Distribution of Lightning- and Man-Caused Wildfires in California[1]

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Abstract: During the 1970 decade on lands under fire jurisdiction by the California Division of Forestry (CDF) and the United States Forest Service (USFS) there were over 100,000 wildfires, 16.2 percent of which were lightning-caused and these accounted for 13.1 percent of all area burned. On USFS land, August is the peak month for lightning fires whereas July is the peak for man-caused fires. On average, lightning fires occur at higher elevations than man-caused fires and this is reflected in differences in the types of vegetation providing fuel for iginition. The number of lightning fires is positively correlated with distance from the coast and latitude whereas the number of man-caused fires is negatively correlated with these two parameters. Correlations between other parameters are presented and the question of "natural" burning patterns is discussed.

Wildfires are a major influence on the structure and function of most mediterranean-type ecosystems (Mooney 1977). This is certainly true for the brushland and forest communities of California. Many plant species in these communities have adaptations such as basal burls, refractory seeds or serotinous cones which are generally interpreted as evolutionary responses to a long association with fire. In light of this, desirable management of such fire-prone systems requires an understanding not only of the present characteristics of the fire regime but some understanding of the prehistorical (natural) fire regimes. The purpose of this paper is to provide a picture of the present burning pattern in California and attempt to evaluate the relationship between this pattern and that produced under "natural" conditions. With respect to fire regime, the term "natural" has various interpretations (Keeley 1980). In this paper I will be using the term in reference to the fire regime unaltered by contemporary or aboriginal man.

The question "what was the natural fire regime in California wildlands" can be approached several ways. Forested ecosystems provide a limited view of presettlement fire frequency through fire scars on long-lived fire-resistant trees (e.g., Kilgore and Taylor 1979). Byrne and others (1977) have approached this question by using sediment cores which contain charcoal deposits and then developing models for interpreting these deposits in terms of the presettlement fire regime. A third approach has been to examine the recent distribution and frequency of lightning fires and extrapolate these findings to estimates of presettlement fire frequency (e.g., Keeley 1977, Parsons in press). At best, each of these methods provides a limited view of the natural fire regime.

In the present study I have assembled statistics on the distribution of wildfires in California. These data give a clear picture of present burning patterns in the state. Additionally, by distinguishing lightning-caused and man-caused wildfires a framework is provided for evaluating prehistorical burning patterns.

METHODS

Fire statistics spanning the 1970 decade for California lands under the jurisdiciton of the California Division of Forestry (CDF) and the United States Forest Service (USFS) form the basis for this analysis. The terms "CDF land" and "USFS land" will be used to indicate lands under the jurisdiction of those agencies, although not necessarily owned by them. Data on the number of fires and hectares burned per year by cause was available from both the CDF and the USFS. Detailed data on cause, month, elevation, acreage and fuel type of ignition for every fire during the 1970 decade was available only from the USFS. Since the area was not reported for fires less than a quarter acre (.10 Ha.) these "spot fires" were arbitrarily assigned a value of .1 acre (.04 Ha). In the early part of the decade several realignments were made by the CDF and USFS. These were taken into account and statistics are presented for forests as they appeared 1979.

These data were computerized and analyzed with the UCLA Biomedical Statistical Programs (BMDP 1977 series). Since CDF ranger units and USFS forest districts differ in size, all data was standardized and expressed on a per million hectare basis.

The distribution of fires was evaluated along a gradient from the coast to the interior and along a latitudinal gradient. For this purpose each ranger unit or forest district was assigned a position along these two gradients which approximated the center of the unit or district.

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Table 1--Average number of, and area burned by lightning-caused and man-caused wildfires on CDF and USFS land in California during the 1970 decade.

	No/Million Ha/Yr Lightning	Man	Ha/Million Ha/Yr Lightning	Man
CDF	31	541	416	3,347
USFS	129	134	189	669

RESULTS

The combined California Division of Forestry (CDF) and United States Forest Service (USFS) land covered by this survey was over 22.8 million hectares. During the 1970 decade there were 76,169 fires on CDF land and 25,084 on USFS lands. The distribution of these fires by cause is shown in table 1. There were twice as many fires and four times more area burned on CDF land than USFS land. On CDF land only 5 percent of the fires were caused by lightning and these fires accounted for 11 percent of the area burned. Lightning accounted for 49 percent of the fires on USFS land but these fires burned only 22 percent of the total area consumed. In general lightning fires were more common on USFS land than on CDF land. However, on average, a lightning fire on CDF land burned 10X more area than one on USFS land.

As one might expect, the distribution of fires was not uniform across the state. A breakdown, by CDF ranger unit and USFS forest district, of wildfires is presented in tables 2 and 3. The arrangement of units or districts is more or less from south to north and coast to interior (see fig. 1 for locations). On CDF land (table 2) the average number of lightning fires varied from a low of 4/million ha/yr in the southern part of the state to a high of 134/million ha/yr in the northern part of the state. A similar pattern was observed on USFS land (table 3) with lightning fire frequency varying from 20/million ha/yr in the southern part of the state to 393/million ha/yr in the northern part of the state. Man-caused fires showed a latitudinal trend opposite to this with more fires in the southern end of the state and fewer in the northern end. These patterns are evident in correlations presented in table 4. With all ranger units and forest districts considered there was a highly significant positive correlation between lightning fire frequency and latitude and a significant negative correlation between man-caused wildfires and latitude. A similar pattern was observed with respect to distance from the coast; a highly significant positive correlation with lightning-caused fires and a highly significant negative correlation with man-caused fires. The same pattern was observed with respect to area burned, however the correlations were not significant for lightning-caused fires.

Table 2--Breakdown by ranger unit for average number of, and area burned by, lightning-caused and man-caused wildfires on CDF land during the 1970 decade.

Ranger Unit	No/Million Ha/Yr Lightning	Man	Ha/Million Ha/Yr Lightning	Man
1. San Diego	31	914	190	2,803
2. Orange	4	4,286	3	12,080
3. Riverside	27	1,735	1,553	31,742
4. San Bernardino	34	934	138	1,086
5. San Luis Obispo	6	325	29	4,384
6. San Benito-Monterey	7	307	13	5,344
7. San Mateo-Santa Cruz	7	1,698	1	4,185
8. Santa Clara	5	402	940	6,859
9. Sonoma	7	868	5	6,162
10. Lake-Napa	17	490	33	12,618
11. Mendocino	40	316	55	3,448
12. Shasta-Trinity	73	539	6,019	2,401
13. Humboldt-Del Norte	42	289	285	4,547
14. Tulare	11	172	186	3,646
15. Fresno-Kings	8	103	197	9,182
16. Madera-Mariposa	36	266	1,253	3,837
17. Inyo-Mono	6	62	31	991
18. Tuolumne-Calaveras	28	713	197	9,183
19. Amador-Eldorado	23	922	111	13,050
20. Nevada-Yuba Placer	15	217	13	7,287
21. Butte	43	748	143	4,455
22. Tehama-Glenn	18	201	211	20,313
23. Siskiyou	133	253	329	1,814
24. Lassen-Modoc	134	104	10,731	546

Table 3-- Breakdown by forest district for average number of, and area burned by, lightning-caused and man-caused wildfires on USFS land in California during the 1970 decade.

Forest District	No/Million Ha/Yr Lightning	Man
1. Cleveland	54	433
2. Angeles	68	372
3. San Bernardino	118	380
4. Los Padres	20	97
5. Mendocino	67	53
6. Six Rivers	32	80
7. Klamath	164	58
8. Shasta-Trinity	263	242
9. Sequoia	116	56
10. Inyo	84	74
11. Sierra	183	138
12. Eldorado	148	172
13. Stanislaus	163	136
14. Lake Tahoe Basin	191	1,147
15. Tahoe	157	154
16. Plumas	393	297
17. Lassen	165	79
18. Modoc	126	21

Table 3--(Continue)

Forest District	Ha/Million Ha/Yr Lightning	Man
1. Cleveland	36	12,101
2. Angeles	1,256	20,190
3. San Bernardino	184	3,919
4. Los Padres	2,237	1,734
5. Mendocino	24	1,619
6. Six Rivers	4	36
7. Klamath	597	171
8. Shasta-Trinity	47	1,709
9. Sequoia	98	1,559
10. Inyo	25	115
11. Sierra	44	1,879
12. Eldorado	24	593
13. Stanislaus	130	558
14. Lake Tahoe Basin	19	122
15. Tahoe	101	99
16. Plumas	209	530
17. Lassen	200	52
18. Modoc	1,699	396

The year-to-year variability in number of fires in a particular CDF ranger unit or USFS forest district was evaluated by comparing the coefficient of variation (CV percent = $(SD \div \bar{X}) \times 100$). On most units and districts CV = 20-30 percent and never >50 for man-caused fires. Number of lightning-caused fires on USFS land was more variable with 2/3 of the districts having CV >50 percent (range 33-96 percent). On CDF land, number of lightning-caused fires ranged from 45-177 percent with nearly half of the units having CV >100 percent.

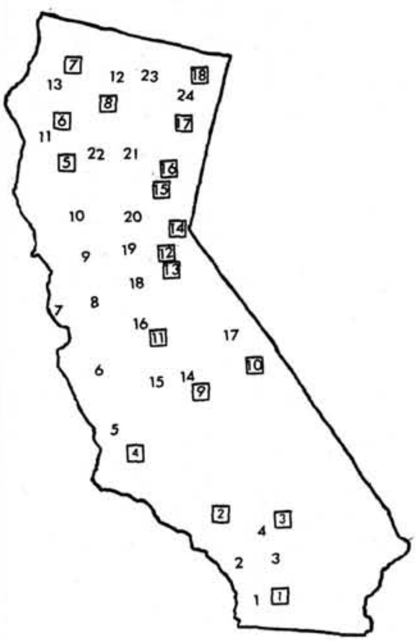

Figure 1--Distribution of CDF ranger units (unenclosed numbers) and USFS forest districts (enclosed numbers) listed in tables 2 and 3 respectively.

Variation in area burned per year was much more variable. Lightning-caused fires had CV >200 percent for half of the CDF units and USFS districts. Man-caused fires were equally variable on USFS districts but less on CDF units; only one unit had CV >200 percent.

Detailed Analysis of Fires (USFS Lands Only)

Month

Lightning-caused fires were most frequent (32 percent) in August whereas man-caused fires were most frequent (21 percent) in July. Lightning-caused fires were more heavily concentrated during the summer with 73 percent occurring in June, July and August whereas only 56 percent of the man-caused fires occurred in these months.

Based on the ten year averages for the 18 USFS forest districts, the correlation of percent of fires occurring in each month from June to September, with various other parameters, was analyzed. For lightning-caused fires, distance from the coast was positively related to the percent of fires occurring in July ($r = +.52$*) and negatively related to the percent in September ($r = -.76$ **). Latitude was positively related to percent

Table 4--Correlation of distance from the coast and latitude with average number of, and area burned by lightning-caused and man-caused wildfires for all CDF ranger units and USFS forest districts in California (N = 42).

	Latitude	Distance From Coast
Lightning		
No/Million Ha/Yr	r = + .37**	r = + .49**
Ha/Million Ha/Yr	r = + .20[NS]	r = + .14[NS]
Man		
No/Million Ha/Yr	r = -.39**	r = -.34*
Ha/Million Ha/Yr	r = -.39**	r = -.34*
NS = P >0.05	* = P <0.05	** = P <0.01

in June (r = +.50*), mean elevation was positively correlated with percent of fires in July (r +.61 **) and negatively correlated with percent in September (r = -.62**). The number of lightning-caused fires (per million ha per yr) was positively related to the percent occurring in June (r = +.65**).

For man-caused fires there was a positive correlation (r = +.54*) between distance from the coast and percent of fires in September. Latitude was positively related (r = +.47*) to the percent in August. As with lightning-caused fires, the average number of man-caused fires was positively related (r - +.55*) to the percent of fires occurring in June. The average area burned by man-caused fires was negtively correlated (r = -.58**) with the percent of fires occurring in August.

Elevation

The elevational distributed of lightning-caused and man-caused wildfires on USFS land are shown in figure 2. Lightning fires typically occurred at higher elevation than man-caused fires, and the latter were more broadly distributed over the elevational gradient.

A breakdown by forest is shown in table 5. The average elevation of lightning fires on a forest (not shown) was positively related to the average elevation of man-caused fires (r = +.78**). Average elevation was also positively correlated with distance from the coast for both lightning-caused (r = +.69**) and man-caused (r = + .80**) fires.

Correlation analysis between area burned per fire and elevation of that fire showed no significant relationship when analyzed across the state. Analysis within particular forests showed two forests with weak but highly significant negative correlations between size and elevation for lightning fires: San Bernardino r = -.14** (N = 548) and Sierra r = -.15** (N = 1,032).

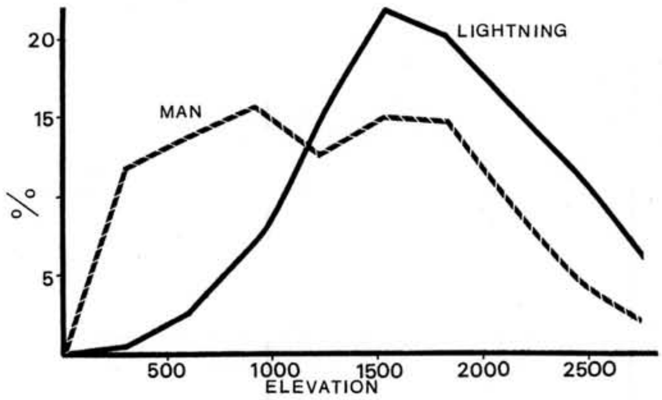

Figure 2--Elevational distribution (meters) of lightning-caused and man-caused wildfires on all USFS lands in California during the 1970 decade.

Area Burned

Size of individual fires was exceedingly variable. On USFS land 97.6 percent of lightning-caused fires and 92.3 percent of man-caused fires were "spot-fires" (<.1 ha.). The remaining fires ranged as high as 17,800 ha for lightning-caused to 47,400 ha for man-caused fires. For the 12,228 lightning-caused fires CV = 5103 percent and for 12,796 man-caused fires CV = 3816 percent.

The percent of fires on a forest district as spot fires was positively related to distance from the coast and latitude for both lightning-caused (r = +.63**, r = +.50*) and man-caused (r = +.58**, r = +.65*) fires. For man-caused fires the size of the largest fire during the decade was negatively correlated (r = -.56*) with latitude.

Fuel Type of Ignition

Table 6 shows the distribution by fuel type for wildfires on USFS lands. The majority of lightning-caused wildfires occurred in timber vegetation, including hardwoods as well as coniferous communities. Grasslands which included meadows and scattered woodlands was the fuel type for only 7% of the lightning-caused fires whereas 27% of the man-caused fires occurred in grasslands.

The percent of lightning-caused fires igniting in chaparral was negatively correlated with distance from the coast (r = -.46*) and latitude (r = -.66**). The percent igniting in timbered vegetations was positively related to distance from the coast (r = +.56*) latitude (r = +.62

Table 5--Distribution, by elevation, of lightning-caused and man-caused wildfires on California lands under USFS jurisdiction during in the 1970 decade.

Forest	Percent by Elevation Lightning		
	<1067m (3500')	-	>1676m (5500')
1. Cleveland	18	60	22
2. Angeles	7	44	49
3. San Bernardino	4	23	73
4. Los Padres	20	41	39
5. Mendocino	19	59	22
6. Six Rivers	47	51	2
7. Klamath	20	54	16
8. Shasta-Trinity	32	54	14
9. Sequoia	3	11	86
10. Inyo	0	1	99
11. Sierra	5	21	74
12. Eldorado	6	28	66
13. Stanislaus	32	54	14
14. Lake Tahoe Basin	1	0	99
15. Tahoe	3	21	77
16. Plumas	5	44	51
17. Lassen	6	41	57
18. Modoc	0	75	25

Table 5--(Continued)

Forest	Percent by Elevation Man		
	<1067m (3500')	-	>1676m (5500')
1. Cleveland	72	18	10
2. Angeles	72	15	14
3. San Bernardino	27	31	42
4. Los Padres	82	10	8
5. Mendocino	53	37	10
6. Six Rivers	87	12	1
7. Klamath	50	39	11
8. Shasta-Trinity	72	23	5
9. Sequoia	37	33	30
10. Inyo	24	43	33
11. Sierra	42	29	29
12. Eldorado	9	30	61
13. Stanislaus	24	36	40
14. Lake Tahoe Basin	0	0	100
15. Tahoe	11	25	64
16. Plumas	32	59	10
17. Lassen	14	69	17
18. Modoc	1	74	25

The average area burned each year by lightning-caused fires was negatively correlated (r =-.53*) with the percent igniting in timbered vegetations.

For man-caused fires the percent igniting in grasslands was negatively correlated (r = -.71**) with distance from the coast. The percent igniting in chaparral was negatively correlated (r = -.69**) with latitude. The percent igniting in timbered vegetation was positively correlated with both distance from the coast (r = +.71**) and latitude (r = +.64**). Additionally, the percent igniting in chaparral was positively correlated with both the number of fires per million ha per year (r = +.63**) and the area burned per million ha per year (r = +.77**). As with lightning-caused fires the percent igniting in timbered vegetation was negatively correlated (r = -.72**) with area burned per million ha per year.

DISCUSSION

One way of summarizing the data which illustrates the potential burning pattern for wildfires is to calculate the recurrence interval to be expected (calculated by dividing the total area in the ranger unit or forest district by the average acreage burned per year). Although some regions within a unit or district are likely to burn more frequently than others, the numbers is a rough estimate of the number of years required to burn the entire area under jurisdiction by a unit or district.

Tables 7 and 8 show these recurrence intervals for CDF and USFS lands. It is not clear how much confidence can be placed in these estimates, though the USFS data for the Cleveland and Angeles Forests suggests there may be a great deal of value in them. The 21 and 27 year interval for these largely chaparral covered forests matches quite well with the commonly accepted notion that chaparral presently burns on a 20-30 year cycle.

The recurrence interval for lightning-caused fires is of little value in terms of absolute numbers but may be useful for comparing regions. For example Modoc County in the northeastern part of the state has one of the lowest recurrence intervals based on both CDF data (table 7) and USFS data (table 8).

Table 6--Distribution, by fuel type of ignition of lightning-caused and man-caused wildfires on California lands under USFS jurisdiction during the 1970 decade.

	Percent	
	Lightning	Man
Grassland	7	27
Sage	3	2
Chaparral	19	22
Timber	50	39
Non-vegetation	<1	10

Table 7--Calculated recurrence interval for lightning-caused wildfires alone and all wildfires on CDF land. Recurrence interval in years = total area/average area burned per year.

Ranger Unit	Years	
	Lightning Fires Alone	All Fires
1. San Diego	3,117	197
2. Orange	37,857	9
3. Riverside	281	13
4. San Bernardino	3,280	369
5. San Luis Obispo	26,842	174
6. San Benito-Monterey	70,078	369
7. San Mateo-Santa Cruz	170,909	167
8. Santa Clara	772	45
9. Sonoma	79,184	63
10. Lake-Napa	19,541	51
11. Mendocino	15,163	239
12. Shasta-Trinity	103	73
13. Humboldt-Del Norte	2,695	159
14. Tulare	3,585	174
15. Fresno-Kings	2,899	132
16. Madera-Mariposa	483	119
17. Inyo-Mono	11,748	355
18. Tuolumne-Calaveras	2,477	52
19. Amador-Eldorado	3,267	27
20. Nevada-Yuba-Placer	27,132	48
21. Butte	2,786	86
22. Tehama-Glenn	3,113	32
23. Siskiyou	1,081	166
24. Lassen-Modoc	55	53

Relating lightning fire frequency to the natural fire frequency for a region such as California is very difficult. Man extinguishes most lightning fires before they spread very far and man ignites many fires which consume a great deal of potential fuel. At the same time there is no a priori reason to assume that present burning patterns reflect natural patterns. Man accounts for most of the acreage burned in California wildlands and these fires differ greatly from lightning-caused-fires in their temporal and spatial distribution.

Several considerations suggest that the present burning potential is greater than under prehistorical conditions, at least for some regions. Man-caused fires occur at lower elevations than lightning-caused fires where fuel conditions are more conducive to fire spread. Also, though the data from this study does not reflect this, the weather conditions during man-caused fires are more conducive to fire spread than during lightning-caused fires. Lightning caused fires consistently are associated with thunderstorms and thus precipitation (Snow and Kotok 1923). Undoubtedly, many of these fires would not spread very far even if they were not suppressed.

One observation I believe is reflective

Table 8--Recurrence interval for USFS land calculated as in table 7 except two estimates were made for southern California forests, one based on a 10 year average for the area burned and another on a 25 year average (additional data from Keeley 1977).

	Year	
	Lightning Fire Alone	All Fires
1. Cleveland	5,679 (1,743)	17 (21)
2. Angeles	223 (554)	13 (27)
3. San Bernardino	2,529 (3,828)	113 (106)
4. Los Padres	356 (854)	201 (189)
5. Mendocino	17,975	265
6. Six Rivers	169,730	15,700
7. Klamath	1,406	1,093
8. Shasta-Trinity	9,807	261
9. Sequoia	12,230	725
10. Inyo	31,260	5,501
11. Sierra	12,725	294
12. Eldorado	13,532	516
13. Stanislaus	3,080	583
14. Lake Tahoe Basin	3,560	482
15. Tahoe	4,803	2,434
16. Plumas	1,533	434
17. Lassen	2,690	2,133
18. Modoc	452	366

of this, is a pattern of increasing numbers of reported lightning-caused wildfires over the past 50 years. This was earlier reported for the Cleveland National Forest in Southern California (Keeley 1977). It is perhaps best illustrated by data from Yosemite National Park. Fire records show that for the 20 yr period beginning in 1931 there were 17.2 (SD = 11.2) lightning-caused fires /yr whereas for the 20 yr period ending in 1979 there were 58.8 (SD = 29.9) lightning-caused wildfires. ($P < 0.01$ by the Mann Whitney U Test). I interpret this to mean that 50 yrs ago many lightning fires were allowed, knowingly or unknowingly, to burn themselves out and would do so today if given a chance. Undoubtedly, much improved detection available today accounts for this phenomenon. What it suggests is that many of the lightning fires which are suppressed as spot fires probably would not have developed any further if left alone. Thus, the number of lightning fires during pre-fire suppression times, which would have produced sizeable fires, is a small subset of the total number recorded in the data for the 1970 decade.

One conclusion from this study does agree with another study concerned with estimating natural fire frequencies. Byrne et. al.[3] have suggested

[4]Bryne, R. Michaelsen, J.; Soutar, A. Fossil charcoal from varved sediments in the Santa Barbara Channel: An index of wildfire frequencies in the Los Padres National Forest (735 A.D. to 1520 A.D.). Unpublished Ms.

based on charcoal depositsoff the coast of Santa Barbara, that whereas fires occurred on average once every 65 yrs along the coast they were approximately twice as frequent further inland. Their conclusion is reinforced by our finding of a highly significant positive correlation between number of lightning-caused fires and distance from the coast.

Other estimates of prehistorical fire frequencies are suggested from studies of fire-scars in long-lived trees, particularly in Sierrean coniferous forests. These estimates however are greatly affected by aboriginal burning. Data from Kilgore and Taylor (1979; as discussed in Keeley 1980) show clearly the tremendous influence of aboriginal burning. It appears that aboriginal burning may have increased the "natural" fire frequency several-fold and to have had a substantial impact on forest structures since the often cited white-fir invasion of mixed conifer forests is clearly traceable to the suspension of aboriginal burning and easily 20 years prior to active fire suppression in that region. That lightning fires alone were inadequate to produce the fire frequencies observed from fire-scar data was also suggested from observations made by Reynolds (1959).

SUMMARY

The data presented in this paper gives an overview of present burning patterns in California. A framework is provided for evaluating the relationship between present and pass fire regimes. The natural fire regime for California may have consisted of fewer fires at lower elevations than presently observed. If this were the case then, due to fuel accumulation, these fires would have been of much greater intensity than is commonly observed today. Any future studies which use this approach to evaluate prehistorical burning patterns will need to go beyond simply assembling statistics. A modeling approach which incorporates lightning fire distribution with fire behaviour characteristics, topographical, weather and fuel conditions could be successful.

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