

# *Quercus kelloggii* (Newb.) Sprout Response to Fire Severity in Northern California<sup>1</sup>

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## Abstract

We counted seedlings and assessed crown characteristics and abundance of fire-induced stump sprout regeneration in California black oak (*Quercus kelloggii*) 11 to 12 years after wildfire. Regeneration was examined across three levels of burn severity (low, moderate, and high) according to the Composite Burn Index. Fire severity affected crown width of oak sprout clumps; clumps of a given width were taller in areas of high severity fire. Multi-stemmed, sprouting black oak genets were more common than black oak seedlings. The data illustrate a positive sprout clump density association with increasing fire severity. Black oak densities were 3.6, 21.7, and 66.0 genets ac<sup>-1</sup> in low, moderate, and high burn severity stands, respectively. Additionally, stand level crown area of the sprouted oak trees was strongly influenced by summed live and fire-killed mature black oak basal area ( $R^2 = 0.83$ ) and density ( $R^2 = 0.73$ ).

*Key words:* 2000 Storrie Fire, California black oak, CBI, Sierra Nevada Forest Plan Amendment

## Introduction

Foresters and ecologists are increasingly appreciating the importance of the California black oak (*Quercus kelloggii*) component in montane ecosystems. Black oak provides significant cover, habitat, and forage that many high-profile avian and mammalian species and their prey require (Innes and others 2007, Zielinski and others 2004). In addition, mature black oak stems can have valuable timber; though historically underutilized, it has potential for developing as a commercial product (McDonald and Huber 1994). Furthermore, black oak promotes and thrives on frequent fire (Cocking and others 2012, Engber and Varner 2012, Odion and others 2010). High frequency fire regimes are characteristic of many black oak ecosystems, promoting black oak by preventing dominance of pervasive shade-tolerant conifer species. In California woodland and montane ecosystems, species such as white fir (*Abies concolor* var. *lowiana*) and Douglas-fir (*Pseudotsuga menziesii*) commonly encroach upon oak individuals and stands, and the threat of ecosystem type conversion increases given long, fire-free periods (Cocking and others 2012, Cocking and others 2014).

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<sup>1</sup> An abbreviated version of this paper was presented at the Seventh California Oak Symposium: Managing Oak Woodlands in a Dynamic World, November 3-6, 2014, Visalia, California.

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It is no surprise, therefore, that public land management policy has been evolving to facilitate black oak individual and community development. The Sierra Nevada Forest Plan Amendment (SNFPA; USDA 2004) mandates that hardwoods be included in stand examinations. The SNFPA additionally requires that managers clear openings around existing black oak to “stimulate natural regeneration” and even “promote hardwoods after stand-replacing [fire] events” (USDA 2004, “Hardwood Management,” p. 53). In response to fire, black oak’s disturbance-activated sprouting mechanism elicits rapid vegetative recovery (McDonald 1990), a competitive growth characteristic in fire-prone environments. Long term assessment of post-fire black oak sprout response on the landscape in a no-action scenario may serve as a platform from which to base future post-fire recovery.

We hypothesized that black oak sprouts vary in size and distribution because fire stimulates severity-dependent responses. We studied black oak sprout regeneration over a 2-year period, 11 to 12 years after the mixed-severity Storrie Fire that burned 21,044 ha (52,000 ac) in 2000. Our objectives were to (1) examine the effect of burn severity on black oak sprouting characteristics; and (2) assess black oak clump (genet) distribution across the burned landscape. We also compared abundance of black oak seedlings versus sprout regeneration. This note provides a snapshot of natural post-fire vegetation response and highlights the rapid recovery rate of an important oak species in California. Our findings provide useful insight for future post-fire recovery decision-making in montane ecosystems with a black oak presence.

## Methods

Study sites were located in the 9371 ha (23,156 ac) Lassen National Forest (LNF) portion of the 2000 Storrie Fire, in the southern Cascades of northern California. The climate is a montane Mediterranean with a mean annual precipitation of 189.5 cm (74.6 inches), most of which falls as snow during the winter months. Site elevations were between 899 and 1798 m (2,950 and 5,900 ft). Typical forest cover types are Sierra Nevada Mixed Conifer and White fir (Eyre 1980). *Quercus kelloggii* was often found in stands co-dominated by *Abies concolor*, *Calocedrus decurrens*, *Pinus lambertiana*, *P. ponderosa*, and *Pseudotsuga menziesii*. The most commonly associated shrubs were *Arctostaphylos nevadensis*, *A. patula*, *Ceanothus cordulatus*, *C. integerrimus*, *C. velutinus*, *Chrysolepis sempervirens*, and *Q. vaccinifolia*.

We stratified the landscape into three fire severity classes (low, moderate, and high) by the Composite Burn Index (CBI; Key and Benson 2006), a burn severity metric derived from the one year post-fire Relative differenced Normalized Burn Ratio (RdNBR; Miller and others 2008). Since the RdNBR is most influenced by the effects of severity on the overstory, it follows that burn severity had an inverse relationship with residual live overstory density (of all species). Over the years 2011 and 2012, a cluster of evenly-spaced 40.47 m<sup>2</sup> (0.01 ac) circular plots was randomly located in each of 25 stands randomly selected from the Storrie Fire (Crotteau and others 2013). Overlaid point samples were used to determine fire-killed overstory characteristics on a

subset of the 482 plots. Black oak seedlings and root-collar sprouts were measured within each plot. Root-collar sprouts were determined by the presence of a fire-killed mature stem. Black oak seedlings (>15.24 cm (6 inches) tall) were tallied and total height was recorded. Four characteristics were recorded for oak sprouts located within plots: (1) total count of stems (ramets) emerging from the base of the clump root collar; (2) crown width of the entire clump (an average of two measurements made at right angles); and, for the tallest (dominant) stem, (3) total height, and (4) diameter at 1.37 m (4.5 ft) above ground (DBH).

To meet our first objective, we examined relationships between fire severity and characteristics of individual stems and sprout clumps. Measured covariates were transformed for normality using the square root function. We used ANOVA to determine if burn severity had an effect on black oak attributes. Since we measured a cluster of plots within each stand, we regarded the stand as a random effect. We examined pooled sprout clump crown allometry by regressing dominant stem height on crown width. To address our second objective, we assessed stand level black oak abundance and cover on the burned landscape. We used a stand-level ANOVA model to test the effect of burn severity on abundance data. Crown area was calculated and summed by stand to determine oak canopy cover on a per acre basis, as an indicator of the extent of black oak recovery on the post-fire landscape. We used linear regression to model the relationship between stand-level crown area and fire-killed overstory characteristics.

## **Results**

We found 119 black oak clumps across all of the study's plots. We then examined the density of sprouts per clump and the dimensions each clump. The number of stems per black oak clump sampled did not differ by burn severity at 11-12 years since fire (ANOVA,  $df = 2/112$ ,  $p = 0.466$ ). The average clump was comprised of 18 stems (table 1), with a range of 1 to 25. Dominant stems in the high-severity burn plots were 215 percent of the dbh of stems in low-severity burns (ANOVA;  $df = 2/112$ ,  $p < 0.001$ ).

Sprout clumps were generally taller in high-severity burns (ANOVA,  $df = 2/112$ ,  $p < 0.001$ ) (table 1). Sprout clump heights in stands that experienced high-severity fire were 169 percent and 217 percent of the height of the average sprout clump in stands that experienced moderate and low severity fire, respectively. Similarly, clump crown widths varied according to fire severity (ANOVA,  $df = 2/112$ ,  $p = 0.016$ ). Black oak sprout clump crown widths after high severity fire were 118 percent and 141 percent of the average sprout clump crown width in stands experiencing moderate and low severity fire, respectively. Fire severity affected sprout clump allometry in terms of height relative to width of the entire crown formed by the clump. Following high severity fire, sprout clumps of any given height had significantly narrower crowns than sprout clumps arising after moderate and low severity fire which were generally shorter in stature and had relatively lower height:width ratio.

**Table 1—Counts of California black oak overstory and sprouting genet (stump sprout clump) displaying mean characteristics 11 to 12 years after the 2000 Storrie Fire (values in parentheses are 1 S.E.)**

Burn severity	Stand-level densities (black oak only)			Sprouting genet characteristics			
	# Live mature stems	# Dead mature stems	# Sprouting genets	# Ramets	Crown width	Crown height	Dominant dbh
	Per acre			Per genet	feet	feet	inches
Low	1.01 (0.71)	3.16 (2.24)	3.63 (3.14)	17.04 (2.96)	7.62 (1.44)	6.98 (2.01)	0.96 (0.44)
Moderate	5.70 (5.70)	9.73 (5.03)	21.67 (12.45)	17.71 (3.23)	9.15 (1.49)	8.95 (2.15)	1.38 (0.42)
High	0.00 (0.00)	45.46 (21.49)	66.02 (31.37)	19.41 (3.09)	10.75 (1.39)	15.14 (2.02)	2.07 (0.39)

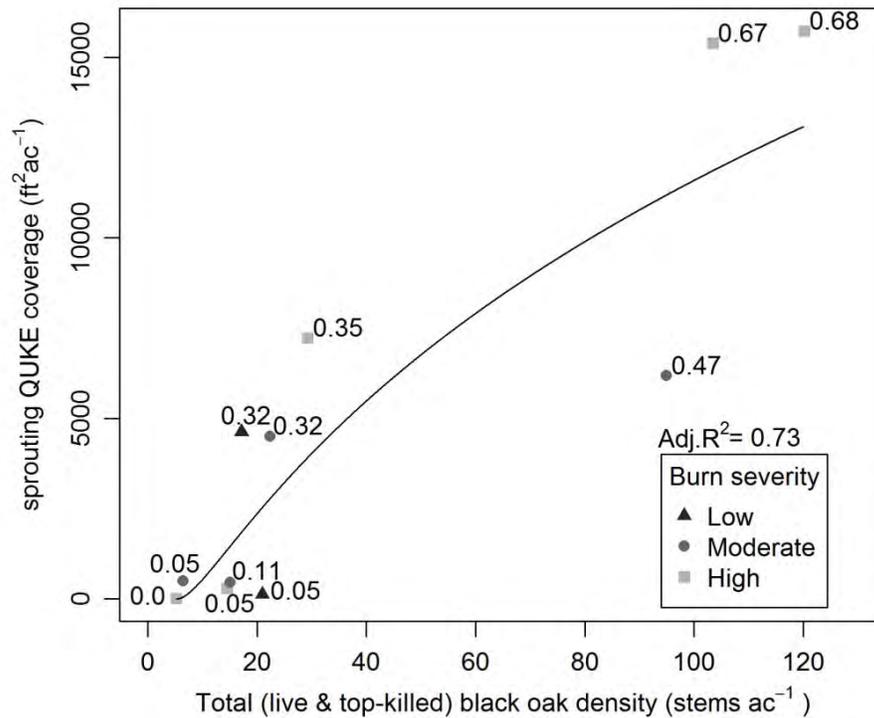
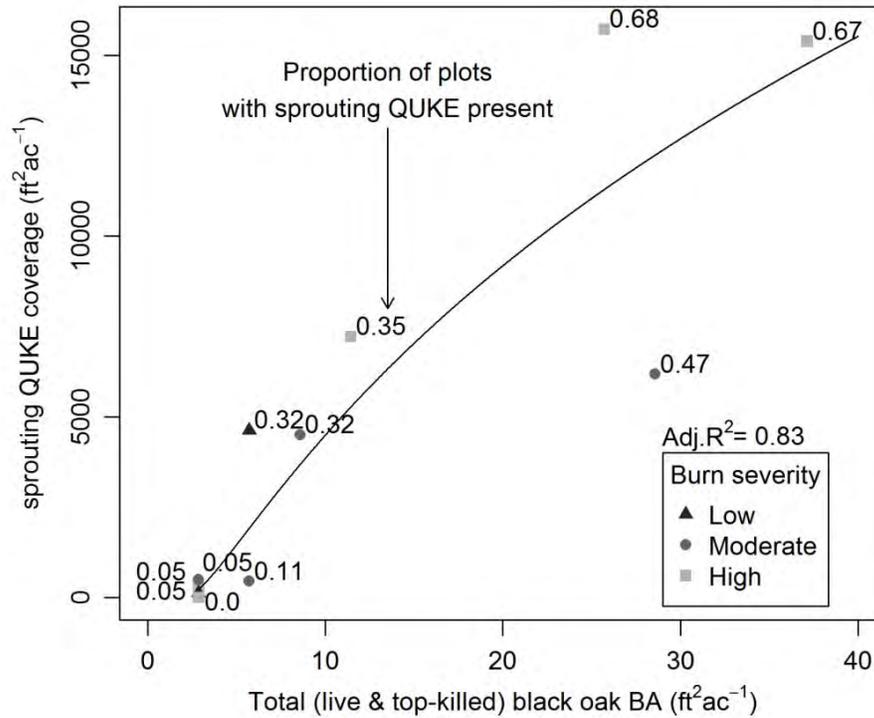


Figure 1—Summed crown area of sprouting *Quercus kelloggii* (QUKE) within stands response to the *Q. kelloggii* component of the live plus fire-killed overstory [A] basal area (BA) and [B] density, 11 to 12 years after the 2000 Storrie Fire.

Black oak seedling and sprout frequency varied across the Storrie Fire landscape. Black oak seedlings were found on 3, 7, and 6 percent of plots in the low-, moderate-, and high-severity burns; in contrast, we observed sprouting clumps on 4, 11, and 29 percent of plots (see labeled data points in fig. 1 for stand-level sprout presence on plots). Across burn severities, we found 8.87 (S.E.: 1.60) seedlings  $\text{ac}^{-1}$ . Stand-level sprouting clump densities varied by burn severity (ANOVA,  $df = 2/22$ ,  $p = 0.045$ ). Mean sprouting clump densities among stands were 3.6, 21.7, and 66.0 clumps  $\text{ac}^{-1}$  with regard to increasing burn-severity classes, which corresponded well to the density of top-killed black oak stems (table 1). Both presence and density of sprouting black oaks in high-severity burns appeared to be approximately three times greater than moderate-severity burns and an average of 13 times the low-severity sites.

Regenerating black oak cover was analyzed in stands with evidence of a pre-fire black oak component in the overstory ( $n = 11$ ). Mean summed crown area of resprouting black oak was 4,999  $\text{ft}^2 \text{ac}^{-1}$  (SE: 1,762), or equivalently, 11.5 percent of the ground area. Summed crown area of regenerating oak had a strong positive association with both the stands' summed live plus top-killed black oak overstory basal area and density (Adj.  $R^2 = 0.83$  and  $0.73$ , respectively; table 2; fig. 2). Too few stands (with black oak overstory trees present before the fire) were available to test for relationships between fire severity and pre-fire BA and density of black oak in the overstory. However, the greatest black oak crown areal cover was observed as a result of high-severity burns having high live and top-killed basal areas and densities (fig. 1 and 2).

**Table 2—Linear model coefficients of black oak canopy areal cover 11-12 years after the 2000 Storrie Fire**

Model	Response	Intercept (SE)	Covariates (in log-space)		P value	Adj. $R^2$
			Live + top-killed basal area (SE)	Live + top-killed stem density (SE)		
1	$\sqrt{\text{oak cover (ft}^2 \text{ac}^{-1})}$	-28.549 (13.033)	41.521 (5.782)	-	<0.0001	0.83
2	$\sqrt{\text{oak cover (ft}^2 \text{ac}^{-1})}$	-61.373 (23.281)	-	36.713 (6.925)	0.0005	0.73



Figure 3—A mixed-conifer and black oak stand a decade into recovery from the 2000 Storrie Fire. This is an example of a high-severity burn, according to the Composite Burn Index. Post-fire vegetation is clearly dominated by abundant, large-crowned black oak sprouts and a dense suite of *Ceanothus* sp. and associates. (Photo credit: Jianwei Zhang, USDA Forest Service Pacific Southwest Research Station, Redding)

## Discussion

We found no effect of fire severity on stem density within clumps, suggesting that severity did not influence sprouted stem retention in black oak 11 to 12 years after the Storrie Fire. We did, however, find a severity-dependent effect on the relationship between height and crown diameter. Overall plant size (height and crown diameter) was positively related to burn severity (as in Cocking and others 2014). Although there was no statistical difference in the height to crown diameter relationship between low- and moderate-severity burns, 95 percent confidence intervals (CIs) on the mean illustrate that the relationship after high-severity burns tends to have a steeper ratio than the lesser severities (greater than 1:1 ratio). It appears that height:crown diameter ratio may decrease from moderate- to low-severity. Our results support observations of sprouting black oak heights and crown diameters in a 1978 silvicultural cutting methods study in the Sierra Nevada (McDonald 1978) that found greater sprout growth in clearcut stands than shelterwood-cut stands. These studies (McDonald 1978, Cocking and others 2014, and the present study) each demonstrate that black oak sprout growth has an inverse relationship with overstory density, which has increased in mixed conifer landscapes due to fire exclusion (Parsons and DeBenedetti 1979).

Black oak establishment 11 to 12 years after fire was more commonly manifested as sprouting clumps than as regeneration directly from acorns. Although sexual reproduction is an integral component of black oak dynamics on this landscape, establishment of seedlings was low (only 3 to 7 percent of plots; mean seedlings per acre = 8.87). Further, seedlings did not vary with fire severity as did regenerative sprouting. The limited presence of post-fire seedlings is at least partially due to the short window of acorn production prior to sampling. Twelve years after top-kill leaves little chance for resprouting individuals to sexually reproduce, despite the observed presence of acorns borne on resprouting clumps (J. Crotteau, personal observation). On the other hand, it is interesting that as much as 6 percent of the plots in high-severity burns had successful acorn regeneration, since typical viable acorn crops are not expected until trees are 30 years of age (McDonald 1990). Our findings suggest further areas for study. For example, can black oak sprouts produce viable acorns at a younger age than acorn-germinated individuals? Does fire severity influence the age of viable acorn production? Further research may elucidate differences in the age-dependency of viable acorn production according to regenerative strategy and burn severity.

Sprouting oak clumps were most frequent in high-severity fire footprints. This observed tendency corroborates that black oak has a synergistic relationship with fire (Cocking and others 2014). Whereas the study area's historic fire regimes may have maintained vegetation community integrity via frequent, low-severity fire, fire exclusion since the beginning of the 20<sup>th</sup> century has enabled shade-tolerant conifers to crowd stands and encroach upon oaks (Cocking and others 2014, Skinner and Taylor 2006). Frequent fire positively influences the black oak community by inducing regenerative sprouting and by reducing densities of fire-sensitive conifers that have the competitive advantage during long, fire-free intervals. Stand-replacing wildfire or intensive mechanical treatment in overcrowded conifer-oak overstory assemblages may enhance the black oak community on this landscape by resetting the contemporary successional trajectory (Cocking and others 2012, Odion and others 2010). Stands burned by high-severity fire are frequently replaced by sprouting woody shrubs (Cocking and others 2014, Crotteau and others 2013) and interspersed with black oak clumps (fig. 3), suggesting that conifer-encroached black oak ecosystems may display latent resiliency similar to frequent-fire ponderosa pine ecosystems in the northern Rockies (Larson and others 2013). Little is known about the transition from the adolescent oak/shrub community phase to the restored mature oak overstory state (Cocking and others 2014), which suggests further research and creative management strategies need to be developed to guide restoration in this common intermediate phase. Maintenance of the black oak component in these landscapes must ultimately take the form of fostering, or perhaps mimicking, frequent low-severity fire to inhibit future shade-tolerant conifer crowding and maintain historical landscape composition and structure.

Characteristics of the black oak component in the fire-killed overstory (basal area and stem density) were important predictors of the 12 year post-

fire sprouting cover response. This study's models affirm a distinct positive trend between mature black oak in stands top-killed by fire and the resultant canopy area re-occupied by the sprout-regenerating clumps. Although an expected phenomenon, these relationships are useful for predicting post-burn vegetation recovery on the landscape. If we assume that the summed live and top-killed black oak overstory basal area (or tree density) approximates pre-fire mature black oak densities, our models are useful for prediction of future post-fire recovery. According to these models, managers with knowledge of the black oak component in stands may expect the square root of oak cover ( $\text{ft}^2$  per ac) to increase by 41.5 for every one unit increase in the natural log of the initial oak overstory basal area ( $\text{ft}^2$  per acre). Similarly, for every one unit increase in the log of initial oak overstory tree density (trees per acre), we predict that the square root of oak cover will increase by 36.7 per acre. Though these predictions ignore burn severity due to lack of sufficient replication, there appears to be a biological effect of high severity fire on the magnitude of sprouting clump areal coverage that must be considered to refine coverage predictions (fig. 1).

Finally, conifer stocking via natural regeneration 10 years after stand-replacing fire in the southern Cascades is often insufficient to meet U.S. Department of Agriculture Forest Service silvicultural goals (Crotteau and others 2014). Planting, therefore, is a typical post-fire management practice in this region. To facilitate black oak (and other hardwoods) given active management, the SNFPA calls for formation of 6.1 m (20 ft) buffers around hardwood crowns, within which planting conifers is to be avoided. This study supports that increased availability of above-ground growing space encourages oak height and crown diameter growth, but enforcing 6.1 m (20 ft) buffers around resprouting oaks may not be appropriate for stands that were previously composed of an admixture of shade-intolerant conifers and black oak. At this level of oak protection, 33 evenly spaced black oaks with 0.3 m (1 ft) crown diameters on an acre practically prohibits any planting of conifers; both the mean and median of black oak clumps  $\text{ac}^{-1}$  observed after the Storrie Fire's high-severity burns are greater than this threshold. Managers should be aware that complete satisfaction of SNFPA guidelines may effectively preclude any conifer planting where oaks are relatively abundant. A density-dependent variable radius buffer or a patchy, systematic application of the crown buffer guidelines may be more appropriate for stands meant to satisfy both oak and shade-intolerant conifer recovery objectives.

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