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Fire Mosaics in Southern California and Northern Baja California

Richard A. Minnich

Summary. In spite of suppression efforts, severe wildfires burn large areas of southern California grassland, coastal sage scrub, and chaparral. Such large burns may not have been characteristic prior to the initiation of fire suppression more than 70 years ago. To compare controlled with uncontrolled areas, wildfires of southern California and adjacent northern Baja California were evaluated for the period 1972 to 1980 from Landsat imagery. Fire size and location, vegetation, year, and season were recorded. It was found that suppression has divergent effects on different plant communities depending on successional processes, growth rates, fuel accumulation, decomposition rates, and length of flammability cycles. These variables establish feedback between the course of active fires, fire history, spatial configuration of flammable vegetation, and fire size. Suppression has minimal impact in coastal sage scrub and grassland. Fire control in chaparral reduces the number of fires, not burned hectarage; fires consequently increase in size, spread rate, and intensity and become uncontrollable in severe weather conditions. The Baja California chaparral fire regime may serve as a model for prescribed burning in southern California.

Wild-land fire, which has been a feature of the southern California landscape throughout historic time and into the recent geologic past (*1*), is a symptom of the prevailing Mediterranean climate. Winter rains nourish extensive carpets of shrubs and grasses; the long summer drought parches them. Dead twigs, foliage, and litter accumulate in vast quantities because of limited microbial decomposition (*2, 3*). Inevitably, fires kindle and spread, fuel and weather permitting.

Spanish and Anglo-European shepherds and farmers living in the Los Angeles coastal plain before the 20th century expressed little concern over mountain fires, even when they reported (*4, 5*) fires burning for months until extinguished by autumn rains. However, with rapid agricultural expansion and urbanization beginning around 1880, the preservation of natural vegetation was recognized as central to the prevention of watershed erosion and flooding (*6*). In 1892 the mountain public domain was federalized as the nation's first forest reserve. Fire suppression was part of this change in jurisdiction.

In recent years, land managers have become increasingly interested in the concept of setting small, controllable fires to prevent excessive fuel accumulation and catastrophic blazes (*7, 8*). This attempt to change the fire pattern requires understanding the impact of fire suppression on vegetation. Since fire suppression has been a long-standing policy, there is no wild landscape in southern California in which such suppression has not been practiced, thus precluding comparisons. Investigators of the fire ecology of California brush and grasslands (*9*) have attempted to reconstruct past fire frequency and stand mosaics from fire scars and dendrochronology (*10*), newspapers, government expeditions, diaries, and old photographs (*5*). The fragmentary nature of such data has been severely limiting to the reconstruction efforts.

Although a similar landscape without fire control exists in neighboring northern Baja California, a formal compilation of Baja California fires was impossible until the 1972 launch of the orbiting Landsat platform. Using this new source of information, I reconstructed the fire history of southern California and adjacent Baja California for the period 1972 to 1980, and thus determined the consequences of fire suppression in grassland, coastal sage scrub, and chaparral. I found that a fire suppression strategy that attempts to extinguish all fires before they become large may promote large burns in some vegetation types. A few fires burning in severe weather easily escape control and denude large areas.

The Physical Environment

The area analyzed extends from 35°N in southern California to 30°N in northern Baja California (Fig. 1). Terrain is mostly mountainous, with scattered coastal plains, alluvial valleys, and basins. Mountain ranges form two distinct structural units: the west-to-east oriented Transverse Ranges (western Transverse Ranges and the Santa Monica, San Gabriel, and San Bernardino Mountains) and the northwest-southeast trending Peninsular Ranges (the Santa Ana, San Jacinto, Palomar, and Laguna Mountains, Sierra Juárez, and Sierra San Pedro Mártir).

Winter precipitation, which results largely from frontal disturbances of the polar front jet stream, decreases southward along the coast from 400 millimeters per year at Los Angeles to 250 millimeters at San Diego and Ensenada

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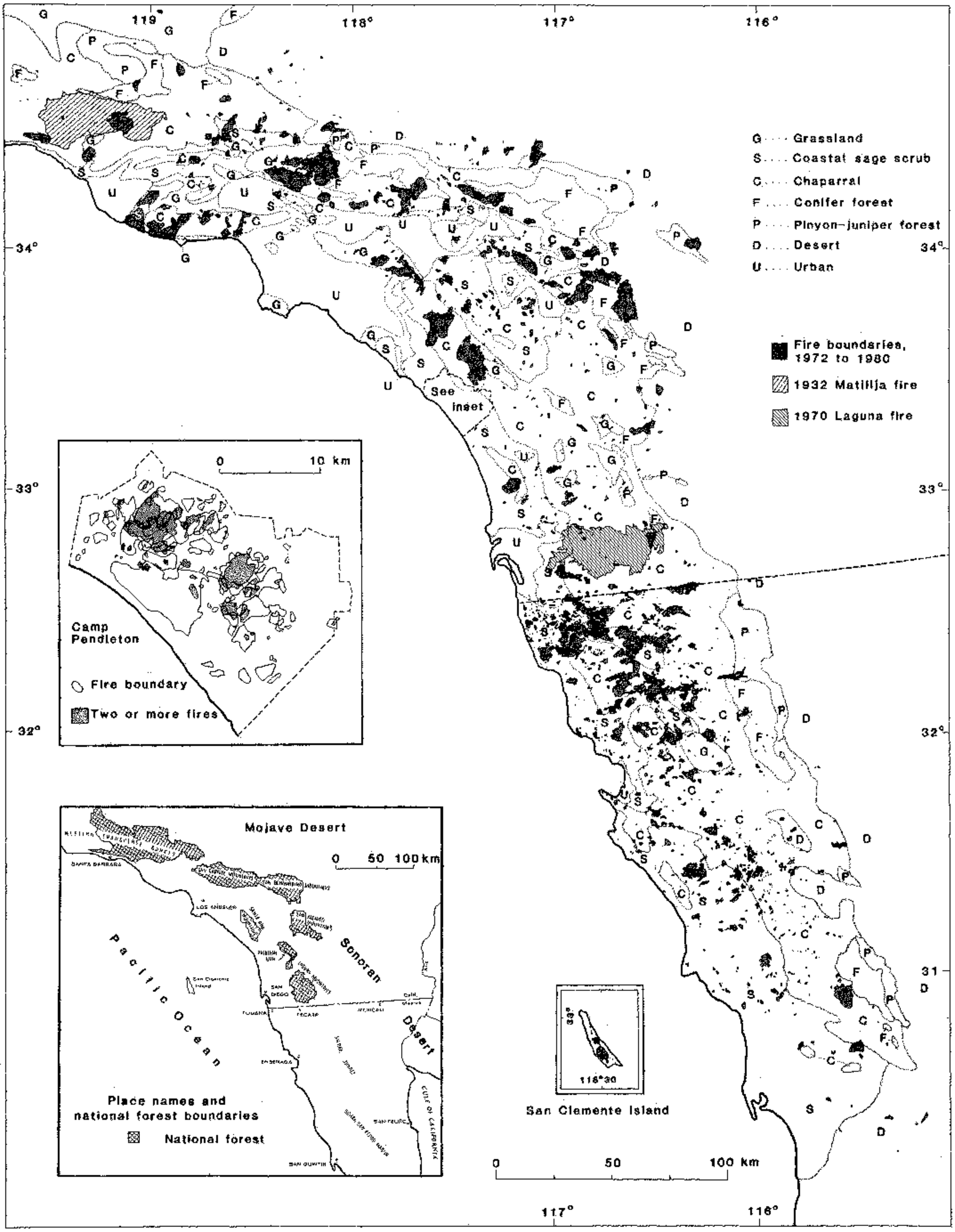

Fig. 1. Wild-land fires in southern California and northern Baja California, 1972 to 1980, with vegetation noted. A broad gradient of increasing fire area northward in Baja California shifts to a pattern of infrequent small to very large fires north of the border. Divergences in fire size between the two countries are most evident in chaparral. Fire data was mapped from Landsat imagery; vegetation was mapped from aerial photography (*33*).

and 150 millimeters at San Quintín. Mountains modify the climate by producing sharp precipitation and temperature gradients, with annual precipitation ranging from 800 mm in the Transverse Ranges to 600 mm in the Sierra San Pedro Mártir (*11*). Passing storms are often followed by a strong northerly jet stream, high barometric pressure over the Great Basin states, and strong, dry Santa Ana winds associated with mountain waves and foehn flow through mountain passes.

During summer (May to September), Hadley cell subsidence associated with the surface Pacific anticyclone and weak circulation aloft prevails as frontal storms travel north of the area. Coastal valleys and lower mountain slopes are influenced by moist coastal marine air that advects onshore with sea breezes from the Pacific Ocean. Surges of tropical moisture arriving from the equatorial Pacific along the Gulf of California produce occasional afternoon mountain thundershowers and numerous lightning fires, especially in July and August.

Vegetation

Major plant communities form broad zonal belts that increase in elevation southward into Baja California. Grasslands and coastal sage scrub in lower coastal valleys are replaced by chaparral on mesic coastal slopes of the mountains. Mixed evergreen forest and mixed conifer forest occupy the highest mountains and grade into pinyon and juniper forests and various scrub communities on the east slope of the mountains adjoining the Sonoran and Mojave deserts (*9*). Grassland, coastal sage scrub, and chaparral, in which nearly all the burning detectable by Landsat imagery occurs, are divergent in terms of physical appearance, rooting structure, phenology, drought stress, fuel, and fire response. Common species for each community are listed in Table 1 (*12*).

Grassland, dominated by exotic European annual grasses (*Avena*, *Bromus*) and forbs (*Erodium*, *Brassica*), forms a continuous herbaceous layer 0.5 to 1.5 meters tall in loamy soils in alluvial valleys and coastal plains. Herb species are shallow-rooted and move rapidly through their growth cycles. Germination occurs after the onset of winter rains and growth, flowering, fruiting, and desiccation are complete by early summer. Stand biomass, depending on the amount of precipitation the previous winter, ranges from 1 to 5 tons per hectare (*8*).

Coastal sage scrub occurs on steep, rocky slopes below 600 to 900 m. Stands form a broken to continuous layer of subligneous shrubs 0.5 to 2.0 m tall, with an understory of European annuals and spring ephemerals. Important southern California shrubs in the genera *Artemisia*, *Salvia*, and *Encelia* are shallow-rooted, mesophytic, and drought-deciduous. South of Ensenada, these shrubs mix with stem and leaf succulents (*Agave*, *Echinocereus*, *Opuntia*, *Bergerocactus*, and *Yucca*), woody deciduous shrubs (*Fraxinus*, *Aesculus*, and *Rosa*), and other subshrubs (*Ambrosia* and *Viguiera*), with a rapid decline in European annuals (*13*). Except among the succulents, shrubs desiccate rapidly to dormancy with the depletion of soil moisture by May or June. Estimated stand fuel accumulation in southern California ranges from 5 to 30 ton/ha (*8*).

Chaparral is composed of deep-rooted, evergreen, sclerophyllous shrubs 1 to 4 m high in carpet-like stands on steep rocky slopes of low fertility. Important genera include *Adenostoma*, *Ceanothus*, *Arctostaphylos*, *Quercus*, *Rhamnus*, *Prunus*, *Rhus*, and *Cercocarpus*. The growing season is March to June, when soils are saturated after the rainy season. During summer and fall, shrubs maintain limited metabolic activity, relying on small moisture reserves in the regolith until the autumn rains (*14*). Herbaceous vegetation is mostly absent. The estimated biomass of mature stands in southern California is 30 to 100 ton/ha (*8*, *15*).

All three communities typically burn "clean," that is, all aboveground biomass is consumed except for the largest stems and twigs. This is attributable to the continuity of the stands and large surface-to-volume ratios that promote rapid oxidation (*8*, *16*).

Table 1. Common plants in southern and Baja California (*12*).

Family	Species	Family	Species
	Grassland		*Chaparral*
Brassicaceae	*Brassica nigra*	Anacardiaceae	*Malosma laurina*
Geraniaceae	*Erodium botrys*		*Rhus integrifolia*
	Erodium cicutarium		*Rhus ovata*
Poaceae	*Avena barbata*	Ericaceae	*Arctostaphylos glandulosa*
	Bromus mollis		*Arctostaphylos glauca*
	Bromus rubens		*Arctostaphylos peninsularis*
			Ornithostaphylos oppositifolia
	Coastal sage scrub	Fagaceae	*Quercus dumosa*
Amaryllidaceae	*Agave shawii*		*Quercus dunnii*
Asteraceae	*Ambrosia chenopodifolia*		*Quercus wislizenii*
	Artemisia californica	Rhamnaceae	*Ceanothus crassifolius*
	Encelia californica		*Ceanothus cuneatus*
	Encelia farinosa		*Ceanothus greggii*
	Viguiera laciniata		*Ceanothus leucodermis*
Cactaceae	*Bergerocactus emoryi*		*Ceanothus megacarpus*
	Machaerocereus gummosus		*Ceanothus spinosus*
	Myrtillocactus cochal		*Ceanothus verrucosus*
	Opuntia littoralis		*Rhamnus californica*
Hippocastanaceae	*Aesculus parryi*		*Rhamnus crocea*
Lamiaceae	*Salvia apiana*	Rosaceae	*Adenostoma fasciculatum*
	Salvia leucophylla		*Adenostoma sparsifolium*
	Salvia mellifera		*Cercocarpus betuloides*
	Salvia munzii		*Heteromeles arbutifolia*
Oleaceae	*Fraxinus trifoliolata*		*Prunus ilicifolia*
Polygonaceae	*Eriogonum fasciculatum*		
Rosaceae	*Rosa minutifolia*		

Table 2. Summary of fire data for the study areas in southern California and Mexico, 1972 to 1980.

Vegetation	Total area (thousands of hectares)	Area burned (thousands of hectares)	Percentage of total area burned	Percentage of burned area burned after 1 September	Number of fires
Southern California					
Coastal sage scrub*	1082	70	6.5	44	210
Chaparral	2019	166	8.2	72	203
Total	3101	237	7.6	67	413
Camp Pendleton†	49	23	46.8	34	94
Mexico					
Coastal sage scrub*	859	88	10.2	22	333
Chaparral	1202	95	7.9	20	488
Total	2061	183	8.9	21	821

*Includes grassland. †Almost exclusively coastal sage scrub.

Dominant species of all three communities possess adaptations that lead to rapid stand recovery. The seed of European annual grassland species either escape fire in the soil or are borne in from adjacent unburned stands; regrowth to former stature may require only a year or two. Where coastal sage scrub has burned, slopes initially host European annuals and spring ephemerals. Stands are reestablished by the sprouting of subshrubs [fire intensity permitting (*17*)] or by long-distance seed dispersal; contiguous shrub cover usually develops in 5 to 10 years. In chaparral, burned slopes are first covered with fire annuals and perennial herbs, then by sprouting and seeding shrubs. Most species, including those in *Quercus*, *Cercocarpus*, *Rhus*, *Prunus*, and *Rhamnus*, adapt primarily by sprouting from lignotubers beneath the soil surface. Shrubs in *Adenostoma*, *Ceanothus*, and *Arctostaphylos* produce seed that remains dormant for long periods until scarified by fire or other disturbances. Numerous seedlings then germinate and, when mature, dominate the stand with sprouters. Shrubs form contiguous cover after 10 to 20 years.

Combustion of Fuels

The dynamics of combustion in these communities vary according to seasonal fuel moisture and stand age. The moisture content of living (green) fuels is normally too high to sustain combustion, even during the drought season. Vegetal flammability is therefore strongly related to the abundance and stratification of dead stems, litter, humus, and desiccated herbs and forbs (*3*, *8*). Grassland and coastal sage scrub propagate rapid, low-intensity fires due to limited fuels and the high dead fuel content (*18*). Chaparral fires are slower moving and more intense because there is more biomass, but stand flammability is dependent on long-term successional processes. Stands as old as 20 years contain little dead fuel and are thus relatively nonflammable (*8*, *19*). Stands older than 30 years show signs of stagnation owing to diminished nutrient cycling (*15*, *16*, *20*, *21*), leading to increased dead fuel content in the canopy, litter, and duff (50 to 70 percent of biomass). Chaparral therefore becomes especially flammable after 30 to 50 years, depending on climate and local fuel accumulation rates, although chaparral with its green fuels requires more desiccating weather for combustion than coastal sage scrub and grassland (*8*).

Landsat Imagery and Methodology

The aftermath of wild-land fires is conspicuous in Landsat imagery because the optical sensor system has sensitivity in the reflected near-infrared bands (*22*). At these wavelengths, highly absorptive ash forms marked boundaries with reflective unburned vegetation. Burned areas were also detected in the visible bands after one rainy season by contrasting reflective soil in the burn site with surrounding dark vegetation. The Landsat system images the same areas of the earth's surface every 18 days. The resultant synoptic coverage and planimetry of imagery permits a comprehensive inventory of fire areas.

One hundred and eighteen 55.8 by 55.8 mm images of eight scenes (five in southern California and three in Baja California; scale, 1:3,369,000) were obtained from the U.S. Geological Survey's EROS Data Center at Sioux Falls, South Dakota. Analysis of southern and Baja California scenes imaged repeatedly between April and October 1973 reveals that fire ash persists for the entire dry season in spite of occasional showers and wind. For each year from 1972 to 1980, therefore, dates for each scene were selected on the basis of image quality, cloud cover, heavy rains associated with Mexican west coast tropical storms (chubascos), and onset of autumn rains. Images were projected onto topographic sheets (scale, 1:250,000) and the perimeters of burned areas were traced. Broad physiognomic vegetation units were also delimited from Landsat imagery and conventional aerial photography. Imagery for consecutive years was registered stereoscopically to prevent confusion between burns and shadows, dark rock, and other persistent features of low albedo.

For each burn the following were recorded: year, dominant surrounding vegetation, location, area, and occurrence before or after 1 September. Burns at Camp Pendleton, a large military reservation in southern California, were tabulated separately because of anomalously high ignition rates caused by munitions activities and minimal fire control. Fire data for coastal sage scrub and grassland were merged because urbanization and agricultural development have reduced the grassland and because of similarity of the fire responses. Although the theoretical resolution of Landsat imagery is 0.5 ha, burns smaller than about 5 ha could not be unequivocally mapped with standard aerial photo interpretation techniques. Comparison of fire boundaries mapped by the above techniques with U.S. Forest Service data (*23*) reveals that only a few minor fires were missed. Coordinates of fire perimeters and vegetation boundaries were digitized on a Talos Floating Cursor digitizer; data were processed on an IBM 370/155 computer and displayed with a K & E Flatbed Plotter.

The Southern California and Baja California Fire Regimes

Figure 1 reveals extensive burning in both southern and Baja California between 1972 and 1980. Fires were most extensive in the wetter coastal valleys and Pacific slopes of the mountains, especially in coastal sage scrub, grassland, and chaparral. The fire regime was quite different south of the Mexican border.

There were more fires in Baja California than in southern California (Table 2), even if the numerous fires mapped at Camp Pendleton are included in the latter. A broad gradient in burn area, not apparent in southern California, occurred with latitude in Baja California. Only limited burning took place at the margin of the Sonoran Desert near San Quintín. From there northward, fires increased in number and extent, especially in coastal sage scrub, with heavy burning doubtless associated with ranching in the valleys between Ensenada and Tijuana. A broad speckling of fires covered the length of the chaparral belt, with concentrations in the northern Sierra San Pedro Mártir, on the west flank of the Sierra Juárez adjacent to Ensenada Bay, and near the Mexican border.

The pace of burning dropped abruptly at the border. Only scattered small fires occurred in brushlands east of San Diego. Farther north, small fires burned grassland and coastal sage scrub in the valleys and foothills around Los Angeles and large fires denuded chaparral in adjoining higher mountains (*24*). The total area of brush and grassland burned north of the border (237,000 ha) exceeded that burned to the south (183,000 ha) (Table 2). When evaluated in proportion to vegetation area, however, coastal sage scrub and grassland were more heavily burned in Baja California, while the proportion of burned chaparral was about equal in both countries.

Year-to-year burning varied enormously in all communities (Fig. 2). In grassland and coastal sage scrub, hectarage burned strongly correlates with precipitation during the previous winter. Heavy burning occurred throughout the area after the wet years from 1978 to 1980, north of 32°N in 1973, and in southern California in 1974 and 1975. Fires were rare after the drought years 1972, 1976, and 1977. Extensive burning is thus clearly related to increases in herbaceous biomass and stand continuity after wet years. Decomposition of unburned nonligneous material is relatively rapid and appears to occur within 1 to 2 years. Therefore, fuels are insufficient to support fires after dry years, in spite of numerous ignitions, as demonstrated by data for northernmost Baja California and Camp Pendleton. Almost no fires occurred in coastal sage scrub south of Ensenada except after the anomalously wet period from 1978 to 1980. This trend correlates with a southward increase in stand deciduousness and succulence and a decrease in European annuals.

Major chaparral fires, in contrast, occurred after both wet and dry years, except for the 1976 and 1977 seasons, which were interrupted by unusual midsummer tropical storms. Flammability of chaparral is more related to long-term accumulation of ligneous dead fuels over a period of decades than to short-term fluctuations in the growth of shrub foliage and spring annuals (*8*, *9*). Moisture in chaparral soil and fuel is normally depleted by June regardless of the precipitation the previous winter (*14*). Although the total area burned was larger after wet years, this is probably fortuitous. The tropical storms followed dry years, and the fire seasons after the wet 1978–1980 winters were extended by several Santa Ana windblown fires attributable to the late arrival of winter rains. Extensive burning of chaparral after dry winters (1972, 1974, and 1975) was accompanied by few fires in coastal sage scrub and grassland.

Fire size characteristics also change across the border (Fig. 1). Most fires in Baja California are relatively small, while fires in southern California range from small to very large. There are also important differences in the size-frequency distribution of fires among coastal sage scrub, grassland, and chaparral that are related to the length of their flammability cycles.

The distance a fire will travel is affected by short-term stochastic processes, such as changes in humidity and in wind direction and velocity. Perhaps the most important variable affecting the spatial properties of fires is antecedent fire. It is common for an active fire to stop at former burns because of insufficient fuel. Moreover, the extent of overlap between previous burns and active fires over some reference period should decrease as the time required for vegetation to reach flammability increases. Thus in slow-maturing communities the growth of fires is more constrained by previous fire history than in fast-maturing ones; fire size should be inversely related to fire frequency.

The number of fires decreased with increasing size class for all vegetation types in both countries (and Camp Pendleton) (Fig. 3). This is to be expected, of course, since vegetation area is finite. The distribution also reflects a natural continuum of fire size owing to fluctuations in weather, topography, and antecedent fires.

The fire size distributions for grassland and coastal sage scrub in both countries are comparable in spite of a proportionately larger burn area in Mexico. In northern Baja California and at Camp Pendleton many recent fires overlapped one another even within the 9-year reference period; fires were not substantially affected by previous fires. Since stand

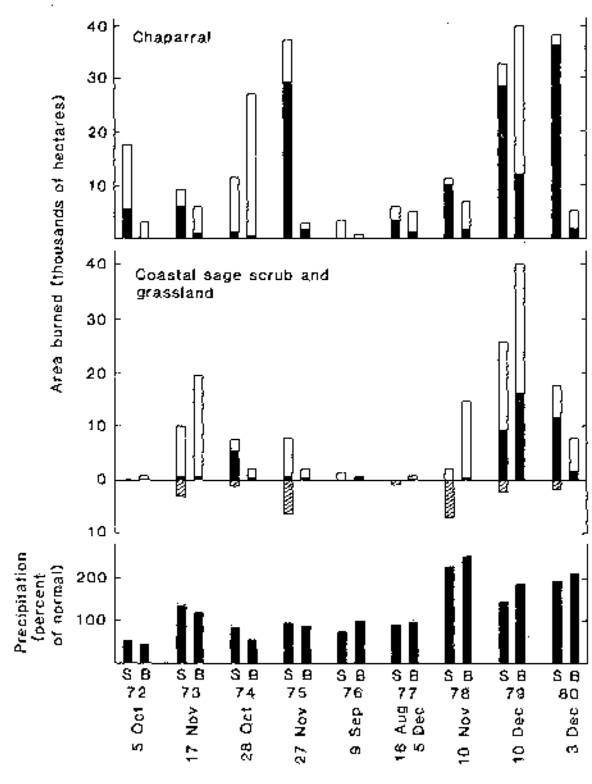

Fig. 2. Annual precipitation (*11*) and area burned during summer (unshaded) and after 1 September (shaded) in southern California (*S*) and northern Baja California (*B*). Burned areas for Camp Pendleton are represented by cross-hatching. Data for 9 September 1976 and 16 August 1977 reflect tropical storms Kathleen and Doreen, respectively.

flammability depends on the desiccation of European annuals and rapid-growing subshrubs, fire potential develops in a few years, provided that precipitation is adequate. Fires grow large because vegetation is universally flammable irrespective of age class arising from previous burning history. Thus, in spite of higher fire frequencies owing to some deliberate burning and minimal fire control, fires in Mexico were as large as those in southern California, especially after wet years. Most burns in both southern and Baja California were less than 100 ha after dry winters.

Fire perimeters in chaparral, in contrast, come into contact without overlapping. Thus, fires spreading in mature chaparral stop at less flammable juvenile stands. This checkerboard pattern may be seen in the mountains north and east of Los Angeles and locally in northern Baja California (Fig. 1). The borders of most other Landsat-mapped burns in southern California also have minimum overlap with burns dating to as early as the 1940's (*23*, *25*). Although few Mexican fires ran into others within the short reference period, the limits of mapped fires were affected by the intricate stand mosaic caused by fires prior to 1972. There were, however, strong differences in the slopes of fire size distributions for Baja and southern California (Fig. 3). In Baja California, burns less than 800 ha are more numerous than in southern California but less numerous above this size. Presumably, the size distribution for Mexico has remained unchanged since the past. Thus, the present burning regime in Baja California reflects an equilibrium between event frequency, fuel turnover, and fire size. Frequent small events preclude large ones because of the relative nonflammability of chaparral mosaic elements. In southern California, fire events are few and evidence of a stand mosaic is almost lacking; hence, active fires spread with less interruption.

Fire size may also be partially related to the burning season and weather. The long axes of chaparral fires are north to south in southern California and west to east in Baja California (Fig. 1), probably reflecting the prevailing winds during dry weather in the summer and fall, respectively (*26*). To test this relation, fires were classified by occurrence before or after 1 September. The proportion of area burned in chaparral after this date was 72 percent in southern California and only 20 percent in Baja California (Table 2 and Fig. 2). National Forest file data (*23*) reveal that, as expected, most large fires were spread by strong north-

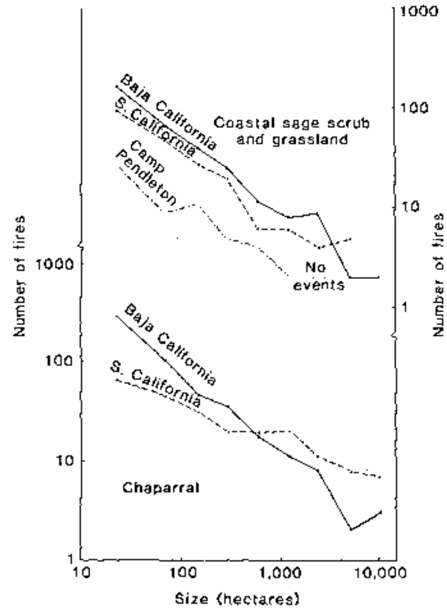

Fig. 3. Number of fires plotted against burn area for the two study regions, 1972 to 1980.

erly Santa Ana winds, which usually arise after 1 September. The west-to-east orientation of burns in Mexico conforms with mild daytime onshore sea breezes and valley winds that prevail during summer (Santa Ana conditions are almost nonexistent), a time when chaparral fires are normally extinguished in southern California. This suggests that fire suppression in southern California restricts uncontrolled fires to more severe weather conditions than in Mexico. Fires blown by Santa Ana winds in Mexico are still relatively small because of the brushland mosaic.

Historical Fire Size Characteristics in Southern California

The distribution of recent fires mapped from imagery demonstrates that fire suppression in southern California has led to larger fires, particularly in chaparral. The most striking evidence is the sharp shift in the area of coastal sage scrub, grassland, and chaparral burned in a narrow zone where fire control ends at the border. Environmental gradients are too limited to explain such a disparity. This trend establishes that suppression reduces burning sufficiently to affect fire size distributions.

The role of fire suppression could be dismissed if it could be shown that, without fire control, the natural frequency of events declines northward into southern California. Many lines of evidence place this in doubt. Ignitions by lightning are suppressed by the hundreds each year (*27*); if left alone, many such events would develop into wildfires because most thunderstorms occur during summer drought. Although lightning is most concentrated in forests at high elevations, where convection normally originates, thunderstorms often move long distances toward the coast, and fires in chaparral are suppressed throughout southern California. Over the several decades necessary for chaparral to mature, thunderstorms are sufficiently numerous for lightning to be a ubiquitous source of combustion. Although native Americans and early European settlers also set fires deliberately or accidentally (*28*), human acceleration of burning in chaparral is unlikely given its nonflammability during the first decades of succession after fire (even Santa Ana–blown fires stop in young chaparral). Thus, man-caused fires probably have less effect on the natural fire regime in chaparral than in coastal sage and grassland, where abundant herbaceous cover permits burning at frequent intervals. Whatever the source, many ignitions evolve into active fires in chaparral by slowly consuming larger fuel (logs and snags of trees in the canyons) until drier weather arrives. The Forest Service has recorded numerous "sleepers" that smouldered for as long as 2 weeks before discovery and suppression.

It could be argued that, in chaparral, higher productivity and fuel accumulation associated with heavier precipitation in southern California would yield larger fires, even with ignition rates equivalent to those in Baja California. More rapid fuel accumulation, however, should also encourage higher effective ignition rates. Indeed, 19th-century accounts describe a mosaic of small burns in what are now the San Gabriel, San Bernardino, and San Jacinto national forests. In fact, the effect of former burns on active fires was well understood. According to W. V. Mendenhall, the first supervisor of the Angeles National Forest, many early settlers found that "fires were not extensive due to the fact they ran into older burns and checked themselves" (*4*). During the 1890's, several fires around the Mount Wilson Observatory in the western San Gabriel Mountains burned for 2 to 3 months, yet none was reported to exceed 7000 ha (*4*). In the San Bernardino Mountains, "the entire area on the western and southern slopes showed indications of repeated burnings" (*29*, p. 453). In the San Jacinto Mountains, fires during the 1890's burned 5000 to 6000 ha "scattered throughout the reserve in small tracts" (*30*, p. 354). The chaparral was described as "a growth which varies from extremely dense to thin or open, but rarely forms large uninterrupted patches" (*29*, p. 463). These accounts strongly suggest a past fire mosaic in southern California chaparral that resembles the present one in Baja California.

The effect of fire control in chaparral may also be evaluated by examining fire size characteristics in southern California national forests since records began in 1911. A more Mexican pattern of size-class distribution should be sought early in the record, when fire suppression efforts were limited. National forest fire size frequencies most resembled those in present-day Mexico during the 1910's, although Mexican fires less than 800 ha are more abundant (Table 3). Four U.S. fires were massive (> 20,000 ha) compared with recent burns in Mexico. From 1920 to 1950, national forests experienced a marked decline in small fires, accompanied by rare conflagrations. Total area burned declined from 206,000 ha in the 1920's to 92,500 ha in the 1940's. Continued limited occurrence of small fires after 1950, however, was accompanied by numerous extensive conflagrations, which increased the area burned to 200,000 ha in that decade. Between 1911 and 1980, 41 fires in national forests exceeded the largest chaparral fire in Baja California (9725 ha). The median fire size in southern California by decade ranges from 3500 to 13,500 ha, compared with 1600 ha in Baja California (Table 3). The two largest burns, the 70,100-ha Laguna fire in San Diego County and the 89,000-ha Matilija fire northeast of Santa Barbara (Fig. 1), represent 14 percent of the total area burned in the national forests since 1911.

Management Implications

The effect of fire suppression in the coastal sage scrub and grassland of southern California appears to be limited. Since biomass in these stands is dominated by herbaceous dead fuels, fires easily escape control. Most occur in ordinary weather in summer and have a size distribution similar to those in Baja California (Table 2). Year-to-year burning rates in both countries are affected by herbaceous growth resulting from the previous winter's precipitation. Rapid decomposition of nonligneous fuels limits its increase in the amount of fuel that might otherwise result from lower fire frequencies.

The present regime of large, intense conflagrations in southern California chaparral appears to be an artifact of fire suppression. The great achievement of suppression is the extinguishing of small fires. Once fires are large, man has trivial impact on their progress. Thus, prevention efforts by a few forest rangers and settlers between 1880 and 1910 may have interrupted burning sufficiently to erase some of the presuppression mosaic. Since 1910, small fires have been replaced by ever-larger ones, with numerous conflagrations since the 1950's despite increased suppression investment. In effect, a fine mosaic has been replaced by a coarser one. There is no evidence of such large fires in the Baja California chaparral mosaic. Indeed, the present mosaic in southern California is capable of supporting even more enormous fires, possibly as large as 100,000 ha, particularly north of Santa Barbara, at Mount Palomar, and in the northern Santa Ana Mountains, where 50- to 80-year-old stands of decadent chaparral are widespread. Fires will probably be spread in autumn by severe Santa Ana winds, instead of during summer as in Baja California (Table 2). As a consequence of fire control, large fire sizes are almost guaranteed because Santa Anas, being a product of regional circulation, yield high winds and low humidity day and night until the storm system leaves the region.

The Forest Service has recently adopted a policy that recognizes the role of controlled burning in land management as an alternative to absolute fire prevention (*31*). Such a policy is clearly needed in southern California chaparral. Although limited prescribed burning programs have been initiated in several areas, such practices are futile unless their scale is extensive and they proceed at a rate commensurate with plant productivity and fuel accumulation. Prescribed burns must be sufficiently large (1000 to 2000 ha—approximately the median size of fires in Baja California) and must be implemented at a pace perhaps 50,000 to 100,000 ha per decade greater than present burning rates to maintain the mosaic configuration (*32*). Burns should be conducted in summer, when the vegetation is dry enough to carry fires of sufficient scale and weather is dominated by predictable mesoscale circulations (onshore advection of marine air, valley winds, air drainage, and ground inversions) that yield moderate humidity and diurnal winds of almost constant direction and velocity. Such a policy is a compromise, for the consequences of fire would only be ameliorated, not eliminated. Howev-

Table 3. Frequency of fire events by size class. Values for Baja California were derived from satellite imagery. Values for the United States were compiled from files at forest supervisor's offices at Goleta, Pasadena, San Bernardino, and San Diego and include all fires originating within or spreading to national forests, whether on private and public inholdings or outside these boundaries.

Observation period	Size class (thousands of hectares)											Total area burned (thousands of hectares)	Median fire size (thousands of hectares)
	0.04 to 0.1	0.1 to 0.2	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6	1.6 to 3.2	3.2 to 6.4	6.4 to 12.8	12.8 to 25.6	25.6 to 51.2	> 51.2		
						Baja California							
1972 to 1980	167	84	61	29	19	17	4	4	1	0	0	182.8*	1.6
						Southern California							
1911 to 1920	76	60	55	27	15	10	4	2	2	2	0	147.0†	7.5
1921 to 1930	71	36	45	41	23	23	5	7	4	2	0	206.1†	6.8
1931 to 1940	42	15	19	19	19	9	6	1	0	0	1	140.4†	7.6
1941 to 1950	35	44	31	25	24	19	16	2	1	3	0	92.5†	3.5
1951 to 1960	55	32	34	12	16	9	15	5	2	3	0	197.5†	5.0
1961 to 1970	47	24	30	24	17	7	6	5	5	3	1	201.6†	13.5
1971 to 1980	110	57	38	19	26	16	9	7	2	0	0	164.7†	3.5

*Vegetation area, 2,060,800 ha. Since succulent coastal sage scrub near San Quintín and Valle de la Trinadad (50 kilometers east of Ensenada) is almost nonflammable, the effective area covered by the statistic is 1,500,000 ha. †Fire hectarage within national forest boundaries and inholdings only. From analysis of 1972 to 1980 Landsat imagery, more than 80 percent of the total area burned in southern California is within national forests.

er, the initiation of such a program is without proper foundation since there has been little controlled burning of large units of vegetation.

The creation of chaparral mosaics in southern California is highly desirable since the mosaic is the basis of fire control. Fires would become smaller and would be distributed more evenly over time and space. Such was apparently the case in southern California before fire management.

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