THE YOSEMITE AND SEQUOIA-KINGS CANYON PRESCRIBED NATURAL FIRE PROGRAMS 1968-1978

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ABSTRACT: The prescribed natural fire management programs in Yosemite and Sequoia-Kings Canyon National Parks have been designed to reintroduce fire as a natural process into vegetative communities from which it has been largely excluded for about 100 years. The size and distribution of fires have followed predicted patterns, and, as a result, management units have been expanded to include 586,500 hectares of subalpine, lodgepole-hemlock, red fir, and mixed-conifer forest. The 325 prescribed natural fires which occurred between 1968 and 1978 burned a total of 11,232 hectares. These fires provided significant insights into the behavior and effects of lightning fires within affected vegetative communities.

DESCRIPTION OF THE MANAGEMENT AREAS

Physical Features, Vegetation, and Climate

Yosemite and Sequoia-Kings Canyon National Parks have developed similar prescribed natural fire management programs since they have similar climate, topography, vegetative communities, and natural fire incidence. The three parks encompass 657,388 hectares on the western slope of the Sierra Nevada mountains at elevations ranging from 600 meters to almost 4,300 meters. Vegetative communities include, at successively higher elevations, chaparral-oak woodland, lower mixed-conifer, upper mixed-conifer, red fir, lodgepole-hemlock, subalpine, and alpine. The major representative plant taxa are: chamise (*Adenostoma fasciculatum* Hooker and Arnott), ceanothus (*Ceanothus spp.*), manzanita (*Arctostaphylos spp.*), mountain mahogany (*Cercocarpus betuloides* Nutt. ex Torrey and Gray), blue oak (*Quercus douglasii* Hooker and Arnott), interior liveoak (*Quercus wizlizenii* A. DC.), and canyon live oak (*Quercus chrysolepis*

Liebm.) in the chaparral-oak woodland; ponderosa pine (*Pinus ponderosa* Laws), incense-cedar (*Libocedrus decurrens* Torr.), black oak (*Quercus kelloggii* Newb.), and bear clover (*Chamaebatia foliolosa* Benth.) in the lower mixed-conifer; white fir (*Abies concolor* [Gord. and Glend.] Lindl.), sugar pine (*Pinus lambertiana* Dougl.), Jeffrey pine (*Pinus jeffreyi* Grev. and Balf.), and giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchh.) in the upper mixed-conifer; red fir (*Abies magnifica* A. Murr.), western white pine (*Pinus monticola* Dougl.), western juniper (*Juniperus occidentalis* Hook.), and Jeffrey pine in the red fir; and lodgepole pine (*Pinus contorta var. murryana* Engelm.) and mountain hemlock (*Tsuga mertensiana* [Bong.] Carr) in the lodgepole-hemlock. In Yosemite, the major subalpine taxon is whitebark pine (*Pinus albicaulis* Engelm.), while in Sequoia-Kings Canyon, the subalpine also includes limber pine (*Pinus flexilis* James.) and foxtail pine (*Pinus balfouriana* Grev. and Balf.), with the foxtail pine being most abundant. The alpine community consists of grasses, sedges, and forbs in a treeless environment. The significant difference between the upper and lower mixed-conifer for the purposes of prescribed natural fire management lies in the fact that in the upper community the litter layer is dominated by the presence of fir, sugar pine, or sequoia needles, while in the lower, it is dominated by ponderosa pine needles. The area and elevational limits of each community are listed in tables 1 and 2.

In Sequoia-Kings Canyon, there is a rather abrupt transition from the chaparral-oak woodland to the upper mixed-conifer, and from the red fir to the alpine community. The climate consists of cool, wet winters and hot, dry summers. The orographic lifting of air generated by the interaction of the high mountains and the prevailing west wind produces frequent summer and fall electrical storms over the parks, especially in areas over 2,000 meters in elevation. The average precipitation from June through September is less than three centimeters. Midafternoon relative humidity at the base fire weather station in Yosemite at 2,025 meters averaged 35 percent from June through October for the years 1973-1978.

The topography is steep and mountainous with deeply incised canyons. Densely forested plateaus and middle-elevational drainage basins are separated by extensive areas which are barren of forest and shrub cover, such as alpine ridges, lake surfaces, and open glaciated granite. In Yosemite, these "barren" areas cover 49,174 hectares, or 16 percent of the Park, while in Sequoia-Kings Canyon, they cover a substantially greater percentage of the total area.

History of Naturally Occurring Fires

The presence of hot, dry summers together with frequent electrical storms, low relative humidities, and flammable vegetation has created an ideal situation for the occurrence of frequent and widespread lightning fires. The average precipitation (of less than three centimeters) during the "fire season" is insufficient to extinguish major fires, and, consequently, they may burn throughout the summer until extinguished by

winter snows or by suppression crews. In Yosemite, 1,878 lightning-caused fires were recorded between 1931 and 1978 for an average of 39 fires per year. A similar situation exists in Sequoia-Kings Canyon in which 1,404 lightning fires were recorded between 1922 and 1978. Actual natural ignitions were probably even more numerous since prior to the 1950's detection methods were less sophisticated, and many low-intensity fires probably went undetected. From 1931 to 1949, the recorded lightning-fire incidence was only 16 per year in Yosemite and 12 per year in Sequoia-Kings Canyon, compared to 54 per year in Yosemite and 34 per year in Sequoia-Kings Canyon for the period 1950-1978. This apparent 285 percent increase in lightning-fire incidence between the two periods almost certainly results from an increase in fire detection. Incidence in Yosemite has varied from 121 lightning fires in 1967 to one fire in 1954.

The post 1950 fire incidence yields an average distribution of one fire for every 4,780 burnable hectares of Yosemite per year. In Sequoia, the average distribution is comparable since it has both a lower yearly average number of fires and less burnable area. In actuality, fires are not evenly distributed but are concentrated in the central and western areas of the parks where the fuels are denser and more flammable.

Studies of fire scars on trees further confirm the frequent presence of fire in the environment of the central and southern Sierra Nevada (Wagener 1961, Kilgore and Taylor 1979). Kilgore and Taylor (1979) report an interval between fires of 8 to 18 years for .4- to .8-hectare clusters of trees in an upper mixed-conifer forest near Kings Canyon National Park and an interval between 11 and 39 years for individual trees. Although burning by Indians may have contributed to some of these ignitions, present lightning-fire incidence indicates that most were undoubtedly the result of natural events. The influence of Indian burning on the higher-elevation red fir, lodgepole-hemlock, and subalpine forests must have been even less significant, since the Indians were only seasonal transients in these areas.

The ecological role of fire has been discussed for the chaparral-oak woodland (Parsons 1976, Biswell 1974), for the mixed-conifer (Weaver 1967, Kilgore 1973, Rundel et al. 1977, Harvey et al. 1977, van Wagtendonk 1977, Kilgore and Taylor 1979), and for the red fir (Kilgore 1971). Fire was found to exert a pervasive influence on many aspects of succession and regeneration in these communities, in which many plants are adapted to a regime of periodic fires. Less is known concerning the role of natural fire in the higher-elevation forests, although its frequent presence there is well documented in park fire history records (Yosemite 1931-1978, Sequoia-Kings Canyon 1922-1978). Most lightning fires occur in the middle-elevational zone containing upper mixed-conifer and red fir forest (tables 1 and 2) even though these areas comprise only 25 percent of the parks. Although precise data are lacking, lightning strikes are known to decrease in frequency with a decrease in elevation, being most frequent in alpine areas and least frequent in

Table 1. Lightning fire occurrence by vegetative community in Yosemite National Park, 1931-1978.

Vegetative Community	Approximate Elevational Limits (Meters)	Area (Hectares)	Percent of Park	No. of Fires	Percent of Total Fires in Community
Chaparral-Oak	650-2400	10,278	3.3	11	.6
Lower Mixed-Conifer	900-1800	59,801	19.4	319	17.0
Upper Mixed-Conifer	1700-2300	37,471	12.2	569	30.3
Red Fir	2300-2900	31,451	10.2	691	36.8
Lodgepole-Hemlock	2600-3050	105,908	34.3	273	14.5
Subalpine	3050-3350	19,677	6.4	15	.8
Alpine	3200-4010	43,640	14.2	0	0.0
Total		308,226	100.0	1,878	100.0

Table 2. Lightning fire occurrence by vegetative community in Sequoia-Kings Canyon National Parks, 1931-1978.

Vegetative Community	Approximate Elevational Limits (Meters)	Area (Hectares)	Percent of Park	No. of Fires	Percent of Total Fires in Community
Chaparral-Oak	600-2400	29,526	8.5	92	7.6
Mixed-Conifer	1000-2500	61,614	17.7	504	41.7
Red Fir	2300-2900	40,947	11.7	449	37.2
Subalpine-Alpine	2700-4419	217,074	62.1	163	13.5
Total		349,161	100.0	1,208	100.0

chaparral areas. Electrical storms rarely move westward beyond the region of the upper mixed-conifer.

There is evidence from the historic record and from what we can discern of prehistoric burning patterns that lightning fires originating in and above the red fir were almost entirely low-intensity, surface fires. Under a full suppression policy (1890-1972) in Yosemite, no fire in this zone ever exceeded 20 hectares. Of the 11 major lightning fires (>20 hectares) suppressed during this period, four originated in the upper mixed-conifer, three in the lower mixed-conifer, and four in the chaparral-oak woodland. The four upper mixed-conifer fires all contained substantial areas of highly flammable montane chaparral species, such as *Ceanothus cordulatus, Arctostaphylos patula,* and *Quercus vaccinifolia.* All of these fires burned primarily in an upslope direction.

THE EVOLUTION OF A PRESCRIBED NATURAL FIRE PROGRAM

For over 100 years after the arrival of European settlers in the Sierra Nevada, fire was generally viewed as a destructive force in the environment, and efforts were made to suppress all "wildfires" whether caused by humans or nature. This practice of fire suppression intensified after the establishment of Sequoia and Yosemite National Parks in 1890 and the proliferation of commerical logging in the Sierra Nevada. Although a small minority of land managers frequently questioned the wisdom of this policy even in the early 1900's (Ernst 1943), no significant changes occurred until the report issued by the Special Advisory Board on Wildlife Management for the Secretary of the Interior (Leopold et al. 1963) became incorporated as Park Service policy in 1968. The Board recommended that ecosystems be restored as nearly as possible to their condition before the arrival of European man, using natural means whenever possible. Lightning fires soon became recognized as one of the significant natural processes which should be restored in the park environment to the extent possible. Defining the permissible role of naturally occurring fires in parks annually visited by millions of people became a problem for much speculation, research, and experimentation.

Management Considerations

The development and conduction of these prescribed natural fire programs have involved a number of basic steps necessary to any such program. The foundation of such management must be an understanding of the natural fire ecology of the unit. Natural fire frequently exhibits a variety of behaviors, intensities, and effects; and, unless the results of the program can be accepted, it should not be undertaken. Objectives of the program must, therefore, be clearly defined and agreed upon. Mortality of plants and animals, scorch height, smoke production, visibility impairment, flame characteristics, long-range expectations for results, and influences on wildlife are all important considerations.

Adequate fire monitoring must accompany the program and is responsible for developing the prescriptions used in prescribed natural fire, observing the success of these prescriptions in meeting the program's objectives, and prescription refinement. In addition, monitoring provides the on-site information critical to making fire management decisions.

Prescription development and utilization is as central to prescribed natural fire management as it is to prescribed burning. A prescription should take into consideration vegetation type, fire incidence, behavior, history, the presence or absence of natural or human-created barriers, accessibility, smoke dispersal and air quality, probability of multiple fires, and visitor use. Prescribed natural fire must be managed as carefully as are prescribed burns. If prescriptions are violated, prescribed natural fires may be partially contained or suppressed entirely.

Air quality, especially visibility impairment, are important considerations in prescribed natural fire management. Smoke drift direction and duration of impairment as negative impacts on park visitors and local communities must be balanced with the objective of allowing fire to play as natural a role as possible. In addition, since Yosemite, Sequoia, and Kings Canyon are Class I areas for air quality, conflicts between the Clean Air Act and Park Service policy must be resolved. Fire management must comply with air quality regulations, but the regulations must take into account National Park Service mandate to perpetuate or restore ecosystems, to which fire and smoke are necessary.

Fires which occur in prescribed natural fire units do not carry with them an implied guarantee to be "good" fires; certain vegetation types may have natural burning intensities that are incompatible with public safety. New areas should be added cautiously and initial burns in these areas monitored to ensure resources management objectives are being met and unacceptable impact avoided. Prescribed burning may have to be used to produce acceptable fire behavior instead of prescribed natural fire.

Prescribed Natural Fire Management

In 1968, the first prescribed natural fire units were established in Sequoia-Kings Canyon (Kilgore and Briggs 1972), and Yosemite followed in 1972. Since prior to this time all lightning fires were suppressed, little was known about the potential extent, intensity, or longevity of such fires, or about the management problems they might present. A conservative approach was adopted. Prescribed natural fires were initially restricted to alpine and sparsely vegetated areas and to high-elevation forests with only moderate fire incidence, which were contained within secure barriers to fire spread. These units were gradually expanded to include almost all areas in which the vegetative communities have experienced only minor changes as a result of fire suppression activities. In these "primary" units, which include almost all of the red fir, lodgepole-hemlock, subalpine, and alpine communities, lightning fires are allowed to burn without interference from humans as long as

they remain within designated units, do not threaten human safety, and can be managed within the constraints of Federal and state laws and regulations pertaining to cultural, physical, and air resources.

In the high-elevation primary units, the restricted growing season, due to cold temperatures and heavy snowpack, has resulted in light fuel accumulations and a less dense understory than in lower vegetation communities. These elevations also receive more rainfall in the summer and fall and remain more mesic than lower elevations. This situation, together with fuel characteristics, such as highly compact fuel beds and low surface area to volume ratios for downed fuels, results in a low probability that a lightning strike will start a fire. At the inception of the program, it was theorized that resulting fires would, for the most part, spread slowly and burn with low intensity. As these units were expanded into the red fir and upper mixed-conifer communities, which contain more continuous and flammable fuels, it was theorized that burning intensities would slightly increase and that fires originating in a propitious spot might eventually cover large areas by slowly expanding over several months.

Conditional Fire Management

Additional areas encompassing more of the upper and lower mixed-conifer were designated as secondary or "conditional" units. In these units, fire suppression activities have produced dramatic changes in dead fuel loadings and tree densities, which have created a potential for unnaturally severe fire behavior. Consequently, in Yosemite, lightning fires are allowed to burn in these units only after September 1, when a prescribed level has been achieved for the Burning Index as measured by the National Fire Danger Rating System (Deeming et al. 1977). This level has been found to mark the inception of a seasonal downward trend in fire danger in Yosemite (Botti 1979).

In Sequoia-Kings Canyon, lightning fires are allowed to burn in these units throughout the year but under a more stringent prescription which includes values for the Burning Index, the Energy Release Component (Deeming et al. 1977), and a ceiling on the total number of fires greater than 80 hectares which may be allowed to burn at one time. The Burning Index is a value equal to 10 times the predicted flame length of a headfire, and the Energy Release Component is a number equal to the available energy in British Thermal Units per square foot divided by 25.

At present, 84 percent of Yosemite and 94 percent of Sequoia-Kings Canyon (tables 3 and 4) are managed under either one or the other of these prescribed natural fire strategies. Primary units in all three parks consist of 523,214 hectares, while secondary units contain 63,286 hectares.

The fire management plans in Yosemite and Sequoia-Kings Canyon direct that most of the area in all-year fire suppression units will be placed under prescribed natural fire management once natural vegetative and

Table 3. Vegetation types occurring in each fire management zone, Yosemite National Park

Vegetation Type	Zone I		Zone II		Zone III	
	Prescribed Natural Fire All Year (Hectares)	Percent of Type	Prescribed Natural Fire Based on Seasonal & NFDRS Prescription (Hectares)	Percent of Type	Fire Suppression (Hectares)	Percent of Type
Chaparral-Oak	1,417	14	1,822	18	7,039	68
Lower Mixed-Conifer	9,020	15	11,443	19	39,338	66
Upper Mixed-Conifer	20,935	56	13,799	37	2,737	7
Red Fir	28,161	90	3,290	10	--	--
Lodgepole-Hemlock	105,908	100	--	--	--	--
Subalpine	19,677	100	--	--	--	--
Alpine	43,640	100	--	--	--	--
Total	228,758		30,354		49,114	

Table 4. Vegetation types occurring in each fire management zone, Sequoia-Kings Canyon National Parks

Vegetation Type	Zone I		Zone II		Zone III	
	Prescribed Natural Fire All Year (Hectares)	Percent of Type	Prescribed Natural Fire Based on Seasonal & NFDRS Prescription (Hectares)	Percent of Type	Fire Suppression (Hectares)	Percent of Type
Chaparral-Oak	7,752	26	--	--	21,774	74
Mixed-Conifer	32,934	55	28,680	45	--	--
Red Fir	36,696	90	4,251	10	--	--
Subalpine/Alpine	217,074	100	--	--	--	--
Total	294,456		32,931		21,774	

fuel conditions have been sufficiently reestablished by prescribed burning.

CHARACTERISTICS OF PRESCRIBED NATURAL FIRES

Number and Distribution

Under the present management program, the majority of lightning ignitions in the three parks will be allowed to run their course. Analysis of the past 29 years of Yosemite fire history shows that 57 percent of all lightning ignitions have occurred in areas that are presently designated as primary prescribed natural fire units, and another 17 percent have occurred in areas that are now secondary units. The number of fires and the area burned each year (tables 5 and 6) for each park has varied considerably. To some extent, this is a function of the normal yearly fluctuations in lightning activity and weather conditions, and to some extent it has resulted from expansion of the management units. Units were increased in size on three occasions in Yosemite and four times in Sequoia-Kings Canyon. Sequoia-Kings Canyon has averaged 14 prescribed natural fires per year, while Yosemite has averaged 24.

The expansion of management units on several occasions has caused difficulty in analyzing prescribed natural fires by vegetative community. Analysis of all 325 prescribed natural fires occurring over the past 11 years would show a deceptively high percentage of fires in the lodgepole-hemlock and subalpine communities, since in the early stages of the program few other areas were included. The 1978 data from Yosemite reveal a more accurate pattern of the current and predicted distribution of fires in the various upper-elevation communities. In that year, 21 (64 percent) fires occurred in red fir, 5 (15 percent) occurred in lodgepole-hemlock, 4 (12 percent) occurred in upper mixed-conifer, and 3 (9 percent) occurred in the subalpine community.

Prescribed natural fires originate most frequently on ridge tops, west-facing slopes, or south-facing slopes. Of the 170 fires in Yosemite, 51 (30 percent) occurred on ridge tops, 44 (26 percent) occurred on west-facing slopes, 24 (14 percent) occurred on south-facing slopes, 21 (12 percent) occurred in valley bottoms, 15 (9 percent) occurred on north-facing slopes, and 15 (9 percent) occurred on east-facing slopes. These findings support similar conclusions drawn by Kilgore and Taylor (1979) from analysis of fire scar data. They concluded that there is strong indication that fires are more frequent on dry sites, such as ridge tops and west-facing slopes, than on more moist sites, such as midslopes and east-facing slopes.

There have been 19 prescribed natural fires in Yosemite greater than 20 hectares. For these, the distributional variation is even more striking. Nine (47 percent) were on ridge tops, 6 (32 percent) were on west-facing slopes, 2 (11 percent) were on south-facing slopes, 1 (5

Table 5. Prescribed natural fires (including conditional fires) by year in Yosemite National Park.

Year	Hectares in Units	Percent of Park	Number of Fires	Hectares Burned
1972	75,711	19	8	.31
1973	188,018	61	27	22.70
1974	188,018	61	22	1,502.71
1975	248,679	81	20	313.31
1976	248,679	81	36	325.22
1977	248,679	81	24	60.63
1978	259,111	84	33	1,019.28
Total			170	3,244.16

Table 6. Prescribed natural fires (including conditional fires) by year in Sequoia-Kings Canyon National Parks.

Year	Hectares in Units	Percent of Park	Number of Fires	Hectares Burned
1968	52,361	15	2	3.24
1969	52,361	15	1	.10
1970	223,767	65	24	200.20
1971	237,539	69	25	60.28
1972	242,892	71	16	61.49
1973	242,892	71	11	1,952.83
1974	242,892	71	19	1,340.65
1975	242,892	71	7	23.56
1976	242,892	71	20	31.42
1977	242,892	71	9	4,312.11
1978	327,388	94	21	2.07
Total			155	7,987.95

percent) was in a valley bottom, and 1 (5 percent) was on an east-facing slope. None occurred on north-facing slopes.

Size and Duration of Burning

Prescribed natural fires exhibit great variation in size (tables 7 and 8) and burning duration. Sixty-seven percent have been less than .1 hectare in size, but collectively these have burned less than 1 percent of the total burned area. In contrast, 4 percent of the prescribed natural fires have been greater than 120 hectares, but these have collectively accounted for 91 percent of the total burned area. The average size of a prescribed natural fire now stands at 34.56 hectares. It has varied from a high of 132.51 hectares in 1977 to a low of .25 hectares in 1969.

As management units have been expanded into lower-elevation forests with more continuous and flammable fuels, the size of fires has increased dramatically. In 1972 in Yosemite, there were no fires greater than .5 hectare. From 1973 to 1974, 12 percent of all prescribed natural fires fell within this range. From 1975 to 1977, 25 percent were greater than .5 hectare, and, with the last expansion in 1978, 45 percent were greater than .5 hectare.

Duration of burning has varied from a few days for many of the small fires to 136 days for the 4,049-hectare Ferguson Fire in Kings Canyon National Park. One fire in Yosemite burned for a record 108 days in 1978 but covered only 1.22 hectares.

Fire Behavior

The intensity of prescribed natural fires less than .5 hectare rarely exceeds the smoldering stage, and these comprise the vast majority of natural ignitions. Those which burn for extended periods and cover large areas can exhibit significant fluctuations in intensity and spread rate in response to changes in weather or changes in topography. Van Wagtendonk (1978) found that rates of spread on the 1,417-hectare Starr King prescribed natural fire varied from 2.5 centimeters per hour to 37 meters per hour and intensities of .95 British Thermal Units/second/meter under western juniper; 8.75 BTU/second/meter under lodgepole pine; 1,769 BTU/second/meter under Jeffrey pine; and 2,320 BTU/second/meter under red fir. It is not uncommon for such fires to experience periods of near dormancy induced by summer showers interspersed with periods of rapid spread and localized torching of understory or canopy trees.

Burning conditions can be classified as moderate to mild throughout most of the middle and upper elevations (>1,800 meters) of the three parks during most of the summer and fall months usually referred to as the fire season. The average Burning Index from June 1 to October 30 at a base fire weather station located at 2,025 meters in Yosemite was 48.1 for the period 1973 to 1978. For a comparable station in Sequoia-Kings

Table 7. Prescribed natural fires by size class in Sequoia-Kings Canyon National Parks, 1968-1978.

Size Class (Hectares)	Number of Fires	Percent in Size Class	Hectares Burned	Percent of Total
0- .09	115	74.2	2.51	.03
.1- .49	11	7.1	2.83	.04
.5- 3.99	9	5.8	22.31	.28
4- 19.99	10	6.5	136.59	1.70
20-119.99	3	1.9	158.55	1.98
120-399.99	3	1.9	638.46	8.00
>400	4	2.6	7,026.72	87.97
Total	155	100.0	7,987.97	100.00

Table 8. Prescribed natural fires by size class in Yosemite National Park, 1972-1978.

Size Class (Hectares)	Number of Fires	Percent in Size Class	Hectares Burned	Percent of Total
0- .09	102	60.0	1.93	.06
.1- .49	27	15.9	7.23	.22
.5- 3.99	18	10.5	28.14	.87
4- 19.99	4	2.4	30.36	.94
20-119.99	12	7.1	646.56	19.93
120-399.99	6	3.5	1,112.96	34.31
>400	1	.6	1,417.00	43.67
Total	170	100.0	3,244.18	100.00

Canyon, the average Burning Index was 49.9. The actual Burning Index on site at major prescribed natural fires is usually somewhat lower than this since most are above 2,025 meters and since the fire weather stations are situated to represent the most severe fire weather conditions in the area.

Large prescribed natural fires have continued to burn under what are normally considered severe fire weather conditions without requiring any suppression or containment action. In Yosemite, the 1,400-hectare Starr King Fire burned down to 1,951 meters with relative humidities as low as 17 percent and a Burning Index as high as 92 as measured at the base fire weather station. The 210-hectare Watkins Fire burned with a relative humidity as low as 17 percent and a Burning Index as high as 112. In 1978 in Yosemite, seven fires, each over 80 hectares, were burning simultaneously with relative humidities as low as 18 percent and a Burning Index as high as 72. None of these fires presented any management problems resulting from fire intensity or rate of spread. Localized torching of canopy trees occurred even on fires burning downslope when the Burning Index exceeded 90.

Intensity tends to vary suddenly in response to changes in wind and burning direction. The 1975 Surprise Fire burned only about .5 hectare of red fir in over a month and then, with a shift in the wind direction and speed, burned 91 hectares in two days as it moved up a steep, brushy ridge. It then became dormant until extinguished by rain two weeks later.

High elevation fires in dense forests of dwarfed whitebark pine have also exhibited intense behavior resulting from a sudden change in burning direction. One fire burned about one hectare in over a month at 3,230 meters by backing downslope, then shifted to an upslope direction and doubled its size in 15 minutes with flames reaching 10 meters.

Even large prescribed natural fires tend, on the average, to be slow spreading. The 4,049-hectare Ferguson Fire in Sequoia burned for 136 days and thus spread an average of only 29.8 hectares per day. The 1,400-hectare Starr King Fire burned for 72 days and spread an average of 19.7 hectares per day. During its most active period, this fire spread over about 80 hectares per day. The Ferguson Fire in Kings Canyon National Park also exhibited spurts of activity driven by high winds and low humidities in which it spotted about two miles ahead.

The presence of a xeric phase in the upper mixed-conifer and red fir communities is an important determinant in fire behavior. This xeric phase occurs along ridges and rocky areas and contains large stands of Jeffrey pine and associated montane chaparral species, such as *Ceanothus cordulatus, Arctostaphylos patula,* and *A. nevadensis*, and the shrub-like huckleberry oak. Fires entering these areas will accelerate in intensity and rate of spread. The xeric phase is also predisposed to ignition by having lower fuel moistures and more flammable vegetation types than surrounding areas. Of the 19 prescribed natural fires larger than 20

hectares in Yosemite, 11 (58 percent) originated in or near this xeric phase; six (32 percent) originated in almost pure stands of red fir; one (5 percent) originated in red fir and Jeffrey pine without many shrubs; and one (5 percent) originated in lodgepole-hemlock. A similar situation exists in Sequoia-Kings Canyon in which seven (70 percent) of the 10 prescribed natural fires in this size range occurred in the xeric phase of the upper mixed-conifer.

Fifteen (79 percent) of the 19 large prescribed natural fires were primarily backing fires (those moving downslope and against the prevailing daily upslope winds). These 15 fires burned 2,872 hectares, or 89 percent of the total burned by all 170 fires. The four large headfires (those burning upslope with the wind) burned an average of only 76.25 hectares per fire in contrast to the average of 191.47 hectares per fire for the large backing fires.

Large prescribed natural fires in Sequoia-Kings Canyon tend to exhibit higher intensities and to burn upslope more frequently than similar fires in Yosemite. This results from steeper topography in the southern Sierra Nevada and differences in vegetative cover. In Yosemite, there is a middle-elevational zone consisting of plateaus and gently sloping drainages which is covered almost entirely by a dense red fir forest. Fires occurring in this zone originate on or near forested ridge tops and tend to spread laterally or back slowly downhill. In Sequoia-Kings Canyon, the middle-elevational terrain is much steeper, and the dense vegetation is concentrated more on lower slopes and in valleys. This more open terrain is adapted to the xeric phase of upper mixed-conifer consisting of the highly flammable Jeffrey pine and chaparral. Fires tend to start on midslopes and make frequent upslope runs. Of the 10 prescribed natural fires in Sequoia-Kings Canyon greater than 20 hectares, three were backing fires, three were headfires, and the four largest, accounting for 88 percent of the total burned area, were a fairly even combination of headfire and backing fire. Six of the ten >120-hectare prescribed natural fires in Sequoia-Kings Canyon originated in one valley and drainage containing extensive areas of xeric upper mixed-conifer and surrounded by steep slopes.

CONCLUSIONS

The prescribed natural fire experiment begun in 1968 in Sequoia-Kings Canyon has now become a successful management program encompassing 89 percent of Yosemite and Sequoia-Kings Canyon National Parks. Crown fires have not occurred. The lack of fast-moving and sustained high-intensity fires in and above the upper mixed-conifer community has confirmed management's prediction on fire characteristics at the inception of the program. No prescribed natural fire has ever required full suppression. Partial containment action was initiated against four fires which were judged to be threatening to burn out of the management units. Management has refrained from passing judgements on burning intensities since great variations were probably always characteristic

of fires in the Sierra Nevada and helped to create and sustain the diversity of the vegetative communities.

An "average" prescribed natural fire originates on a ridge top or west-facing slope in the red fir community and burns 34.56 hectares by moving slowly downslope over a period of 42 days in late summer and fall. This profile is somewhat deceptive, however, since management unit boundaries have been expanded on several occasions to include more flammable lower-elevation vegetative types and since great variation has been noted in burning intensities, rates of spread, and duration even within a particular vegetative community.

Large fires, which were virtually unknown in the lodgepole-hemlock community during the years of fire suppression, continue to be rare under prescribed natural fire management.

Large, slow-moving backing fires originating in the upper mixed-conifer and red fir communities have burned 89 percent of the total burned area in Yosemite even though they are only 8 percent of the total fires. It is significant that this middle-elevational zone is also the zone of highest lightning-fire incidence. The normal seasonally severe drought in the Sierra Nevada insures that even slow-moving fires can become quite large; even drainage-wide fires are possible over several months. The occurrence of these large, slow-moving, low-intensity fires must have provided a moderating influence on the occasional headfire of greater intensity moving up from more flammable vegetation and fuel types in the lower mixed-conifer and chaparral.

Lightning fires in the southern Sierra Nevada stand a greater chance of becoming quite large than those in the Yosemite region because they tend to exhibit more upslope and high-intensity burning. The presence of some moderate-intensity prescribed natural fires will continue to be a periodic occurrence in Sequoia-Kings Canyon parks and has been judged to meet all of the criteria for management acceptability.

Further expansion of prescribed natural fire unit boundaries remains a distinct possibility as prescribed burning reduces unnaturally heavy fuel loadings and as more is learned about burning patterns and intensities in the lower mixed-conifer and the chaparral-oak woodland. Certain areas near developments and park boundaries must be permanently excluded due to potential risks to resources managed for other purposes.

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