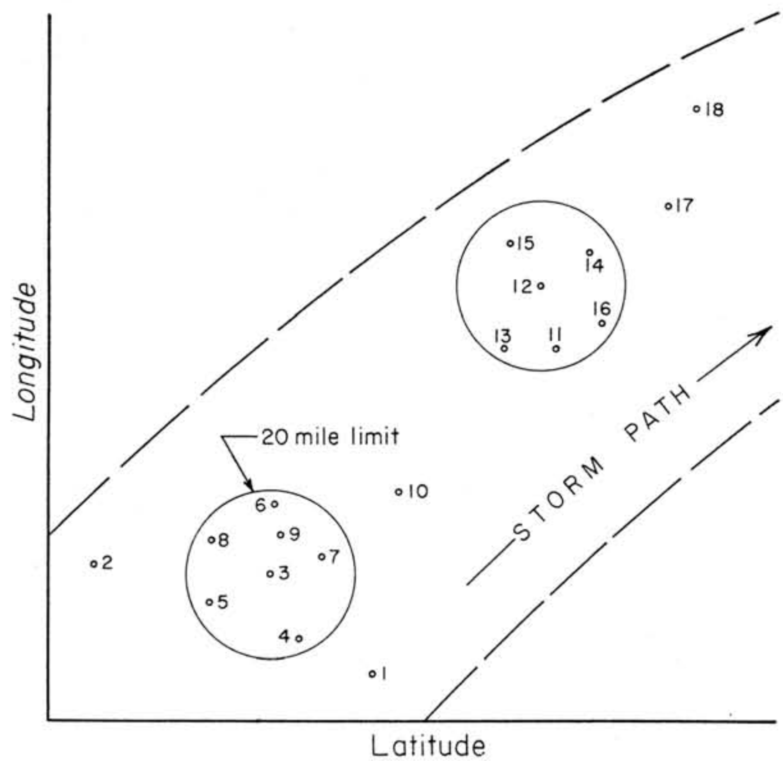

Figure 2—A series of lightning fire starts caused by a hypothetical storm. Fire starts are numbered in order of time. Circled fires are multiple fires related to the earliest start in each circle; fires 9 and 11 are exceptions outside the required time limit of 3 hours.

or more fire starts, all of which are within the given distance and time limits.

For example, in the storm pattern shown in *figure 2,* the limits were set at 3 hours and 20 miles from an initial lightning occurrence. Here 18 lightning fire starts were observed at times indicated by their numerical order. Fires 1 and 2 were single occurrences; no other fires occurred within the required limits. Fire 3 was followed by 4, 5, 6, 7, and 8 within the time and distance limits. Fires 9, 10, and 11 were single occurrences. Initial fire 12 was followed by four fires within the required limits. Although fires 9 and 11 were within the required radial distance of fires 3 and 12, respectively, they were not within the required time limit of 3 hours.

The computer program by which this summary is produced identifies the initial fires and prints their location and time of discovery, the number and length of multiple occurrences, and the distance and time from each multiple lightning fire to its initial fire.

A useful tool in decision-making is an estimate of the probability of multiple lightning fire starts with respect to time and distance. The following set of cumulative sample distributions is based on the years 1960 through 1969 for the Deschutes National Forest. From these curves it is possible to reconstruct the past 10 years of lightning fire history and to attempt some predictive statements. Furthermore, by sampling on a uniform 0 to 1 interval, it is possible to simulate the past 10 years and use the output in other computer models for which estimates of the location and frequency of lightning fires are needed.

First, the cumulative distribution of the number of multiple fire starts is given in *figure 3.* The curve indicates, for example, that given an initial fire start, the probability of an additional two or three fire starts within 20 miles and 6 hours is about 10 percent.

Next, the 346 multiple fires were uniformly spread within a 20-mile radius of their initial fire starts *(fig. 3).*

The distribution curve for multiple lightning fire starts *(fig. 3)* shows the distribution of the same 346 fires within the 6-hour limit.

The cumulative distribution curves for latitude, longitude, and time of year for the initial fire starts *(fig. 4)* may clarify the role of these variables in lightning fires.

Starting with the curves from *figure 4,* it is possible to select the location and time of an initial fire start and use *figure 3* to find the number of multiple fire starts associated with it. Finally, *figure 3* can also be used to determine the time and distance relation of each multiple fire to its initial fire. This procedure, applied to data from a specific area, may be of value

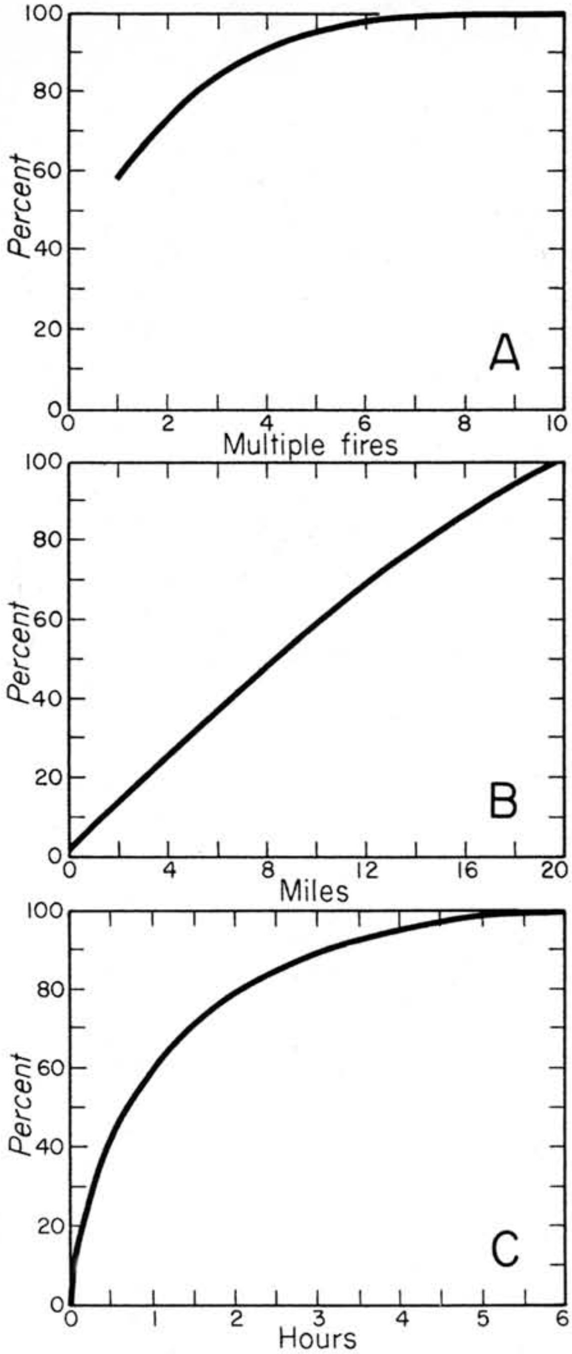

Figure 3—Cumulative distribution of 346 multiple fire starts on the Deschutes National Forest, Oregon, 1960-69: **A**—by number of later fire starts; **B**—by radial distance from initial fires; and **C**—by time span from initial fire starts.

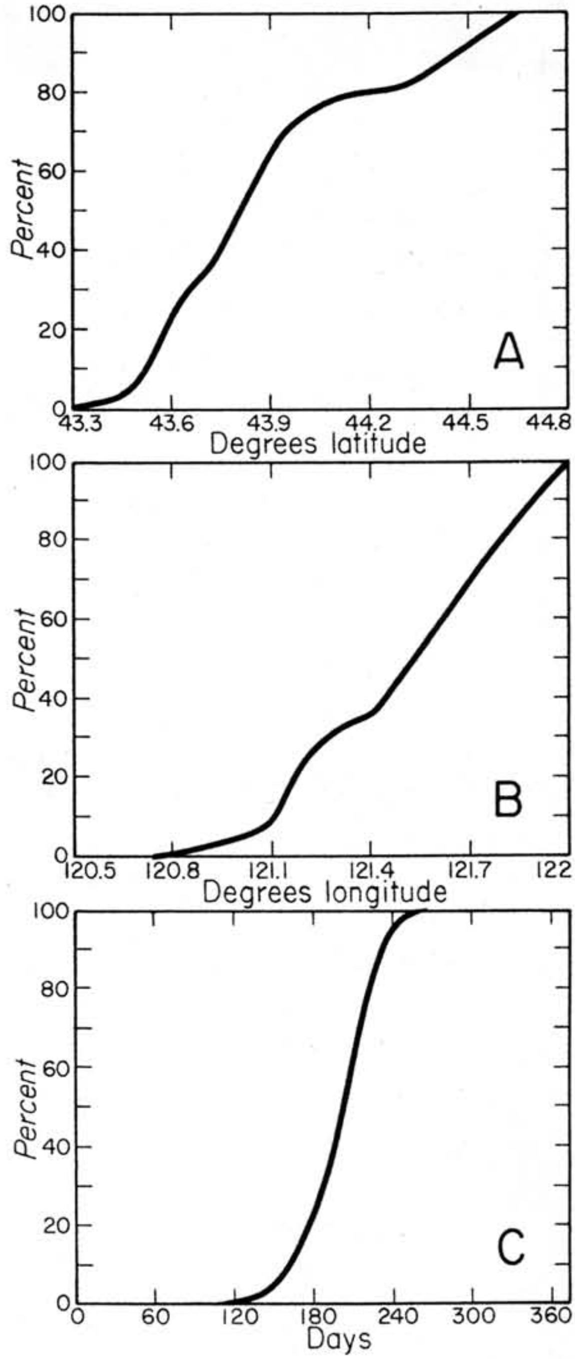

Figure 4—Cumulative distribution of 175 initial lightning fires, Deschutes National Forest, Oregon, 1960-1969; **A**—by latitude north; **B**—by longitude west; and **C**—by time of year.

in determining what detection capability should be and how to allocate forces for the initial control attack.

FIRE DETECTION AND INITIAL ATTACK TIME PROGRAM

The computer program developed to analyze detection or initial attack time allows examination of these two quantities or their sum as a function of the variables available from the 5100-29 data (size, weather, fuel, slope, etc.). Any other variable available from the form may be substituted for detection and initial attack time. To illustrate the output of this program, cumulative sample distributions are given here for combined detection and initial attack time as a function of three variables: size of fire *(table 2)*, fuel *(table 3)*, and burning index *(table 4)*. (The following definitions are used: Detection time is the elapsed time from the estimated start time of the fire to the reported time of discovery; initial attack time is the elapsed time from detection to the time the first suppression action is started.)

Table 2—*Cumulative distribution of combined detection and initial attack time, fires from all causes, on three National Forests in California, by size of fires, 1960-1969*

Time (min.)	Angeles		Cleveland		San Bernardino	
	< 10	> 10	< 10	> 10	< 10	> 10
1	0.03	–	0.02	–	0.04	–
3	.04	0.03	.04	–	.02	–
5	.09	.06	.08	–	.04	–
8	.16	.16	.15	0.02	.10	0.05
10	.25	.22	.18	.07	.13	.07
12	.31	.38	.27	.14	.19	.14
15	.39	.52	.34	.21	.25	.28
21	.51	.63	.46	.29	.33	.49
30	.61	.79	.57	.53	.41	.68
39	.65	.85	.65	.63	.46	.73
60	.73	.92	.74	.77	.54	.83
90	.80	.96	.82	.86	.61	.89
180	.88	.97	.88	.87	.73	.92

Table 3—*Cumulative distribution of combined detection and initial attack time, from all causes, on the San Bernardino National Forest, by type of fuel, 1960-1969*

Time (min.)	Timber (748)[1]	Brush (365)[1]	Grass (296)[1]
3	0.01	0.02	0.04
6	.03	.05	.11
8	.05	.10	.21
10	.07	.12	.32
15	.12	.29	.51
18	.15	.35	.59
24	.19	.42	.69
30	.24	.50	.75
40	.29	.57	.85
60	.36	.65	.88
120	.51	.78	.93

[1]Number of fires shown in parentheses.

Table 4—*Cumulative distribution of combined detection and initial attack time for fires from all causes, on three National Forests in California, by burning index, 1960-1969*[1]

Time (min.)	Angeles		Cleveland		San Bernardino	
	B.I. below 28	B.I. above 28	B.I. below 28	B.I. above 28	B.I. below 28	B.I. above 28
3	0.04	0.06	0.03	0.03	0.01	0.02
5	.05	.07	.07	.06	.03	.06
6	.10	.13	.09	.07	.04	.08
9	.20	.20	.16	.11	.10	.15
12	.32	.29	.25	.30	.15	.25
15	.41	.40	.32	.38	.20	.35
18	.46	.47	.39	.43	.24	.43
24	.54	.62	.49	.55	.29	.51
30	.60	.75	.56	.60	.35	.59
45	.68	.84	.70	.66	.42	.69
60	.71	.88	.75	.67	.48	.73
90	.80	.92	.83	.81	.56	.78
180	.87	.94	.88	.84	.70	.84
	Number					
Fires	503	178	511	63	1,006	450

[1]B.I. = Burning index.

SAMPLE DISTRIBUTION, GOODNESS-OF-FIT PROGRAM

The sample distributions given earlier are computed from the data-retrieval programs by a third program, which then attempts to fit the data with a known continuous distribution.

In the sample output from the second program *(table 5)*, the data represent detection times (hours) for 204 class A fires (up to 0.25 acre). All were started by lightning. They cover all such fires during the years 1967-69 on the Clearwater National Forest.

The program attempts to fit the sample data with a set of known probability density functions by applying the Kolmogorov-Smirnov goodness-of-fit test (Whitney 1959). Six possible densities are available in the program.[1] While fitting the data, the program reduces the sample data to a histogram and sample distribution function $S_n(x)$. The detection times (hours) for the 204 class A fires can be fitted with a

Weibull distribution (with parameters λ = .291 and β = .517).[1] As a result, we can say, for example, that the probability of detecting a class A fire caused by lightning in less than 5 hours is

$$= (1 - e^{(-.291 * 5.^{.517})}) - (1 - e^{(-.291 * 0.^{.517})})$$

$$= 1 - e^{-.291 * 5.^{.517}}$$

$$= 0.4876$$

This type of goodness-of-fit test has some definite advantages over the standard Chi-square process (Hoel 1971). It is an exact method, whereas the Chi-square method is only valid for reasonably large samples. Furthermore, in the classification of data, all frequencies need not exceed five observations.

The program is designed so that the user can delete or add new distribution functions to estimate the distribution of the data. The new distribution must be continuous, however, and one or more subroutines must be provided to evaluate the distribution of the sample data.

[1]Mees, Romain M. *A method of fitting distributions to forest data.* 1972. (Unpublished report on file at Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.)

Table 5–*Detection times (elapsed hours) for lightning caused fires, class A size, Clearwater National Forest, 1967-69*

0.0000	0.3000	1.6667	7.8167	14.0000	46.0000
0.0000	0.4167	1.6667	7.9167	14.0000	47.6667
0.0000	0.4167	1.6667	8.0000	14.3333	48.5000
0.0000	0.4167	1.9167	8.0000	14.5833	49.7500
0.0000	0.4500	2.0000	8.4167	14.8333	54.3333
0.0000	0.5000	2.0000	8.5000	15.0000	60.1000
0.0000	0.5000	2.1500	8.8333	15.0833	60.6667
0.0000	0.5000	2.4167	9.3333	15.5000	62.7500
0.0000	0.5833	2.8333	9.5000	15.5000	68.0000
0.0000	0.5833	3.0000	9.6667	16.8333	69.0000
0.0000	0.5833	3.0833	9.8333	17.0000	71.0000
0.0000	0.5833	3.5833	10.0833	17.1667	73.0833
0.0167	0.5833	3.6667	10.2500	17.8333	78.8333
0.0667	0.5833	3.8333	10.8333	18.0000	84.3333
0.0833	0.6667	4.0000	11.0000	18.0000	84.4667
0.0833	0.6667	4.6667	11.0333	18.3333	84.6667
0.0833	0.6667	4.6667	11.5000	18.4167	91.8333
0.0833	0.6667	4.8333	11.5000	18.5000	92.6667
0.0833	0.7500	4.8333	12.3333	19.3500	100.6500
0.1167	0.8333	5.0000	12.3333	19.5000	100.6500
0.1167	0.8333	5.1667	12.4167	19.5000	100.6500
0.1667	0.9167	5.3000	12.4667	21.5000	100.6500
0.1667	0.9167	5.5000	12.4667	22.8333	100.6500
0.1667	0.9167	5.7500	12.4833	24.7500	100.6500
0.1667	1.0000	5.9167	12.5000	26.3333	100.6500
0.1667	1.0000	6.0000	12.6667	31.0000	100.6500
0.1667	1.0000	6.4000	12.7500	31.7833	100.6500
0.1667	1.0833	6.6833	12.7500	35.0833	100.6500
0.1833	1.2500	6.7667	12.9167	35.2000	100.6500
0.2000	1.3333	6.8333	13.1667	36.1667	100.6500
0.2500	1.4000	7.4000	13.2333	37.1667	100.6500
0.2500	1.4167	7.4167	13.2500	38.0500	100.6500
0.2500	1.4167	7.5000	13.3333	38.9333	100.6500
0.2500	1.5333	7.6500	13.5000	44.5000	100.6500

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