Tree mortality 6 years after burning a thinned *Quercus chrysolepis* stand[1]

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Managers do not currently use prescribed fire in stands of canyon live oak (*Quercus chrysolepis* Liebm.) because it is highly susceptible to fire injury. A preliminary study investigating the effects of prescribed burning on this species was initiated on the San Bernardino National Forest in southern California. The purpose was to assess the feasibility of using thinning and prescribed burning to develop shaded fuel breaks in these stands. This paper addresses aboveground tree mortality inventoried 2 and 6 years after a prescribed burn. Aboveground tree stems were judged as live or dead (irrespective of root-zone sprouting). Fire caused approximately 50% mortality in DBH classes ≤15 cm and <10% in larger classes. Between the 2nd and 6th years after burning, tree mortality increased by only 3%. Our results suggest that prescribed fire can be used as a management tool in *Q. chrysolepis* stands and that tree mortality might be evaluated sooner than previously believed. More investigations are required to identify favorable conditions for prescribed burning in this species, as well as applicability for (*i*) degree of hazard reduction near the urban wildland interface, (*ii*) stand improvement by thinning small or crowded trees, and (*iii*) revitalizing wildlife habitat.

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Les aménagistes utilisent rarement le brûlage contrôlé dans les peuplements de chênes à écailles dorées (*Quercus chrysolepis* Liebm.) parce que cette essence est très sensible aux blessures causées par le feu. Une étude préliminaire portant sur les effets du brûlage contrôlé sur cette espèce a été démarrée dans la Forêt Nationale de San Bernardino dans le sud de la Californie. L'objectif consistait à évaluer la possibilité d'utiliser l'éclaircie et le brûlage contrôlé pour établir des pare-feu boisés dans ces peuplements. Cet article porte sur la mortalité de la partie aérienne des arbres inventoriés 2 et 6 ans après un brûlage contrôlé. La partie aérienne des arbres a été jugée morte ou vivante indépendemment du drageonnement. Le feu a causé environ 50% de mortalité dans les classes de DHP ≤15 cm et moins de 10% dans les classes supérieures. Entre la deuxième et la sixième année après le brûlage, la mortalité a augmenté de seulement 3%. Nos résultats suggèrent qu'on peut utiliser le feu comme outil d'aménagement dans les peuplements de chêne à écailles dorées et qu'on peut évaluer la mortalité plus tôt qu'on ne le croyait. D'autres études sont nécessaires pour identifier les conditions favorables au brûlage contrôlé chez cette espèce aussi bien que son applicabilité pour (*i*) réduire le niveau de risque près de la limite entre le territoire urbain et la forêt, (*ii*) améliorer les peuplements en éliminant les arbres rapprochés ou de petite dimension et (*iii*) revitaliser l'habitat faunique.

[Traduit par la rédaction]

Introduction

Canyon live oak (*Quercus chrysolepis* Liebm.) is the most widely distributed oak species in California (Mallory 1980) and one of the more important forest cover types in southern California. It is Society of American Foresters cover type No. 249 (Mallory 1980). In southern California, the species occurs in pure and mixed stands that are a source of both fuelwood and recreation. Tree structure and mast production make them prime habitat for many wildlife species (McDonald 1988).

Stands of canyon live oak occur in a broad elevational zone that includes elements of chaparral, hardwood, mixed conifer – hardwood, and conifer types. Stand characteristics (such as steep slopes, high stem density, and abundant ground fuels), plus the geographical distribution (especially with regard to proximity to human activities) of canyon live oak, make this species susceptible to wildfire.

Canyon live oak is readily top-killed by wildfire and sprouts vigorously (Plumb 1980; Plumb and Gomez 1983; Paysen et al. 1991). The flakey outer bark of this species is highly flammable and is often ignited even during low intensity surface fires. This trait and its vigorous sprouting ability could be fire adaptations. The suggestion that canyon live oak evolved in ecosystems influenced by fire (Plumb and McDonald 1981; Rouse 1986) further suggests that prescribed fire may be useful in the management of this species.

Managers on the San Bernardino National Forest initiated a preliminary study to investigate two silvicultural techniques that may be effective in creating a shaded fuel break in canyon live oak. Shaded fuel breaks are created by thinning the overstory, thus interrupting the continuity of the canopy fuels. No guidelines existed for silvicultural treatments in this forest type. Thus, management needed more information in order to establish guidelines for this species.

Thinning was used as one treatment in this study. Guidelines from the U.S. Forest Service Region 5 Hardwood Local Volume Table for tanoak (*Lithocarpus densiflorus* (Hook & Arn.) Rhed.) were modified and used (letter to Forest Supervisors, Region 5 and Lake Tahoe Basin Management Unit from S. Undi, Director of Region 5 timber staff) for applying the thinning treatment to a canyon live oak forest on the Mill Creek District of the San Bernardino National Forest. Results of canyon live oak response to thinning have already been reported (Paysen et al. 1991).

Residual slash form thinning increases dead fuel loading and potential fire hazard. Therefore, a second treatment, thinning plus prescribed understory burning, was also used. Burning was applied following thinning to reduce dead fuel loading, hence, minimize hazard within the covered fuel break.

Canyon live oak is known to be susceptible to wildfire damage but its response to prescribed fire is not documented.

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It has been ranked as being "sensitive" to wildfire and may take up to 8 years for mortality to occur even if cambial damage effectively girdles the bole (Plumb 1980). Because this species is prone to fire injury, an unacceptably high tree mortality was anticipated from a prescribed burn. Therefore, a burning only treatment was not considered reasonable for this preliminary study. However, the combination treatment of thinning plus understory burning was believed to reduce the risk of high mortality.

A preliminary survey was made 6 months after the burn treatment to develop our methodology for burn damage assessment. Damage indicators used are related to research by Plumb and Gomez (1983). They related cambial tissue damage and girdling to mortality of trees that had died after wildfire. We chose fire damage criteria that could be evaluated visually, simply, quickly, and nondestructively. Indications of injury needed to be obvious such as color changes related to charring, cambial tissue death, or actual loss of bark owing to consumption. Parameters were further evaluated by measuring the extent of the damage, such as the dimensions (size, shape, and depth) of the charring, as well as its location and extent on the tree. For example, a thin fire scar that was 1 m in vertical height could be less damaging to a tree than a thin 0.5-m scar that ran horizontally and completely encircled (potentially girdling) the tree.

This paper addresses the feasibility of using prescribed understory burning to reduce litter and slash accumulated in a thinned canyon live oak forest. Specifically, we present data showing that fire induced aboveground tree mortality 2 and 6 years after prescribed burning was minimal. This low mortality is notable in light of the extended drought that southern California was experiencing and the previously recorded high wildfire mortality (Plumb 1980). Based on our findings, we recommend that further studies using prescribed fire be conducted in canyon live oak.

Methods

The study area is located in the San Bernardino Mountains in southern California, on the north facing slope of Skinner Ridge, at an elevation of approximately 1676 m (5500 ft.). Study plots are located in a closed forest of canyon live oak. Aspect varied slightly among blocks and slopes ranged from steep (35°) and convex to moderate and concave. The soil type is in the Winthrop Family (sandy–skeletal, mixed mesic Entic Haploxerolls) (Retelas 1980). The ground surface varied from predominantly large rock, through gravelly soil, to deep (1 m) organic matter. The study area had burned approximately 100 years earlier.

The forest overstory is dominated by single- and multi-stemmed canyon live oak. Interior live oak (*Quercus wislizeni* A. DC.) is found near ridgetops and drainages. An occasional big-cone Douglas-fir (*Pseudotsuga macrocarpa* (Vasey) Mayr.), white fir (*Abies concolor* (Gord & Glend.) Lindl.), and California bay (*Umbellularia californica* (Hook & Arn.) Nutt.) are found in the forest. Average stand density was initially 3100 trees/ha (1255 trees/acre). Average overstory height was 8.2 m (26.9 ft.); average diameter at breast height (DBH) was 16.5 cm (6.5 in.). Distributions for tree height and DBH are presented in Fig. 1. We assumed that our study plots were in an even-aged canyon live oak forest. Smaller trees were considered to be less vigorous (Thornburgh 1990), even suppressed, since they generally had sparse crowns and were frequently overtopped by larger trees.

Three treatments (control, thin, and thin plus burn) were randomly assigned to 30 × 40 m (92 ft. × 130 ft.) plots in each of three blocks laid out in the study area. Thinning treatments were carried out through a fuelwood sale operation from spring 1984 through spring

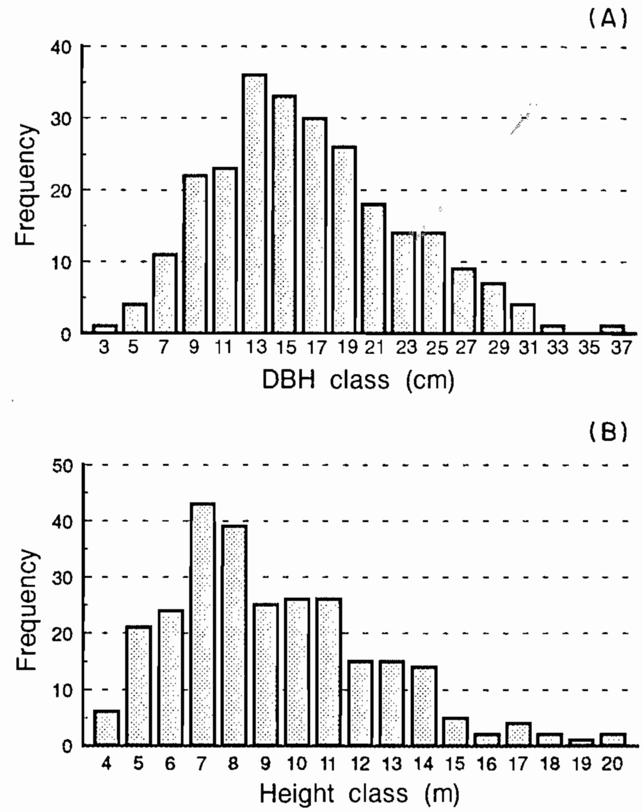

FIG. 1. Diameter (A) and height (B) distributions for canyon live oak stands on Skinner Ridge in the San Bernardino Mountains.

1985 (Paysen et al. 1991). Subcontractors used a hand-held chainsaw for their cutting operation. Except for control plots, the forest on the ridge was thinned from a stand basal area of 54 m^2/ha to approximately 22 m^2/ha (235 $ft.^2$/acre to 98 $ft.^2$/acre). Thinning was distributed proportionally across diameter size classes and between single-stemmed trees and stems from multiple-stemmed clusters. This allowed us to determine if trees from different size classes, growing under a variety of conditions, respond similarly to treatments.

All logging slash >5 cm (2 in.) in diameter was removed from the site. Thus, the fuel bed for the burn treatments was composed of light slash and oak leaf litter. Fuel moisture for ground fuels was collected before the burn. Fuel moisture was separated into six categories: twig, leaf, three litter layers (judged by decomposition status), and duff (composite of all three litter layers).

The burn treatment was carried out on November 5 and 7, 1985. November 6 had a Santa Ana wind condition that was unacceptable weather under our burning prescription. During the burns, relative humidity averaged 30% on both days (range = 26–35%) and wind from the northeast was between 8 and 10 km/h (5–10 mph). Snow fell on November 8, 1985. The treatment fell near the beginning of an extended drought that began in southern California with the reduced rainfall of 1984. Below normal annual precipitation was recorded between 1984 and 1990, with the exception of 1986, which was normal (data courtesy of the U.S. Weather Service, South Coast Drainage District, Los Angeles, California).

An inverse chevron firing technique (Sackett 1969) was used to assure that neither heat nor flame encroached upon adjacent plots. Firing proceeded from top (elevation) to bottom on the plots. Fire behavior was erratic within and between plots. Fire did not carry well on portions of some plots owing to the discontinuity of the fuels. On steeper slopes small piles of litter and twigs frequently backed up against the uphill sides of tree boles. Most flame heights were less than 1.5 m (4.5 ft.), yet flame lengths varied from 10 cm to 2.5 m.

Owing to the extreme potential fire danger from the Santa Ana wind conditions, and the precautions taken during mop-up, postburn

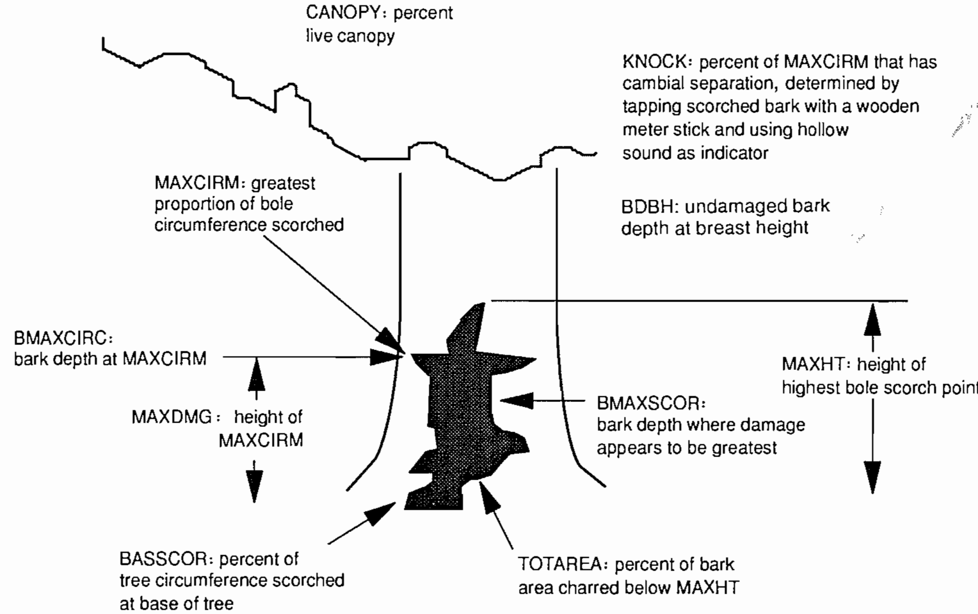

FIG. 2. Damage indicators used as mortality predictors for canyon live oak trees following prescribed burning.

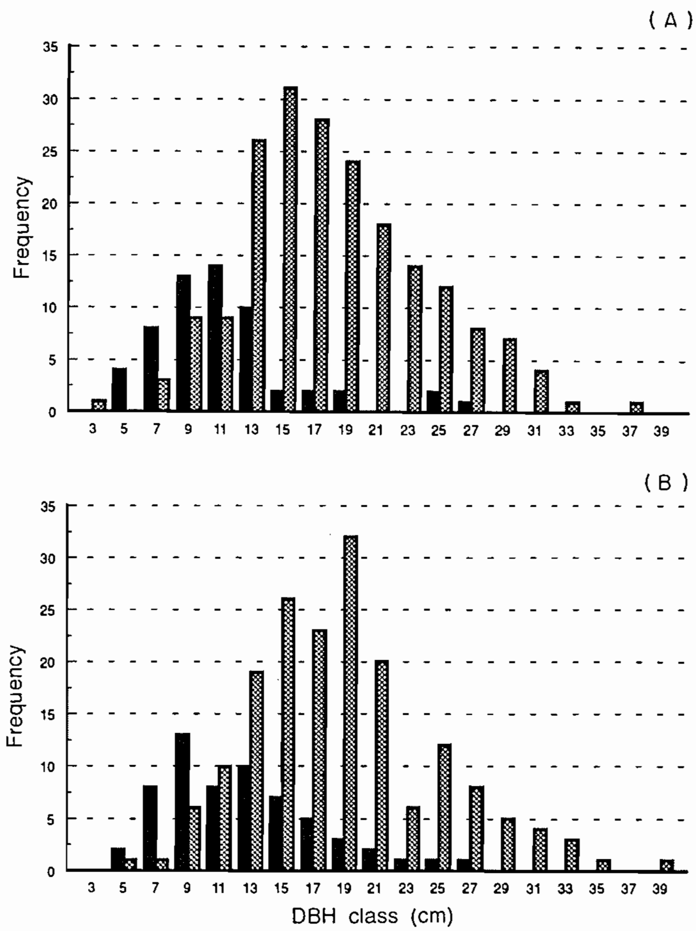

FIG. 3. Diameter class distributions of live (shaded bars) and dead (solid bars) trees 2 years (A) and 6 years (B) after the burn treatment.

data for duff and fuel consumption could not be systematically evaluated. To eliminate any potential for escape following the burn, the fire crew completely saturated the entire area of the burned plots with water. Therefore, visual inspection had to be used to evaluate consumption.

A number of fire damage indicators were evaluated to determine which criteria would be most useful for predicting fire-induced mortality (Fig. 2). In addition to the damage indicators mentioned in Fig. 2, we also used two tree characteristics, DBH and height, as potential predictors of mortality.

Actual aboveground tree mortality was determined in surveys by visual inspection of trees for peeling bark and dead cambium layer, defoliated crown, and hard, dry exposed wood in the bole. For our purposes, we considered trees whose stems had died but that were still producing root sprouts as dead.

Mortality assessment was carried out 2 years and 6 years after the prescribed burn. Mortality was measured on two sets of trees. One set, consisting of 30 tagged trees, which were randomly located within each of the three plots, were used for intensive monitoring. To provide our mortality survey with a larger sample of trees that would better represent the mortality response of a variety of size classes and different site characteristics, we added a second set of samples. Set two consisted of all trees within four belt transects (3 m × 30 m) in each of the burn plots. Starting from the bottom of the plots, the transects ran horizontally across the slope every 10 m. In this way, transects were established in plot zones that were potentially distinct in terms of terrain shape, soil depth, and heating from the fire. Distributions of live and dead trees presented in Fig. 3 and Table 3 reflect both (nonoverlapping) sets of trees. All other results reported in this paper are based on the 90 trees tagged for intensive monitoring.

A stepwise discriminant analysis was performed on the damage indicators, plus tree height DBH, to find which damage indicators had the greatest potential for predicting mortality. We then performed a straight discriminant analysis, using a generalized squared distance function (SAS Institute Inc. 1985), on these indicators together and in various lesser combinations. Because few trees had died by 6 years after the burn, we could not carry out a complete discriminant analysis. We could not split the sample, perform a calibration analysis on one portion, and test the resulting model on the other. So the results of the analysis only suggest possible damage indicators that might be useful.

Results

No mortality occurred in any of the control plots and only one tree died in the thinned plots. Therefore, in this report we discuss only the burned plots.

TABLE 1. Fuel moistures for ground fuel layers

Fuel layer	Mean (%)	SD
Duff[a]	11.96	2.39
Lower litter	14.08	13.46
Middle litter	16.40	13.84
Top litter	9.25	0.92
Leaf	7.90	1.37
Twig	9.26	1.04

[a]Separate composite of all three litter layers.

TABLE 2. Summary statistics (mean and standard deviation) for damage predictors, arranged by live or dead condition of trees after 6 years

	Live		Dead	
Predictor	Mean	SD	Mean	SD
BDBH (mm)	18.6	6.3	14.0	4.9
TREEHT[a] (m)	10.3	3.6	7.6	2.8
BMAXCIRC (mm)	7.3	5.5	6.8	3.2
BMAXSCOR (mm)	6.7	5.4	4.6	3.8
MAXHT (m)	0.7	0.9	1.6	1.2
MAXDMG (m)	0.6	2.8	1.5	4.6
BASSCOR (%)	51.7	40.9	90.0	28.3
TOTAREA (%)	26.0	20.9	54.6	20.5
MAXCIRM (%)	51.5	40.5	86.9	29.3
KNOCK (%)	3.7	12.3	28.1	29.3
CANOPY (%)	29.9	35.8	2.3	8.3

[a]TREEHT, Tree height.

TABLE 3. Proportion of live and dead trees less than, and greater than or equal to, 15 cm (6 in.) DBH in burned plots by block

		2 years		6 years	
Block	DBH	Live	Dead	Live	Dead
Block 1	<15 cm (6 in.)	0.625	0.375	0.632	0.368
	≥15 cm (6 in.)	0.878	0.122	0.857	0.143
	Total	0.742	0.258	0.740	0.260
	n	89		73	
Block 2	<15 cm (6 in.)	0.500	0.500	0.465	0.535
	≥15 cm (6 in.)	1.000	0.000	0.955	0.045
	Total	0.639	0.321	0.713	0.287
	n	81		87	
Block 3	<15 cm (6 in.)	0.714	0.286	0.500	0.500
	≥15 cm (6 in.)	0.952	0.048	0.881	0.119
	Total	0.893	0.107	0.785	0.245
	n	84		79	
Total	<15 cm (6 in.)	0.587	0.413	0.535	0.465
	≥15 cm (6 in.)	0.940	0.060	0.899	0.101
	Total	0.722	0.228	0.745	0.255
	n	254		239	

NOTE: Trees include those tagged for monitoring and those evaluated in the belt transects. Different sample sizes between years 2 and 6 are a result of sampling error while relocating transects.

TABLE 4. Classification summary for discriminant analysis of burn damage indicators

Condition after 6 years	Classified condition		
	Live	Dead	Total
Live	69 (89.6)	8 (10.4)	77
Dead	2 (15.4)	11 (84.6)	13
Total	71 (78.9)	19 (21.1)	90

NOTE: Values are the number of observations with the percentages of the total observations given in parentheses. Included are a cross tabulation of predicted live and dead trees versus actual live and dead trees. The burn damage indicators used were TREEHT, TOTAREA, KNOCK, and MAXCIRCM.

The chevron firing technique drew both heat and flame toward the center of the burn plots, killing the foliage in the upper canopy. Crown injury was at first difficult to detect since perceptible changes in leaf color or leaf fall did not occur immediately after the burn. However, the intense heat convected into the crowns of many trees ultimately was responsible for high foliage losses (100% in most trees). The crowns of most of these trees eventually recovered (Paysen and Narog 1990). With few exceptions (overtopped trees only), ignited bark did not carry fire into tree crowns. Tree canopies were not consumed and no heat damage was observed in the crowns of trees adjacent to the burned plots. Preburn fuel moisture for ground fuels were relatively low (Table 1). After the burn, visual estimates of fuel consumption made at the site indicated 95% reduction of woody material, leaf, and upper litter layer.

Bark thickness varied between trees. The correlation was weak between bark depth at breast height (BH) and measures of tree size. Kendall's τ was 0.29 bark depth at BH versus DBH and 0.28 for bark depth at BH versus tree height. The preliminary damage assessment 6 months after the burn showed that bark damage, in terms of char depth, was generally light in most trees. Medium to heavy char was found on localized portions of some tree boles. A number of trees (see below) had charred bark all the way around the circumference of their boles, though the char had variable depth. Summary statistics are presented in Table 2 for the damage indicators, grouped by tree condition (live or dead) after 6 years.

Two years after the burn, tree mortality appeared primarily in smaller diameter classes (Table 3), which were neither dominant nor codominant. Our data showed little additional mortality between the 2nd and 6th years following the burn (Fig. 3). The few additional trees that died were in the larger DBH size classes. Thirty out of the 90 tagged trees had 100% of their bole circumference charred. After 2 years, only 10 trees (11%) had died; after 6 years, only 3 more (3%) had died.

Approximately half of the trees in this stand were less than 15 cm (6 in.) at DBH, of which approximately half died by the end of the 6th year. In contrast, less than 10% of the trees with DBH ≥15 cm (6 in.) died (Table 3). Smaller trees suffered greater mortality than larger trees (Fig. 3). A weak correlation was observed between DBH and tree height (Kendall's τ = 0.627). The proportion of total dead trees (Table 3) appears to be higher than for the 90 tagged trees. The data in Table 3 includes trees from all the strips in each plot and had a higher proportion of smaller diameter trees (less than 15 cm (6 in.)) than the 90 tagged trees (65% vs. 48%, respectively).

However, the proportion dead within each size class is the same between the two data sets.

Results of the discriminant analysis on the damage indicators are presented in Table 4. One combination of indicators best classified the burn plot trees as live or dead: maximum circumference burned, the knock technique, the total proportion of charred bark area below maximum bole scorch height, and tree height.

Discussion

Tree survival after fire generally depends upon a complex of factors having to do with heat penetration and duration, tree vigor (Thornburgh 1990), and degree of crown and cambium damage (Wagener 1961; Plumb 1980). Tree physical characteristics (bark thickness and outer bark fuel properties), fire behavior characteristics (including flame residence time), and time of year (which determines whether the tree is actively growing or not and perhaps has an effect on cambium temperature) all contribute to tree survival. In our study, it appears that the degree of direct damage from the burn and apparent tree vigor interacted to determine whether or not the tree survived.

Plumb (1980) reported that trees less than 15 cm (6 in.) in diameter were at the highest risk, even when damage is only light char. In our study, we assumed that the 30 tagged trees that sustained extensive bark injury would die and that others would follow. This did not occur. Only 13 of these monitored trees (14%) died from the prescribed burn. Ideal environmental, climatic, and fire behavior conditions, at the time of treatment application, may have decreased the expected mortality. In this study, plots were burned in November when trees were not actively growing. Heat damage occurred on the crowns of most trees and there was evidence of some fire injury to the boles but these factors did not produce a high stand mortality.

Discriminant analysis results should be tentatively entertained. Damage predictors can produce variable results (Table 2). Therefore, they should be used for stand-level evaluations and not for predicting mortality for the individual tree. They do suggest that DBH is less important than height in determining risk. In reality, probably neither determine risk in a stand of this age but are simply indicators of relative vigor. Had there been a stronger correlation between DBH and tree height (for this study, Kendall's $\tau = 0.627$) either would have served as well as the other. However, in a uneven-aged stand, where DBH might be presumed to be correlated with age and bark thickness, DBH might be expected to be an important indicator of fire susceptibility. In our even-aged stand, this was not the case.

Fire damage was minimal when compared with the level of damage often expected from wildfires. Fire injury seemed to be within the tolerance of most of the larger trees in the stand. Residual logging slash probably generated more heat than normally produced by a fire propagated by leaf litter and twigs found in untreated stands. Yet, thinning may have reduced the intensity of the chimney effect (upward convention) that tree boles tend to produce, thereby minimizing damage to the boles of the trees.

The generally north-facing stand may have buffered the effects of the drought that occurred in southern California. Higher mortality was expected because the drought conditions began about the same time as our treatments (1984 and 1985, respectively). After the preliminary 6 month postburn damage assessment, we decided that, if canyon live oak was as sensitive to fire as reported, we could assume that the extent of charred bole circumference would be a good indicator of ultimate tree mortality. Perhaps the single "good" precipitation year (1986) that followed the stand treatments occurred at a critical period and was sufficient to carry the stand through a prescribed burn. Or perhaps the decrease in competition because of the reduced demand from thinned trees was sufficient for the remaining trees to withstand the impacts of both fire and drought.

Conclusions

Our results show that prescribed burning can be used in canyon live oak forests with minimal tree mortality. Therefore, a shaded fuelbreak in canyon live oak can be improved by reducing dead fuel loading with prescribed burning and thus probably reduce fire hazard at the wildland urban interface.

Damage indicators can undoubtedly reflect cambial damage directly, though the particular indicators used here require rigorous testing. They imply favorable effects of tree vigor in withstanding damage. Trees less than 15 cm (6 in.) DBH seem to be at higher risk of fire injury than those of larger diameter. However, with prescribed fire, the risk may be less than reported by Plumb (1980) for wildfire response. Reducing stand density through thinning may have been helpful in reducing tree mortality in this canyon live oak forest. Yet, higher mortality in smaller diameter trees suggests that fire may also be useful for thinning crowded canyon live oak stands without increasing wildfire hazard with logging slash.

Further research should be done to determine if prescribed burning alone can create a shaded fuelbreak (thus reducing fire hazard), or improve stand quality (through selective thinning of crowded stands), and whether wildlife habitat is enhanced (with regard to forage quality and increased habitat diversity).

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