

Effects of Fire on Naturally Occurring Blue Oak (*Quercus douglasii*) Saplings¹

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Abstract

We studied the survival and regrowth of naturally-occurring blue oak saplings burned in a September 1996 arson fire in Vacaville, California. The saplings (pre-fire height 33-353 cm) were burned in a rapid, low-moderate intensity fire. Of 67 blue oak saplings surveyed, 4 failed to resprout after the fire and 2 more died within the following 5 years (9 percent mortality overall); all mortality was among saplings less than 100 cm tall. Saplings which were completely topkilled (51/67) were significantly smaller on average than those which were only partially topkilled (12/67). Saplings taller than 201 cm or with a stem diameter greater than 5.6 cm at 30 cm height were only partially topkilled. Only 20 percent of the completely topkilled saplings had regained both their post-fire height and diameter by 5 years after the fire. Height growth of new shoots from completely topkilled saplings was highest in the first year after the fire, but declined in succeeding years. High levels of vole damage in resprouted topkilled saplings has adversely affected growth and shoot survival. Our observations indicate that fire negatively impacts small blue oak saplings and does not favor blue oak regeneration, as has been suggested by other authors.

Introduction

Fire plays an important role in the maintenance of numerous plant communities in California but little is known about the role of fire in the sustainable management of California oak woodlands. Several lines of evidence have suggested that fire is necessary to prevent areas with black oak (*Q. kelloggii*) and Oregon oak (*Q. garryana*) from being invaded by conifers (Fritzke 1997, Hastings and others 1997). Change in fire frequency has been suggested as a reason for the failure of oak regeneration in many areas (Pavlik and others 1991), but there is no direct evidence indicating that fire actually aids regeneration of blue oak (*Quercus douglasii*).

In a previous study on blue oak sapling recruitment in 15 locations, we found that sapling recruitment was not dependent upon fire and that repeated fires reduced sapling populations (Swiecki and others 1997). Similarly, Roy and Vankat (1999) found no blue oak regeneration when they resurveyed plots in Sequoia National Park, some of which had burned. Mortality of mature trees was greater in burned plots, but the paper does not report whether the differences were statistically significant. Employing dendrochronological methods to age trees and fires, Mensing (1992) and McClaren and Bartolome (1989) showed an association between blue oak stem age

¹ An abbreviated version of this paper was presented at the Fifth Symposium on Oak Woodlands: Oaks in California's Changing Landscape, October 22-25, 2001, San Diego, California.

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and fire occurrence. Some authors (McClaren and Bartolome 1989, Mensing 1990, Pavlik and others 1991) have suggested that this association supports the hypothesis that fire promotes blue oak regeneration, perhaps by accelerating growth rates of post-fire shoots and suppressing competitive weedy vegetation.

An alternative explanation of the historical association between fire and blue oak regeneration is that fire destroys the tops of young, pre-existing blue oaks which resprout after the fire. Under this hypothesis, cohorts of new sprout-origin trees would all date to the time of the fire occurrence. Because this recruitment is the direct result of fire-induced topkill of existing oaks, fire does not cause a net increase in the oak population and thus has no positive effect on regeneration.

In this study, we observed the fate and regrowth of naturally-occurring blue oak saplings burned during an arson fire in Vacaville, California. The objectives of this study were to document the sensitivity of small blue oak saplings to topkill by fire and to determine the length of time required for new shoot growth to replace shoots destroyed by fire. Partial results of this study have been reported (Swiecki and Bernhardt 1999).

Methods

The study site is on City of Vacaville open space lands located south of Interstate 80 on the northeast end of Lagoon Valley. The hillside supports a mixed oak woodland dominated by blue oak, valley oak (*Q. lobata*), interior live oak (*Q. wislizeni*), and California buckeye (*Aesculus californica*). The woodland, some of which was previously cultivated as orchards, contains a number of large old clearings. Vegetation in the clearings consists mostly of nonnative annual grasses and weedy forbs, but we had observed relatively high numbers of small blue oak seedlings and saplings along the edges of clearings. The complete grazing history of the study site is not known. The area was not grazed during the study and has not been grazed at least for 10 years prior to the study.

In late September 1996, an arson fire burned much of the open grassland areas and partway into the understory of the adjacent oak woodland. Fire fuels in the openings where the blue oak saplings were located consisted primarily of dry annual grasses and forbs, which were completely consumed in the rapid, low-moderate intensity fire. No mature trees were killed by the fire although a few mature interior live oak trees (*Q. wislizeni*) in the burned area developed moderate to severe trunk scarring after the fire.

Due to characteristics of the fire, the small blue oak saplings at the site were heat-killed but not consumed by fire. We were therefore able to locate and measure the height and diameter of the heat-killed stems, which were still standing and intact at the time of our initial survey (June 2-5, 1997). At that time, we located and tagged 67 blue oaks saplings located in several groupings in the burned area. We recorded the post-fire status of each sapling (partially topkilled, completely topkilled with live basal sprouts, or dead).

For completely topkilled saplings, we measured the height of the tallest heat-killed stem, as well as the diameter at ground level and at 30 cm (D30) of the largest stem. Due to dehydration of killed stems prior to initial measurements in June 1997, these pre-fire stem diameters are likely to be somewhat smaller than actual pre-fire diameters of live stems. We also counted the number of heat killed and live shoots

and the height of the tallest live shoot. Because these sprouts were very thin (generally 0.5 cm or less) we did not attempt to measure their diameters in the first post-fire survey.

For partially topkilled saplings we recorded the height of the tallest branch prior to the fire. This was the greater of the tallest dead shoot or the height to the previous season's live shoot tip (based on the location of terminal bud scars). We measured the height of the tallest currently live stem, and stem diameters at ground level, 30 cm, and 137 cm diameter at breast height (DBH) if applicable. We also visually estimated the percent of the canopy which had been heat-killed.

Tagged saplings were relocated and reevaluated annually through July 2001. Annual measurements were made in midsummer or later, after the current season's shoot was largely complete. Because basal diameter and D30 measurements were highly correlated and D30 measurements were much easier to make, we only measured D30 and DBH for the largest stem of each saplings after 1997. Only D30 stem diameters are reported in this paper. We also measured the height of the tallest shoot, the number of stems, and rated the presence and severity of meadow vole (*Microtus californicus*) damage in the annual evaluations. Data for one to two saplings are missing in certain years because they were not located during the survey.

We used JMP statistical software (SAS Inc., Cary NC)³ for data analysis. Unless otherwise indicated, effects or differences are referred to as significant if $P \leq 0.05$. We used logistic regression models to examine the effects of plant factors on the binary outcome total or partial topkill. We used paired t tests to compare heights of saplings made in different years. Because delayed topkill and mortality occurring during the study caused annual changes in the number of trees in each status category, the sapling counts are presented along with percentages if based on a total other than all 67 tagged saplings.

Results

Effects of Fire on Plant and Shoot Survival

Of the 67 saplings included in the study, 12 (18 percent) were only partially topkilled as of June 1997. In June 1997, levels of crown damage in partially topkilled saplings ranged from less than 2.5 percent to over 80 percent crown dieback. Two saplings that showed only partial topkill in June 1997 died back to root sprouts between June 1997 and October 1999; both of these saplings had more than 50 percent crown dieback in June 1997. These saplings are included in totals for completely topkilled saplings in the data for 1999 onward.

The fire caused complete topkill of aboveground shoots in 55 (82 percent) of the saplings. Four topkilled oaks (6 percent) failed to resprout and were dead as of June 1997. In addition, 2 oaks that had resprouted from topkilled saplings died between the 1999 and 2001 evaluations. Hence, by 5 growing seasons after the fire, overall mortality was 9 percent (6/67) and 84 percent (51/61) of the surviving oaks were represented by resprouts whose shoots originated after the fire.

Pre-fire heights of saplings from the burned area ranged from 33 to 353 cm. Of the saplings that were shorter than 150 cm, 98 percent (51/52) were completely

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topkilled; this includes all 4 of the topkilled saplings that failed to resprout. In contrast, only 27 percent (4/15) of the saplings that were at least 150 cm tall were topkilled and no sapling taller than 201 cm was completely topkilled. Although we do not have the exact pre-fire stem diameter of the saplings, stem diameters measured in June 1997 show a similar threshold effect for sensitivity to topkill. Only 4 percent (2/55) of completely topkilled stems measured in 1997 were thicker than 4 cm D30. No sapling greater than 5.6 cm D30 in 1997 was completely topkilled, but some saplings with stems as small as 1.7 cm D30 were only partially topkilled. Both sapling height and stem diameter were highly significant ($P < 0.0001$) predictors of complete topkill in univariate logistic regression models.

Post-fire Regrowth

Prior to the fire, most saplings (52 percent) had only a single stem at ground level. Among the saplings that were completely topkilled by the fire and resprouted, 57 percent (29/50; data for 1 sapling missing) had a single stem and only one (2 percent) had five stems. In the second year after the fire (1998), only 10 percent (5/50) of the completely topkilled saplings had a single stem and 86 percent (43/50) had 5 or more stems. Due to damage by voles and other factors, the number of stems among the completely topkilled plants has declined over time. By July 2001, only 61 percent (30/49) of the surviving completely topkilled oaks had 5 or more stems. The situation for the partially topkilled saplings was somewhat different. By 1998, fire had reduced the stem number of three of the partially topkilled saplings by destroying small suppressed stems and basal sprouts. The remaining trees either showed no change in stem count (5/12) or an increase in stem count due to damage-induced stimulation of new basal sprouts. Because most of the new or lost stems in the partially topkilled saplings were much smaller than the main stem, the overall form of these saplings was not affected substantially by the fire.

New shoots produced by completely topkilled saplings grew most rapidly in the first season after the fire (*fig. 1*). Height growth slowed considerably after this initial growth spurt. This is due in part to the fact that most resprouted saplings were multistemmed and in part due to the loss of dominant stems after 1998 as the result of vole damage. By five years after the fire (2001), 27 percent (14/51) of the surviving topkilled saplings had regained their pre-fire heights. However, surviving completely topkilled saplings were still significantly shorter overall in 2001 than they were pre-fire (paired t test $P < 0.0001$).

Average stem diameters of completely topkilled saplings decreased significantly after the fire because new shoots were much narrower than the original heat-killed stems (*fig. 2*). Five years after the fire, stem diameters of the resprouting shoots were still significantly less than those of the pre-fire saplings (paired t test $P < 0.0001$). Only 25 percent (13/51) of the surviving topkilled saplings have diameters equal to or greater than those measured in June 1997.

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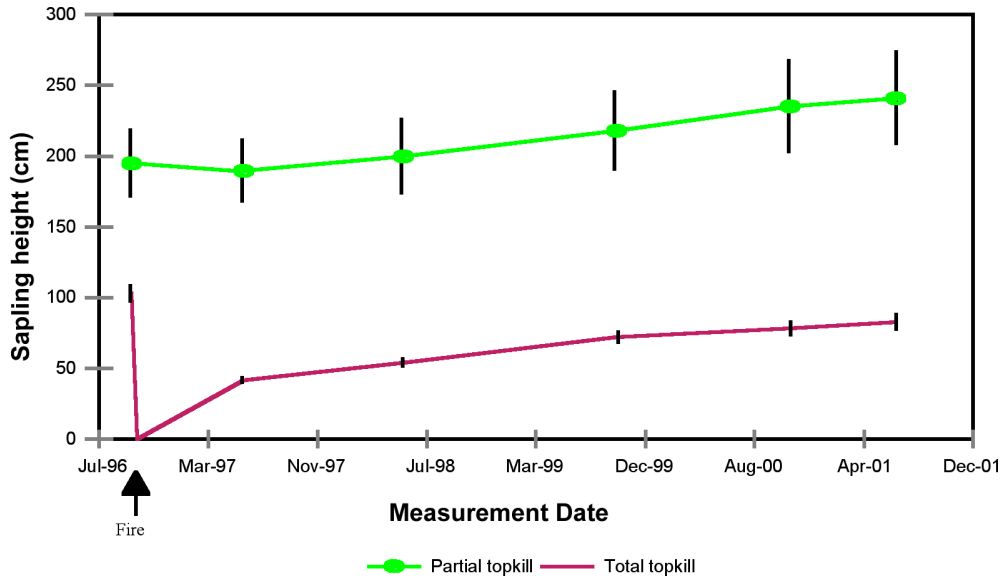


Figure 1 Average heights over time of saplings initially partially or completely topkilled by fire. Graph excludes heights of two saplings initially rated as partially topkilled that later died back to root sprouts. Vertical bars at each data point represent standard error, note that error bars for total topkill data points are mostly smaller than the rectangular markers.

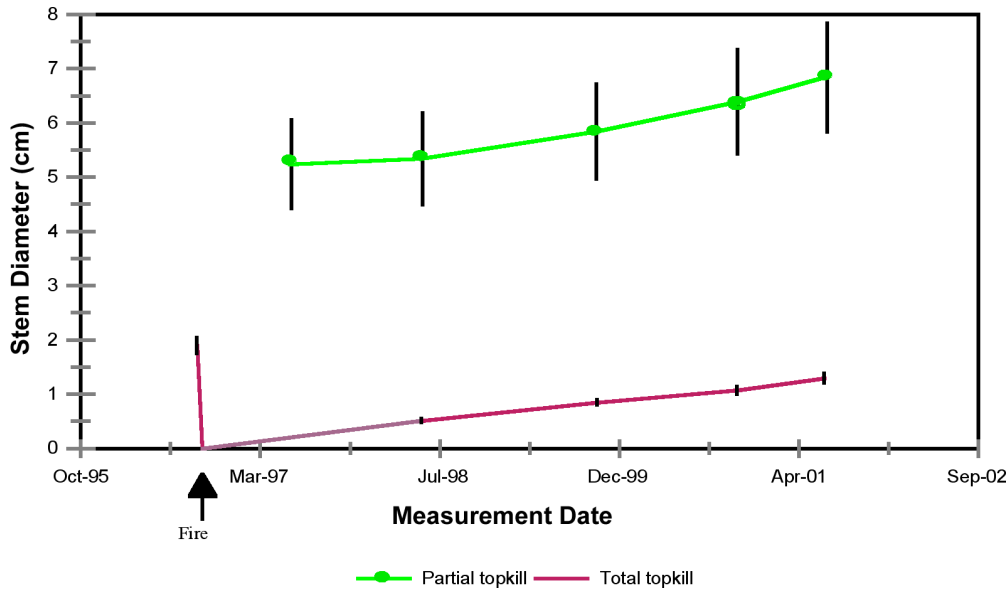


Figure 2 Average stem diameters at 30 cm of saplings initially partially or completely topkilled by fire. Graph excludes diameters of two saplings initially rated as partially topkilled that later died back to root sprouts. Vertical bars at each data point represent standard error, note that error bars for total topkill data points are mostly smaller than the rectangular markers.

If pre-fire height and stem diameter in June 1997 are used jointly to determine that a sapling has gained parity with its pre-fire condition, only 20 percent (10/51) of the completely topkilled saplings had reached parity within 5 years after the fire (*fig. 3*). June 1997 stem diameters of the saplings that achieved parity within 5 years were all less than 3 cm. Only one sapling that achieved pre-fire parity within 5 years was taller than 100 cm (*fig. 3*).

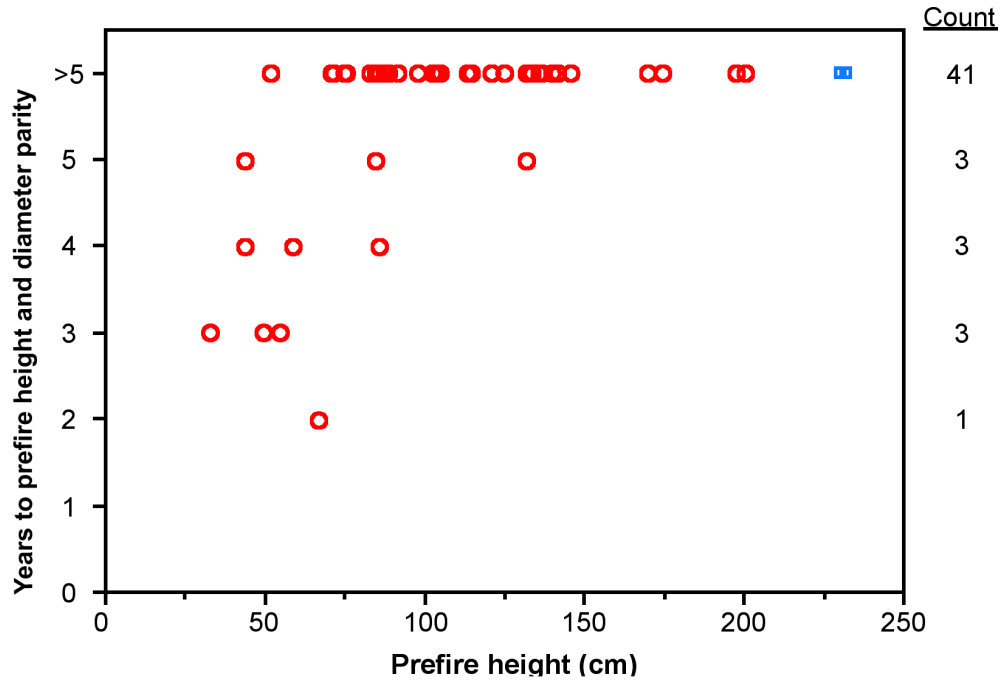


Figure 3 Years required for completely topkilled saplings to regain both pre-fire height and diameter at 30 cm as a function of pre-fire height. Square symbols represent two saplings originally classified as partially topkilled that died back to the ground after June 1997.

With the exception of two saplings which eventually died back to root sprouts, saplings with only partial topkill recovered within about 2 years from the effects of the fire (*figs. 1 and 2*). Annual rates of diameter and height growth were comparable to those of two unburned saplings from the same area (data not shown). Partially topkilled saplings showed significant increases in both height and stem diameter between 1997 and 2001 (paired t tests, $P=0.0052$ and $P<0.0001$, respectively). These analyses do not include the two partially topkilled saplings that later died back to the root crown.

In the October 1999 survey, we observed substantial amounts of vole damage on both study saplings and other woody vegetation in the study area. Due to their smaller stem diameters, the completely topkilled saplings experienced both higher rates of damage and greater damage severity than the partially topkilled saplings (*table 1*). Besides contributing to the reduction in shoots per plant as noted above, vole damage sometimes eliminated the tallest shoot, resulting in losses in height (*table 1*). Vole damage apparently contributed to the demise of the two topkilled saplings that died after 1999. Although deer are present in the area, damage due to deer browsing was not appreciable over the course of the study.

Table 1—Current-season vole damage and losses in stem height observed in the 1999 through 2001 evaluations.

Variable	Sapling class	Evaluation date		
		Oct 1999	Nov 2000	July 2001
Saplings with current season vole damage	Partially topkilled	20 pct (2/10)	40 pct (4/10)	10 pct (1/10)
	Completely topkilled	68 pct (36/53)	83 pct (43/52)	39 pct (20/51)
Saplings with height reductions relative to the previous year	Partially topkilled	10 pct (1/10)	0 pct (0/10)	10 pct (1/10)
	Completely topkilled	13 pct (7/53)	23 pct (12/52)	22 pct (11/51)

Discussion

Our observations at this site provide no support for the hypothesis (McClaran and Bartolome 1989, Mensing 1990, Pavlik and others 1991) that fire promotes blue oak regeneration. Rather, it is apparent that even in a fairly mesic site, fire damage retards the advancement of small saplings to the overstory. Although resprouting topkilled saplings may show high rates of height growth immediately after a fire (*fig. 1*), fast growth rates are not sustained over time. Many years are required for topkilled saplings to simply regain the aboveground biomass that they possessed before being burned (*fig. 3*). During this period of regrowth, saplings remain highly vulnerable to damaging agents including voles, browsing vertebrates, and additional fires. Furthermore, the regrowth of preexisting saplings cannot be interpreted as net regeneration. When mortality due to fire and other post-fire factors are considered, it is clear that fire negatively affects tree recruitment from small saplings.

Similar conclusions were drawn by Allen-Diaz and others (1990) who reported on a small study involving blue oak saplings between 50 and 70 cm tall. In that 3-year study, which included only 24 burned and 24 nonburned saplings, the authors concluded that fire set back the growth of small shrubby blue oaks and did not stimulate regeneration or regrowth. Associations between estimated fire history and blue oak regeneration drawn from dendrochronological studies (McClaren and Bartolome 1989, Mensing 1992) result because fire temporally concentrates shoot ages of sprouts through topkill. Although other studies that report on direct effects of fire on blue oak have involved either larger (Haggerty 1994, Roy and Vankat 1999) or smaller (Allen-Diaz and Bartolome 1992, Schwan and others 1997) oaks than those in our study, none of these studies provide evidence that fire favors blue oak regeneration.

The threshold for initial complete topkill in this study was about 1.5 m to 2 m height or about 4 cm to 5.5 cm diameter at 30 cm. Data from more fires of varying intensities would be needed to determine whether sapling height or diameter is a better predictor of complete topkill across a range of fire characteristics. Knowledge of the size threshold for sapling topkill has important implications for the use of fire in blue oak woodland management. Land managers might avoid the use of fire or otherwise protect saplings below the threshold size if recruitment of such saplings to the tree stage is a management goal. Furthermore, when combined with site-specific growth data, the threshold size could be used to determine the minimum fire interval needed to permit trees to be recruited from sprouts of topkilled saplings. After 5

years, none of the completely topkilled saplings at this site have grown large enough to survive another fire equivalent to the 1996 burn. Even at this relatively favorable site, it seems likely that many saplings will not grow beyond the topkill threshold for at least another decade. At a site where height growth is limited by livestock or deer browsing, repeated fires may serve to eliminate regeneration (Swiecki and others 1997).

The number of unburned saplings in the study area was insufficient to allow for the monitoring of a control population, but our observations of unburned saplings in and near the study area suggest that these were at no disadvantage relative to their topkilled counterparts. Many small, nonburned saplings, and even some small trees were damaged in the vole outbreak years. However, these saplings have had to contend with only a single round of shoot loss or damage over the past 5 years, compared with the two shoot loss events experienced by topkilled saplings that were later attacked by voles. Repeated shoot loss increases the mortality rate of small blue oak seedlings (Swiecki and others 1991). Although blue oak saplings have adaptations that allow them to withstand occasional shoot loss, repeated shoot damage or loss caused by fire or other agents suppresses sapling growth and results in increased sapling mortality.

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