DAMAGE AND RECOVERY IN SOUTHERN SIERRA NEVADA FOOTHILL OAK WOODLAND AFTER A SEVERE GROUND FIRE

P. K. HAGGERTY[1]
Sequoia and Kings Canyon National Parks,
Three Rivers, CA 93271

ABSTRACT

Mortality, epicormic sprouting, basal sprouting, and fire scar formation were evaluated in 148 tagged oak trees in a blue oak woodland in Sequoia National Park, California, for two years after a severe ground fire. Fire-caused mortality was low, 6% in *Quercus douglasii* and 11% in *Quercus wislizenii*. Epicormic sprouts developed in 65% of *Q. douglasii* and were most frequent in trees with more than 50% of the crown scorched. *Quercus wislizenii* showed less epicormic sprouting but developed basal sprouts more frequently. New fire scars developed on a majority of the *Q. douglasii* trees, even in areas of low fire intensity. Despite the severity of the fire, *Q. douglasii* crown recovery was almost complete within two years of the fire. *Quercus wislizenii* was reduced in importance on the site but will regain in canopy cover as basal sprouts develop from shrub form into trees.

The dominant oak of the foothill region of the Sierra Nevada, California, *Quercus douglasii* Hook. & Arn. (blue oak) is a focus of concern because of an apparent lack of regeneration (Muick and Bartolome 1987; Lang 1988) and the conversion of land for urban uses. Recent studies have indicated that fire played a significant historical role in the structure and maintenance of blue oak woodlands (McClaran and Bartolome 1989; Mensing 1991). Fire may have maintained blue oak savannas before European settlement in the mid–1800's; however, during the past century of fire suppression, ingrowth of pine and live oak has created a highly flammable condition (Griffin 1977; Parsons 1981). Information on the effects of fire is limited for the extant oak woodland (Barbour 1988), although relationships between damage and postfire survival in conifers have been well studied (Peterson and Arbaugh 1986; Ryan and Reinhardt 1988).

Low-intensity fires usually cause non-lethal damage to mature California oak trees; however, high-intensity fires can cause severe damage and high levels of mortality (Plumb 1980). Response to

[1] Current address: Forestry Science Laboratory, Pacific Northwest Research Station, USDA Forest Service, 3200 SW Jefferson Way, Corvallis, OR 97331.

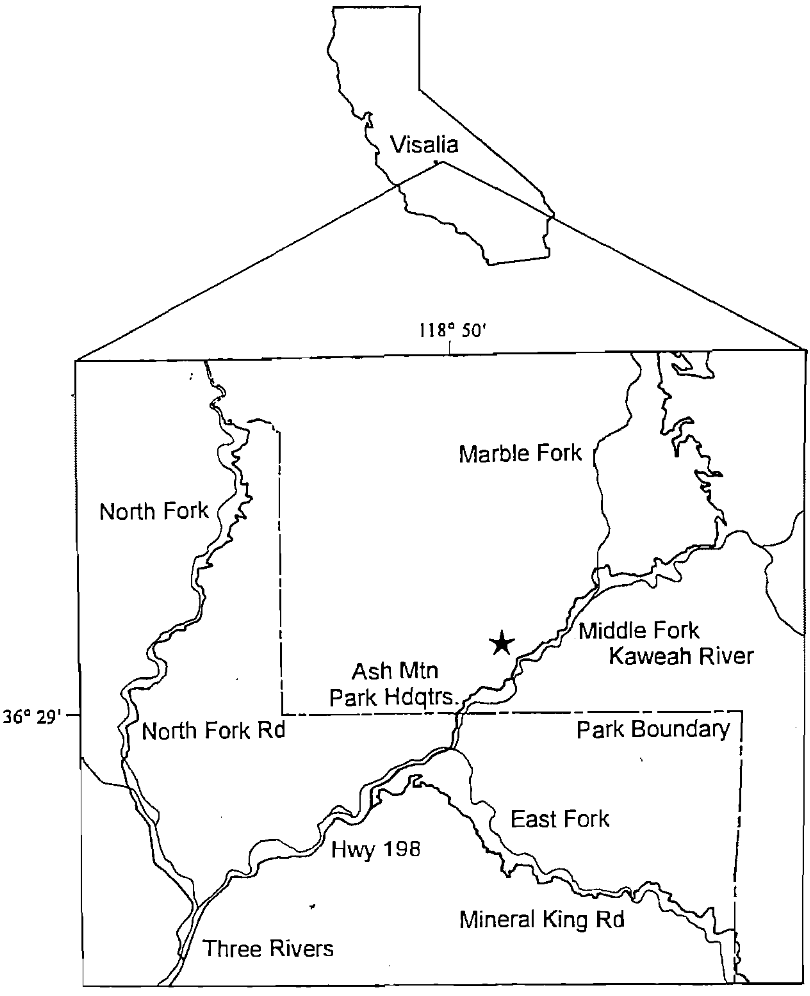

FIG. 1. Location of the study area in the southwest Sierra Nevada, California.

burning varies greatly among species. In California evergreen species, *Quercus agrifolia* Nee (coast live oak) recovers quickly while *Quercus wislizenii* A.DC. (interior live oak) is very susceptible to death of the bole (Plumb and Gomez 1983). Ground fires can cause different responses than crown fire. In a study conducted one year after an extensive 1977 fire, *Quercus lobata* Nee (valley oak) were severely damaged by intense crown burning (48% mortality) but had a relatively high degree of recovery (18% mortality) in areas of severe ground fire (Griffin 1980).

The most important postfire survival mechanism in many oaks is sprouting from dormant buds in the tree crown or on the bole (epicormic sprouting) or in the root-collar zone (basal sprouting) (Plumb and McDonald 1981). Survival also correlates with bark characteristics such as outer and inner bark thickness and surface texture, with thick bark conferring greater protection to the cambium (Plumb and Gomez 1983). Fire scars cause long-term damage to oaks, predisposing the tree to rot and failure (Plumb 1980). Dating of scars has allowed reconstruction of fire histories (McClaran and Bartolome 1989; Mensing 1991), despite the assumption that most grass or woodland fires do not result in a sufficient scar record (Parsons 1981).

Variation in fire sensitivity between two common oak species in the sierran phase of the blue oak woodland (Barbour 1988), *Q. douglasii,* a deciduous species, and *Q. wislizenii,* an evergreen, may affect stand structure and composition for decades after a fire. Mortality, crown damage, basal sprouting, and scar formation were studied in blue oak woodland after a severe ground fire that occurred in June 1987. This paper reports on the results of a two-year postfire evaluation to assess the recovery of the woodland in the absence of mitigation through management, such as culling burned trees or reseeding.

Study Site and Methods

The study site is located in the foothill region (elevation 579 m) of the Kaweah River drainage, Sequoia National Park, Tulare County, California, in the southwestern portion of the Sierra Nevada (Fig. 1). Mean annual precipitation is 66.5 cm, although the range was 40 to 50 cm during the period of the study (25 to 40% below average). The soils are classified as thermic–Ultic Haploxerolls derived from a complex of granitic and metamorphic parent material and are coarse, well drained, and low in organic matter (Huntington and Akeson 1987).

The site spans a steep southeast-facing hillside of open blue oak/live oak savanna with an understory of annual grasses, predominantly *Avena fatua* L. (wild oats) and *Bromus hordeaceus* L., and *Centaurea melitensis* L. (star thistle), grading into a more mesic mixed woodland of blue oak, interior live oak, and *Aesculus californica* (Spach) Nutt. (California buckeye) in a west-facing draw. The Blue oak-interior live oak/grass (QUDO-QUWI/GR) subseries of the blue oak community classification (Allen-Diaz and Holzman 1991) describes the vegetation sufficiently well, with the exception that *Pinus sabiniana* Douglas (foothill pine) is absent from the Kaweah drainage. Basal area of *Q. douglasii* (12.5 m^2/ha) on the site is greater than the mean (5 m^2/ha) of the QUDO-QUWI/GR subseries, although total density of the stand is somewhat lower (155 trees/ha) than the series (198 trees/ha). Very few seedlings or saplings are present. The diameters of the trees range from 6 to 75 cm at 1.37 m (dbh). Shrub density is very low (39 stems/ha).

There has been little human use of the site since the designation of Sequoia National Park in 1890. Grazing and frequent burning occurred in the Kaweah drainage from 1869 to 1890 during the period when the foothills were explored and settled (Vankat and Major 1978). Earlier, a substantial indigenous population inhabited the area. However, their numbers declined rapidly following the arrival of Europeans (Dilsaver and Tweed 1990). Park records dating from 1925 did not report any known burns on this site. Moderate grazing by National Park Service pack stock last occurred in 1977. Grazing was not allowed during the two years of this study.

The arson-caused fired was ignited during the night of June 26, 1987, about 400 m north of the Ash Mountain park headquarters along the General's Highway. Initial fire conditions were extreme, with air temperatures in the range of 30°C, relative humidity of 17%, and fine fuel moisture of 3.5%. The fire burned on slopes of 20° to 39°. Dry grass was the primary carrier of the fire. Flame lengths were estimated at 1 to 4.6 m. Cooler down-canyon breezes began after midnight and raised relative humidity to about 50%, considerably moderating the fire's intensity.

The extent of crown damage suggested that the fire burned most of the site as a "severe ground fire" in the sense of Griffin (1980) in which trees still had leaves but the leaves were dead. The remainder burned as a "moderate ground fire" in which the upper crowns remained green, except in the mesic area of the draw where the fire backed downhill and crowns were only slightly scorched. Observations made of weather and fuel conditions during the fire were used to develop estimates of fireline intensity, a measure of the rate of energy release at the flaming front (Rothermal 1983). Fireline intensity at the fire front ranged from 315 to 1072 kW/m, while backing fireline intensity may have been as low as 17 kW/m.

The study was established in the autumn following the burn (1987). To capture the variation in fire intensity, I stratified the burn topographically into four transects: northwest (WEST), ridge (RIDGE), lower southeast slope (EAST1), and upper southeast slope (EAST2). The RIDGE, EAST1, AND EAST2 transects were burned by heading and flanking movement of the fire, while the WEST transect burned under flanking and backing conditions. The RIDGE transect experienced the highest fire intensity. Although it was not the steepest area of the burn, it was above the location where the arsonist started the fire.

Along each 300 m transect, trees were selected for long-term evaluation using the point-centered quarter method at 30-meter sampling intervals (Mueller-Dombois and Ellenberg 1974). In each of four quarters, the closest tree to the sampling point was tagged and height and diameter at breast height measured. The tree was inspected for fire damage including visual estimation of percent of crown scorched, height of crown scorch (measured with a clinometer), degree of basal char on the tree bole, presence of scars, and evidence of sprouting from epicormic of basal buds. If the closest tree in a quarter was dead, the dead tree was tagged and the next closest live tree was selected also. Scorched leaves did not abscise, thus it was possible to determine the extent of crown scorch in the autumn after the fire. Of the 164 tagged trees, 148 were oaks.

Each tagged tree was reassessed twice, at one-year intervals, to determine survival, sprouting, crown recovery, and fire scar development. I distinguished between aboveground mortality (topkill) in which the root system remained viable after death of the stem and regenerated a new stem or stems, and complete mortality, in which the root and aboveground stem were dead. Additional data on tree and shrub species composition, tree diameter, survival and resprouting were collected from fixed-area 0.05 ha circular plots centered around the sampling points eighteen months after the fire. A survey for seedlings and saplings (<1.37 m) was conducted in forty two 0.05 ha circular plots along the transects after the second postfire growing season. Acorn production was assessed in early autumn 1988, using Graves' (1980) rating scale; however, acorn production was negligible during the period of the study and the data will not be reported further.

One-way analyses-of-variance (ANOVA), and Scheffe means tests were used to test for significant differences in fire damage characteristics between transects and between size classes of tagged trees. This wildfire was an event without possibility of replication, so observations of fire damage on trees were not independent and did not fully meet the assumptions of ANOVA. Tests of significance were conducted at the $\alpha = 0.05$ level, however, the P-values for ANOVA results may be less than stated. Chi square tests were used to assess significance of the binomial variables of mortality, sprouting, and fire scar development. Binary logistic regression was used to investigate the relationship of mortality and resprouting responses with tree and fire damage characteristics. Logistic regression has been used to identify important variables or to develop predictive models in situations where the outcome is restricted to one of two populations, such as tree mortality from fire (Ryan and Reinhardt 1988) or resprouting after fire (Davis et al. 1989). Variables tested in the logistic regression models included site characteristics, such as slope and topographic location, and individual tree attributes such as diameter and the presence of scars.

RESULTS

Fire intensity. Fire damage characteristics, percent of crown scorched, scorch height, and bole char height, all differed significantly

TABLE 1. SITE CHARACTERISTICS, FIRE DAMAGE AND FIRE EFFECTS (TWO YEARS POSTFIRE) ON TAGGED OAK TREES FROM FOUR TRANSECTS IN THE ASH MOUNTAIN FIRE. Within rows, means with different letters indicate significant differences at P < 0.05 by ANOVA. Significant chi-square results are indicated with **.

	Transect			
	WEST	RIDGE	EAST1	EAST2
Site characteristics				
Aspect	283°	149°	92°	108°
Slope percent	67	30	70	52
Canopy cover (%)	47	31	30	30
Oak trees per transect (n)	31	38	37	42
Fire damage				
Mean crown scorch (%)	27 a	90 b	45 ac	54 c
100% crown scorch (n)	3	28	9	6
Mean scorch height (cm)	36 a	58 b	50 ab	50 ab
Mean bole char height (cm)	20 a	60 ab	50 a	100 b
Fire Effects				
Above ground mortality (%)	0	19	5	9
Basal sprouting (%)**	7	32	8	24
Fire scars (%)	65	59	64	40

between transects when analyzed by one-way ANOVA (Table 1). Crown scorch was significantly higher on RIDGE transect where 82% of all trees had completely scorched crowns. All fire damage characteristics of the WEST transect were less severe than those of the other transects. Despite the differences between these indicators of fire severity, chi square tests found no significant differences in mortality between transects, however, there were highly significant differences in the degree of basal sprouting. Basal sprouting on the mildly burned WEST transect was lower than expected, while the hotly burned RIDGE plot had more basal sprouting than expected.

Mortality. Immediate mortality of oak trees due to the fire was low; only two of 148 tagged oaks died during the fire. One *Q. douglasii* tree had extensive damage from previous fire scars and collapsed while burning, and one *Q. wislizenii* of very small diameter was severely burned and did not resprout.

By two years after the fire, aboveground mortality of tagged trees was much higher for *Q. wislizenii* (24%) than *Q. douglasii* (8%). Complete death of the individual occurred in 6% of *Q. douglasii* trees and in 11% of *Q. wislizenii* trees (Fig. 2). All *Q douglasii* trees whose main stems died produced epicormic sprouts, basal sprouts or both before dying, however, only two still had surviving basal sprouts in 1989. By contrast, more than half of topkilled *Q. wislizenii* trees had surviving basal sprouts two years after the fire. Death or

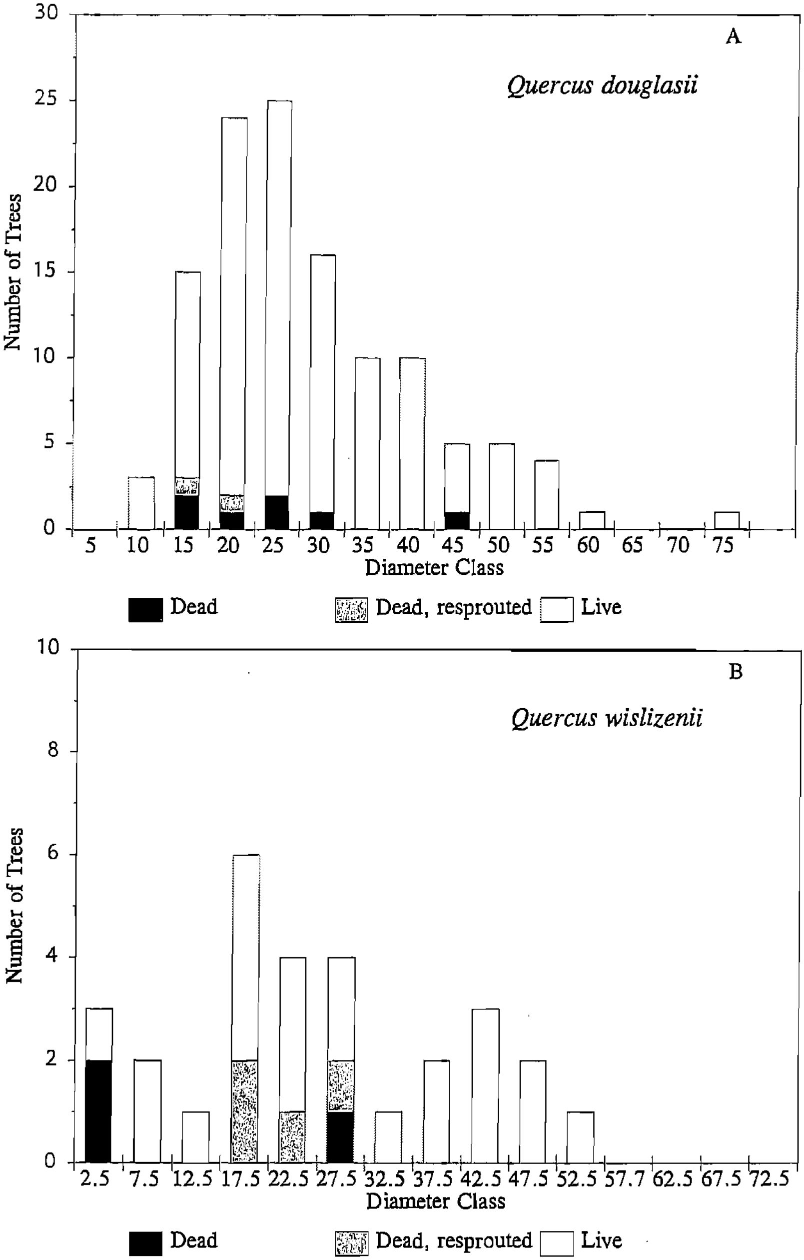

FIG. 2. Mortality of tagged *Q. douglasii* (A) and *Q. wislizenii* (B) by size class two years postfire. The category "Dead, resprouted" indicates dead boles with basal sprouts surviving two years after the fire.

TABLE 2. NUMBERS AND MORTALITY RATE OF *Q. DOUGLASII* AND *Q. WISLIZENII* AS RELATED TO DEGREE OF CROWN SCORCH DURING TWO YEARS OF POSTFIRE EVALUATION.

	Percent of crown scorched							
Species:	*Q. douglasii*				*Q. wislizenii*			
Year	≤25	26–50	51–75	100	≤25	26–50	51–75	100
1987	39	20	22	36	9	7	7	8
1988	39	19	22	36	9	7	7	2
1989	39	19	21	30	9	7	4	2
Mortality	0%	5%	4.5%	16.7%	0%	0%	43%	75%

physical failure of large stems in multiple stem *Q. wislizenii* trees was common but did not lead to death of the whole tree.

The small numbers of both species that died limited statistical analysis. Percent of crown scorched and the presence of old fire scars were the only factors which predicted the probability of mortality in logistic regression models. Mortality was greatest in trees with 100% of the crown scorched, both marked differences between species were found (Table 2). Seventeen percent of *Q. douglasii* trees

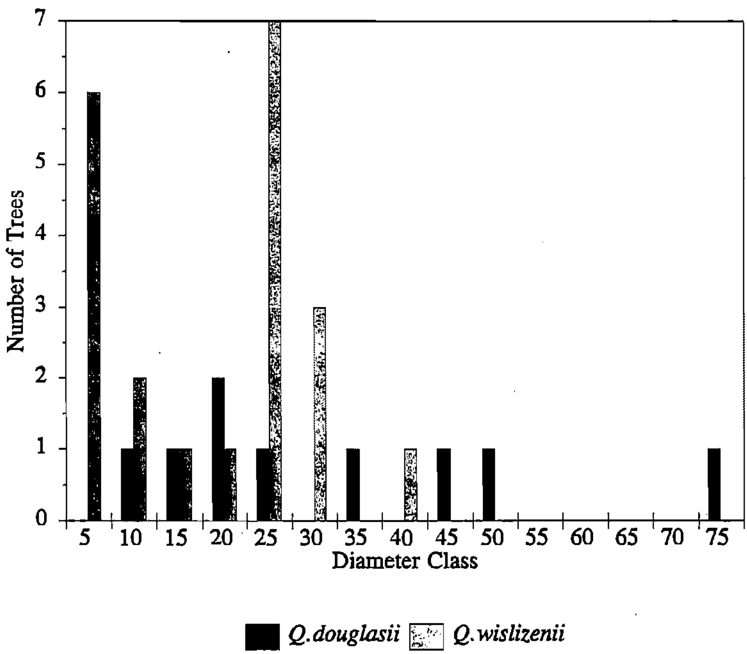

FIG. 3. Aboveground mortality, by diameter class, of oak trees sampled in fixed area plots eighteen months after the fire.

TABLE 3. STAND CHARACTERISTICS OF THE ASH MOUNTAIN FIRE SITE EIGHTEEN MONTHS AFTER THE JUNE 1987 FIRE.

Species	Density (stems/ha)		Basal Area (m^2/ha)	
	Live	Dead	Live	Dead
Trees				
Aesculus californica	18	0	2.5	0
Fraxinus dipetala	11	9	0.2	0.1
Quercus douglasii	109	5	12.5	0.5
Quercus wislizenii	17	13	4.5	0.1
Shrubs				
Arctostaphylos viscida	5	3		
Cercocarpus betuloides	3	3		
Rhamnus crocea	5	0		
Toxicodendron diversilobum	15	0		
Yucca whipplei	5	0		

with complete crown scorch died within two years, whereas 75% of *Q. wislizenii* trees with that degree of crown scorched died.

Data collected in the fixed-area plot survey eighteen months after the fire indicate that 45% of *Q. wislizenii* trees in this sample experienced aboveground mortality and only one of 46 *Q. wislizenii* individuals had died. The average diameter of topkilled *Q. wislizenii* was 18 cm and was significantly smaller than the diameter of the surviving boles of this species. Of the 163 *Q. douglasii* trees sampled in these plots, the aboveground mortality rate was 5% and the true mortality was 4%. Aboveground mortality in this species was not related to diameter size class (Fig. 3). Basal area of dead trees was very low, less than 4% of the total basal area for each oak species (Table 3).

Crown damage and recovery. Epicormic sprouts developed in almost twice as many *Q. douglasii* trees as *Q. wislizenii.* Within two weeks after the fire, large, bright green epicormic leaves were observed in the crowns of heavily scorched *Q. douglasii* trees. By six months after the fire, 65% of all *Q. douglasii* trees had epicormic sprouts developing in the crown and on the boles. Epicormic sprouting occurred most frequently in trees with more than 50% of the crown scorched (Fig. 4) and occurred in all size classes. Percent of crown scorched was the only significant factor predicting likelihood of crown sprouting identified by analysis with logistic regression. Sprouting within the crowns of *Q. wislizenii* trees occurred in 35% of tagged trees and was restricted to trees larger than 20 cm DBH. Deer browsed on available crown and basal sprouts of both species.

The canopy cover of surviving *Q. douglasii* trees was mostly restored by two years after the fire. Overstory crown recovered less in *Q. wislizenii* because of slow growth in scorched portions of the

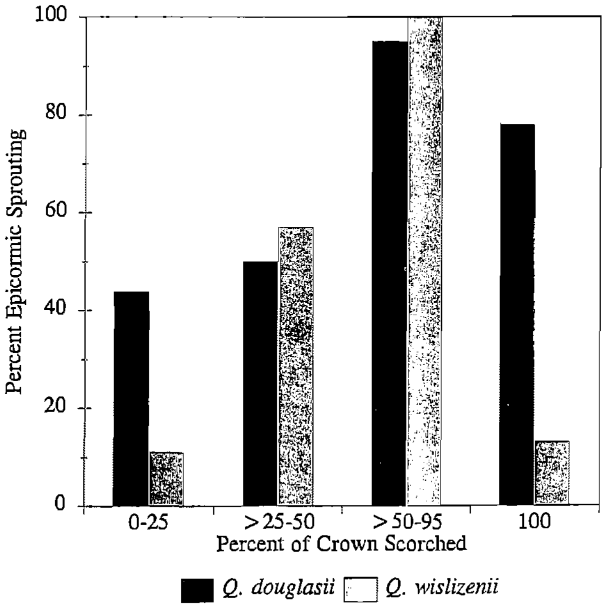

FIG. 4. Percentage of oak trees with epicormic sprouting as a function of the percent of crown scorched.

crown and the death of major stems. However, an abundance of shrubby stems growing from the root collar zone occurred in 36% of surviving *Q. wislizenii* trees. *Phoradendron villosum* (Nutt.) Nutt. (oak mistletoe) was abundant in the crowns of several trees of both species before the fire; however, once scorched, it died completely.

Scarring. Many more old fire scars were found on *Q. wislizenii* trees (86%) than on *Q. douglasii* trees (47%). New scars developed on 59% of *Q. douglasii.* New scars were not clearly discernible on *Q. douglasii* boles until two years after the fire. On some *Q. douglasii* trees, the charred bark surface flaked away and left the bole apparently unharmed. Rescarring of old wounds occurred, but many trees with old scars developed new scars in previously undamaged bark. Forty-one percent of new scars were subjectively categorized as small, 20% as average and 38% as large. New scars formed on 38% of the *Q. wislizenii* trees that had not died. Incidence of scarring did not differ significantly between size classes for either species. Although crown damage varied significantly between transects (Table 1), frequency of fire scar development did not.

Seedlings. A small number of oak seedlings were found after the fire, 9 *Q. wislizenii* and 5 *Q. douglasii.* Based on examination of the stem, the 14 oak seedlings appeared to have established before the fire and had resprouted, and one had died after resprouting. The height of the resprouted seedlings ranged from 10 to 50 cm. The mesic WEST transect had more than half of the seedlings, all *Q. wislizenii.*

There was no evidence of establishment of fire-germinating shrub species in plots surveyed after the fire (Table 3). Some *Cercocarpus betuloides* Torrey & A. Gray (mountain mahogany) and many *Toxicodendron diversilobum* (Torrey & Gray) E. Greene (poison oak) resprouted after the fire.

Discussion And Conclusions

The role of fire in the ecology and conservation of blue oak woodlands requires clarification. Pertinent ecological questions include how much fire, if any, is necessary to maintain open savanna characteristics (Griffin 1977), what is its role in *Q. douglasii* recruitment (McClaran and Bartolome 1989) and in succession (Allen-Diaz and Holzman 1991). One effect of the increasing urbanization of the foothill region is a greater risk of human-caused fire and attendant efforts to reduce wildfire danger at the "wildland-urban interface," including prescribed burning. In reserves such as Sequoia National Park, efforts to simulate natural fire regimes require information on the responses of key species as well as sound fire history information (Parsons 1981).

Savanna-like characteristics were temporarily enhanced on this site by the fire. The results of this case study suggest that the 1987 fire, although severe, did not affect *Q. douglasii* dominance of the stand and resulted in no change in relative dominance between species (Table 3). Density of *Q. wislizenii* was reduced through aboveground mortality of smaller diameter trees with little change in basal area of that species. Shrub abundance, already low, decreased slightly after the fire.

Fire intensity in blue oak woodland has been considered too low to scar trees, resulting in incomplete fire history reconstructions (Parsons 1981). However, on this site, fire scar development was frequent even in areas that burned at low intensity. In contrast to previous assumptions, oak trees may record as scars even low-intensity fires at relatively high frequency, at least under the ambient conditions of high are temperatures and active growth stage that occurred during this fire. Hidden fire scars in intact *Q. douglasii* have been documented by examining cut cross sections (McClaran 1988); therefore my estimate of old scars may be lower than the actual number of scarred trees. Some of the small scars I observed would seemingly heal quickly. The greater number of old scars evident on *Q. wislizenii* trees suggests that they may heal scars more slowly than do *Q. douglasii* trees.

In common with other studies of *Q. douglasii* in this region (Brooks 1969; McClaran 1986), there are few *Q. douglasii* saplings and seedlings on the site. However, the resprouted oak seedlings found after the fire were generally vigorous. Recent studies of *Q. douglasii* (Allen-Diaz and Bartolome 1992) and *Quercus engelmannii* E. Greene Engelmann oak (Lathrop and Osborne 1991) discount fire as a limiting factor in seedling survival, because most established seedlings survived and resprouted after burning. Factors other than fire apparently are responsible for the failure of seedlings to survive to the sapling stage. A flush of *Q. douglasii* regeneration by sprouting from sapling-sized trees was not apparent following this fire, probably because of a distribution skewed towards larger (>20 cm) trees.

Prediction of fire effects is complicated by climatic and phenological interactions unique to each occurrence. The high survival of *Q. douglasii* trees observed on this fire indicates that severe crown injury may not result in the death of trees, despite the additional stress of low precipitation during the study period. Rundel (1980) states that there are suites of traits in many California oak species which allow survival in areas where fires are frequent. The ability of *Q. douglasii* to withstand both extreme drought and brief high-intensity fires may result in part from its deciduous characteristics, which allow it to facultatively add or excise leaves in relatively rapid response to environmental stress. Persistent basal sprouting in *Q. wislizenii* is one factor that allows this species to remain in the blue oak savanna environment; however, reduced survival after fire damage to crown and bole may limit its dominance in this phase of the oak woodland.

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