Influence of Fire on Engelmann Oak Survival – Patterns Following Prescribed Fires and Wildfires[1]

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Abstract

Engelmann oaks (*Quercus engelmannii*) are restricted to extreme southern California and northern Baja, California. Their entire range falls within a landscape increasingly prone to human induced wildfires. The influence of fire on seedlings and saplings has been well studied, but there is less information available on its effects on mature trees. Two monitoring programs tracked *Q. engelmannii* for 13 years in areas experiencing fires and adjacent unburned areas.

At the Santa Rosa Plateau Ecological Reserve, management fires were initiated in 1988. Management units have been subjected to grass-layer fires from one to three times. Damage at the base of the trunk was present in roughly half of the surveyed trees. During the survey period, 4 percent of the trees died in 4 categories; (1) killed directly by fire (46 percent), (2) obtained trunk damage that may have led to mortality 3 to 6 years after fire (15 percent), (3) had no visible fire damage (23 percent), or (4) had fire scars, but died more than 8 years after the most recent fire (15 percent).

An Engelmann oak monitoring program was initiated in 2000 on the Santa Ysabel Open Space Preserve (SY). The 2003 Cedar Fire burned portions of SY and the oak monitoring sites. Sites were surveyed after the fire to assess trees for damage and again in 2008 and 2013. On SY, *Q. engelmannii* grow in three matrix vegetation communities, grassland (with cattle grazing), sage scrub, and chaparral. Fire damage differed among communities. Trees in grasslands received the least amount of damage, those in sage scrub received intermediate damage, and those in chaparral the greatest damage. Survival was inversely related to damage which resulted in large difference in survival among the three communities. In surviving trees, sprouting type appeared dependent on the amount of damage trees received. Basal sprouting was common in highly damaged trees while crown sprouting was most common in trees with low levels of damage.

Engelmann oak trees appear resistant to grass-layer fires which generally result in low levels of damage and mortality rates similar to adjacent unburned areas. Trees are sensitive to higher levels of damage associated with greater fuel loads in sage scrub and chaparral. Although, basal sprouting is uncommon in mature trees following damage, trees able to survive high levels of damage can persist as shrubs for at least a decade. As a result, the structure of the vegetation community is simplified with the loss of the tree canopy.

Key words: Engelmann oak, prescribed fire, *Quercus engelmannii*, wildfire

Introduction

Engelmann oak (*Quercus engelmannii*) is the rarest oak tree species in California, as a result of its very narrow distribution within one of the most urbanized areas of California (Pavlik and others 1991, Scott 1990). Multiple threats, including direct habitat loss and the increased potential for exposure to wildfires, exist to the species as a consequence of its proximity to large human population centers. Wildfires,

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including two of the largest in California since 1932, burned large portions of this species' range in 2003 and 2007 (CalFire 2014). Continued human population growth in southern California will likely increase wildfire ignitions, especially near the wildland-urban interface (Keeley and Fotheringham 2001, Syphard and others 2007). As the climate of southern California is predicted to become hotter (Cayan and others 2008, Loarie and others 2008, Shaw and others 2012), more wildfires could occur if the amount of precipitation remains unchanged or increases (Westerling and Bryant 2008). With multiple factors pointing to the potential for a greater number of wildfires throughout the range of *Q. engelmannii*, it is important to better understand the influence of fire on various life stages.

Quercus engelmannii faces another challenge as a result of altered understory composition. Engelmann oak woodlands and savanna typically contain understory vegetation dominated by non-native annual grasses. These woodlands are often adjacent to grasslands that are also dominated by non-native annual grasses, which include brome grasses (*Bromus* sp.), wild oats (*Avena* sp.), wild barley (*Hordeum* sp.) and rattail fescue (*Festuca myruos*). As a result, management of these areas is generally considered necessary to enhance populations of native grassland and understory species. Management of the non-native grasses at locations with Engelmann oak woodlands and savanna includes prescribed fire and cattle grazing.

In the face of climate change, increased anthropogenic fire ignitions, use of fire as a management tool, and very large recent wildfires, there is a need to increase the understanding of how the role of fire shapes the population structure of this narrowly distributed species. The results of a long-term *Q. engelmannii* monitoring program, from two locations experiencing wildfires and/or prescribed fires over the last 30 years, are examined to better understand the influence of fire on *Q. engelmannii* trees.

Methods

The study was conducted at two locations in southern California. Santa Rosa Plateau Ecological Reserve (SRP) is located at the southern end of the Santa Ana Mountains, in Riverside County, in what is now the northern portion of ecologically intact range of *Q. engelmannii*. Santa Ysabel Open Space Preserve (SY), located in central San Diego County, is in the foothills of the Volcan Mountains in the central portion of its range. The topography of SRP is dominated by mesas and rolling hills with elevations ranging from 380 to 625 m. The SY is split into two non-contiguous units, SY East and SY West, which are separated by approximately 1.5 km. The SY West topography is dominated by the steep Santa Ysabel Creek canyon and the surrounding gently sloping hills with elevation ranging from 870 to 945 m. The SY East topography is dominated by the west-facing slope of the base of the Volcan Mountains with elevation ranging from 915 to 1160 m. The climate at all sites is Mediterranean, with hot, dry summers and cool, wet winters. Approximately 90 percent of the annual precipitation occurs between November and April.

The SRP, SY West and portions of the SY East locations support Engelmann oak savanna and woodland, with a contiguous grass understory and scattered stands of *Q. engelmannii*. The grassland and savanna understory vegetation is dominated by non-native annual grasses and forbs including ripgut brome (*Bromus diandrus*), soft-chess brome (*B. hordeaceus*), wild oat (*Avena* sp.), shortfruit filaree (*Erodium brachycarpum*), and foxtail fescue (*Festuca myuros*). These areas also contain a relatively high abundance of the native purple needlegrass (*Stipa pulchra*). The remaining woodlands at SY East have understories of sage scrub or chaparral. The sage scrub understory is characterized by 0.5 to 1.5 m tall semi-woody shrubs—white sage (*Saliva apiana*) and California buckwheat (*Erigonum fasciculatum*)—with non-native annual grasses growing between shrubs. The chaparral understory is comprised of 2 m-tall dense woody shrubs dominated by ceanothus (*Ceanothus* sp.), growing with scrub oak (*Q. berberidifolia*), toyon (*Heteromeles arbutifolia*) and manazanita (*Arctostaphylos* sp.).

A prescribed burn program was initiated at SRP in 1988 within the grasslands and oak woodlands. Management goals for the program concentrated on the manipulation of the herbaceous plant community following the removal of cattle grazing between 1984 and 1996 from different areas as they were added to the protected lands at SRP. Trees monitored for this study are located in nine management units. Two management units have been burned once and five units have burned three times under prescription since 1988. Two management units act as untreated controls and have not been burned under prescription. The last large wildfires occurred in 1980 and 1981, with each burning opposite thirds of SRP, including the untreated control units. Additional wildfires burned portions of the monitoring location in 1945, 1962, 1968, and 1979.

There is an active year-round cow-calf operation at both SY units and no prescribed burn program. Wildfire history differs by unit. During the time that reliable fire records have been kept, SY East has burned relatively infrequently, with fires burning portions of the Engelmann oak long-term monitoring sites only in 1940 and 2003. Portions of the long-term monitoring sites at SY West have burned in 1956, 1981, 2006 and 2007.

Monitoring was completed using the tree as the sampling unit. A total of 540 permanently tagged oak trees (>10 cm diameter at breast height [1.37 m, DBH]) were monitored from 2000 to 2013. Size was measured using DBH. Survival was documented at each survey date. The presence and size of basal fire scars on the trunk was recorded. The number of sapling in the understory and in an area extending 3 m from the edge of the canopy were counted. If the canopy of a tree intersected another tree, the count ended where the canopies intersect. Based on the long-term data set, individuals ≥20 cm are well-established and had low mortality rates prior to the recent drought. As a result, saplings were defined as individuals ≥20 cm in height.

The 2003 Cedar Fire burned a portion of the long-term monitoring sites at SY East, including roughly half of the grassland and sage scrub sites and all of the chaparral sites. Indices of damage and fire severity were recorded for trees within the Cedar Fire's perimeter immediately after the fire. The area burned under each tree was recorded as percent of the understory burned. Fire severity was ranked based on the completeness of understory fuel consumption and ash deposition (0 to 9, with 0 being the least severe and 9 being the most severe). Damage to the canopy was estimated using maximum and average height of leaves consumed by the fire, maximum and average height of leaves scorched by the fire, and percent of canopy indirectly killed by the fire. Damage to the trunk was estimated based on the area of the trunk with bark scorched (bole charred - outer surface burned, but fire did not penetrate the entire thickness of the bark), bark consumed (bark completely burned to the cambium layer), and wood and cambium consumed.

All analyses conducted were univariate with a single independent variable. For continuously measured response variables, comparisons were made using general linear models (ANOVA and regression). For measurements made using binary scales or categorical rankings contingency table analysis (chi square), a form of the generalized linear model was used. All analyses were conducted in JMP 11.0.

As the last large wildfires, prior to the initiation of the monitoring program at both SRP and SY, occurred in 1981, the year of 1982 will be used as the starting date for the number of fires to which the monitoring trees have been exposed.

Results

Santa Ysabel East

Roughly 53 percent of monitored trees at SY East burned in the 2003 Cedar Fire. Prior to 2003, none of the trees had burned since at least 1940. All indices of fire damage were significantly correlated. Area of bark scorched (bole charred) was selected as the damage index to be used to investigate the influence of vegetation community on damage and damage on performance of oaks following the fires. For a majority of analyses, the area of bark scorched was converted to a categorical variable (high, medium, and low) to allow for easier graphical display and interpretation. For the remainder of this paper, fire damage will refer to area of the bark scorched.

Fire damage

Fire damage differed significantly among vegetation communities following the Cedar Fire ($F = 46.9$; $p < 0.0001$). Trees in chaparral received the highest levels of damage, sage scrub had intermediate levels of damage, and grasslands experienced the lowest levels of damage. The distribution of trees within fire damage classes varied significantly by community ($X^2 = 38.3$; $p < 0.0001$; fig. 1). Most trees in chaparral were in the high damage class. Trees in the sage scrub were fairly evenly distributed among damage classes and a majority of trees in the grasslands were in the low damage class.

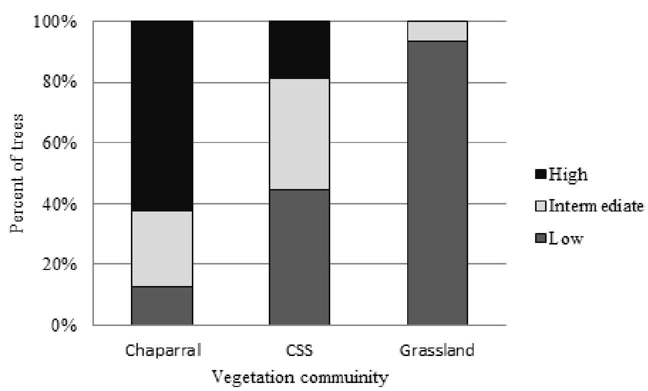

Figure 1—The percent of trees within each of the three fire damage classes in response to the 2003 Cedar Fire at SY West; high (black), intermediate (light grey), and low (dark grey) by vegetation community; chaparral, sage scrub (CSS), and grassland.

Survival

Survival decreased from 2004 to 2008 for trees damaged by the Cedar Fire. Trees dying between 2004 and 2008 occurred only in shrublands, but included trees in all damage classes. Survival did not change between 2008 and 2013.

Survival in 2008 was inversely related to damage class ($X^2 = 30.0$; $p < 0.0001$). A very high percentage of trees with low levels of damaged survived compared to a low percentage of highly damaged trees (fig. 2). As damage varied by vegetation community, a similar pattern was observed across the vegetation communities with trees in grasslands surviving at high rates and trees in chaparral surviving at low rates ($X^2 = 18.5$; $p < 0.0001$).

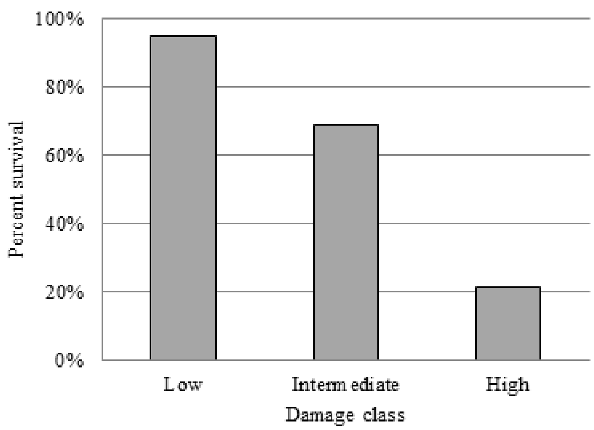

Figure 2—Percent survival of trees at SY West in response to the 2003 Cedar Fire by damage class.

Overall, survival through 2013, for trees damaged by the Cedar Fire, was 75 percent, while survival for trees in areas of SY East outside of the Cedar Fire was 95 percent.

Growth type following damage

For trees damaged by the Cedar Fire, growth type significantly differed by damage class ($X^2 = 29.0$; 0.001). Trees receiving low levels of damage were most likely to sprout from the canopy, while trees with high levels of damage were most likely to basal sprout (fig. 3). Trees receiving intermediate levels of fire damage had a fairly even distribution of growth types, with trees that both basal and canopy sprouted.

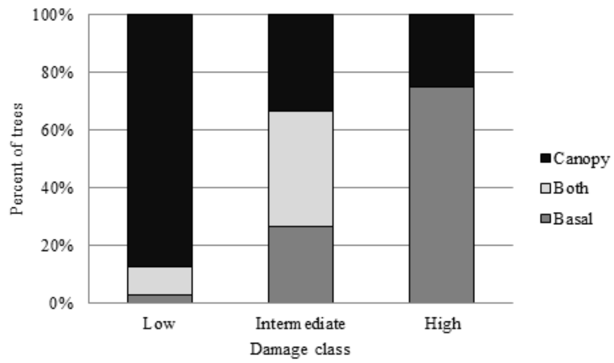

Figure 3—The percent of trees with different growth types following receiving damage in the 2003 Cedar Fire; canopy/crown sprouts (black), basal sprouts (dark grey), and both canopy/crown and basal sprouts (light grey) by fire damage class; low, intermediate and high.

Santa Ysabel West

Survival

Roughly 72 percent of the trees at SY West monitoring sites burned in the 2006 and/or 2007 wildfires. No wildfires had burned any of the sites since 1981. The understory is largely herbaceous and dominated by non-native annual grasses. Survival of trees outside the 2006 and/or 2007 fires was 100 percent at SY West between 2003 and 2013. Survival of trees burned by one or both of these fires was 99 percent between 2003 and 2009. Survival of trees burned by one or both fires dropped to 95 percent by 2013. Two of the three trees that died between 2009 and 2013 had visible fire damage and may have died as a result of that damage. At SY East, for trees exposed to fire and with herbaceous understory, survival through 2013 was also 95 percent.

Santa Rosa Plateau

Survival

A total of 21 prescribed fires and 2 small wildfires have burned long-term monitoring trees at SRP since 1982. Approximately 19 percent of the trees burned once, 63 percent burned three times, and 17 percent have not burned since 1982. Survival of trees not exposed to fire was 100 percent between 2003 and 2013. Survival between 2003 and 2013 of trees burned one or three times was identical at 95 percent. Dead trees occurred in 4 categories; (1) killed directly by fire (46 percent), (2) obtained damage to the base of the trunk that may have precipitated mortality 3-6 years following a fire (15 percent), (3) had no visible fire damage over the course of the survey period (23 percent), or (4) had old fire scars, but died eight or more years after the most recent fire making it impractical to classify cause of mortality (15 percent).

Scars

Santa Ysabel

Basal fire scar data is available for both 2002 and 2013 for trees with herbaceous and sage scrub understories. The presence of basal scars was independent of vegetation community in both 2002 ($X^2 = 0.38$; $p = 0.83$) and 2013 ($X^2 = 0.92$; $p = 0.63$). The presence of basal scars in 2013 was significantly related to the number of fires trees were exposed from 2003 to 2013 (X^2 = 48.9; p <0.0001). Roughly 10 percent of trees not exposed to fires had scars compared to 63 percent of trees exposed to one fire and 26 percent of trees exposed to two fires between 2003 and 2013. As a result, the percent of trees with scars increased from 5 percent in 2002 to 29 percent in 2013. The increase is due to new scars from trees exposed to the 2003, 2006, and 2007 fires. In the footprint of these fires, the percent of trees with scars increased from 5 to 44 percent.

Survival of trees with herbaceous and sage scrub understories exposed to fire from 2003 to 2007 with scars in 2002 was significantly lower than trees without scars (X^2 = 7.7; p = 0.0055). Survival was 75 percent for trees with scars in 2002 and 97 percent for trees without scars.

Santa Rosa Plateau

Basal fire scar data is only available for 2002 from SRP. As a result, the presence of scars was investigated with respect to the number of fires trees were exposed to between 1982 and 2002. The presence of basal fire scars in 2002 was significantly related to the number of fires trees were exposed (X^2 = 30.1; p <0.0001; fig 4). For trees burned from 2003 to 2012, trees with scars in 2002 were more likely to be dead in 2013 than trees without scars (X^2 = 3.9; p = 0.047). Survival between 2003 and 2013 was 90 percent for trees with scars in 2002 and 98 percent without scars in 2002.

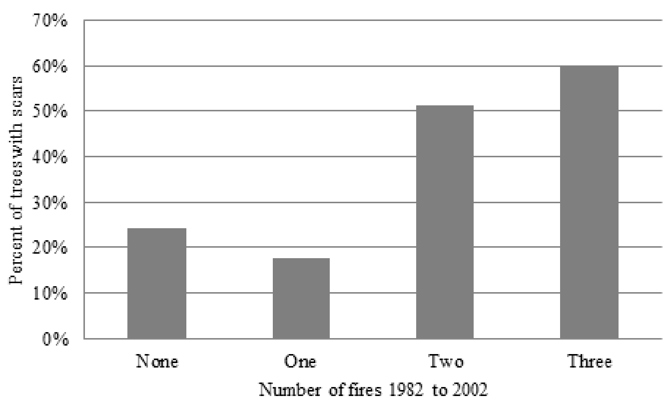

Figure 4—Percent of trees with basal scars at SRP in 2002 based on the number of fires trees were exposed between 1982 and 2002.

Saplings

The percentage of trees with saplings was significantly higher at SRP than SY in both 2003 (X^2 = 9.5; p = 0.0021) and 2013 (X^2 = 15.2; p <0.0001). However, the percentage of trees with saplings at SY East and SY West was higher than some management units at SRP, indicating the distribution of saplings varies at multiple scales on the landscape. With the recent drought, the percentage of trees with saplings at both locations decreased between 2003 and 2013. In 2003, 43 percent of trees at SRP contained saplings compared to 38 percent in 2013. In 2003, 30 percent of trees at SY contained saplings compared to 22 percent in 2013.

With SRP and SY data combined, the percentage of trees with saplings in 2013 was 24 percent for trees not exposed to fire since 1982 and 34 percent for those exposed to fire (X^2 = 4.1; p = 0.04). The number of fires trees were exposed since 1982 had a significant influence on the percentage of trees with saplings (X^2 = 42.1; p <0.0001). The pattern of trees with saplings compared to number of fires is not straight forward with 24 percent of trees exposed to no fires, 23 percent exposed to one fire, 11 percent expose to two fires, and 48 percent exposed to three fires supporting saplings.

Santa Ysabel

The percentage of trees with saplings in 2013 was identical (22 percent) for trees exposed to fire or not exposed to fire since 1982. The percentage of trees with saplings in 2013 varied based on the number of fires to which the trees were exposed. However, the differences were not significant (X^2 = 4.5; p = 0.11). Approximately 22 percent of trees exposed to no fires, 27 percent exposed to one fire, and 11 percent exposed to two fires supported saplings in 2013.

Santa Rosa Plateau

The percentage of trees with saplings in 2003 was 34 percent for trees not exposed to fire between 1982 and 2003 and 46 percent for those exposed to fire, but this was not found to be a significant difference (X^2 = 2.6; p = 0.10). The number of fires trees were exposed to between 1982 and 2003 did have a significant influence on the percentage of trees with saplings (X^2 = 35.0; p <0.0001). Approximately 34 percent of trees exposed to no fires, 14 percent exposed to one fire, 52 percent exposed to two fires, and 75 percent exposed to three fires supported saplings in 2003.

The percentage of trees with saplings in 2013 was 28 percent for trees not exposed to fire since 1982 and 40 percent for those exposed to fire, but this was not found to be a significant difference (X^2 = 2.5; p = 0.11). The number of fires trees were exposed to since 1982 did have a significant influence on the percentage of trees with saplings (X^2 = 23.6; p <0.0001). Approximately 28 percent of trees exposed to no fires, 15 percent exposed to one fire, and 48 percent exposed to three fires supported saplings in 2013.

Discussion

Engelmann oak trees appear resistant to grass-layer fires, moderately sensitive to sage scrub fires, and sensitive to chaparral fires. The difference in survival among trees growing in the different vegetation communities is very likely due to differences in fuel loads. The difference in fuel loads, although not measured for this study, was easily observed. Grasslands have the lowest fuel loads due to both the absence of shrubs and, at SY, the presence of cattle grazing. Sage scrub has intermediate fuel loads due to the presence of short-stature semi-woody shrubs with a grass understory. Chaparral has high fuel loads due to dense tall-stature woody shrubs. The difference in fuel amount and structure was evident on the damage trees received in each community. Very low levels of damage in grassland trees were characterized by minor damage to the base of the trunk and canopy damage only close to the ground. Intermediate levels of damage in sage scrub trees were characterized by minor to intermediate trunk damage and damage to larger areas of the canopy. High levels of damage in chaparral trees were characterized by intermediate and high levels of trunk damage and damage to all or a majority of the canopy. These differences in damage were inversely related to survival. As a result, the greatest change to the *Q. engelmannii* population occurred within the chaparral where mortality was very high. Additionally, the chaparral trees able to survive are generally very different in structure even a decade after the fire. This has resulted in the loss of the tree canopy in this community as most *Q. engelmannii* are multi-stemmed, only slightly taller than the surrounding chaparral shrubs, and appear many years away from regaining tree height or structure.

Although *Q. engelmannii* trees appear resistant to grass-layer fires, there appears to be a trend toward increased mortality for trees with basal scars when they are exposed to subsequent fires. At SY, trees with scars increased five-fold following the 2003, 2006 and 2007 fires, excluding trees growing in the chaparral. As a result, nearly 30 percent of the monitored population now has unhealed basal scars. Overall, mortality was found to be nearly 10 percent higher for trees with scars exposed to fire compared to trees without scars. This is consistent with results found by Fry (2002) where preexisting scars appeared to be responsible for fire-induced mortality of two of the three oak trees killed in response to a prescribed fire in Santa Clara County. The increase in the number of trees with scars and their higher mortality rate lead to the potential for even higher mortality rates in response to future fires at SY. At SRP where nearly 50 percent of trees had scars by 2002, mortality was found to be about 10 percent higher for trees with scars in 2002 that were burned between 2003 and 2012. The mortality rate for trees at SRP, in response to prescribed fires, may be lower than areas burned in wildfires due to pre-burn management actions. At SRP fire crews often clear fuels away from trees near the control lines in order to minimize fuel loads and smoldering adjacent to unburned fuels. Additionally, trees near the control lines are generally burned in back fires, which exhibit less extreme fire behavior. As a result, mortality rates of trees observed at SRP may be lower than they would be in response to wildfires. As the trunk appears to be most susceptible to damage that leads to mortality, relatively simple management actions, such as removing fuels from around the base of the trunk, could be taken to protect trees.

The annual survival from 2002 to 2013 was 0.993 for all trees monitored. If trees growing in the chaparral are removed from the analysis, annual survival increases to 0.995. This survival rate is similar to the 1943 to 2006 survival rate (0.996) of the valley oak (*Q. lobata*) (Davis and others 2011). Annual survival was 0.99 or greater (annual mortality less than 1 percent) for all management units expect SY East due to the high mortality of trees in the chaparral in response to the Cedar Fire.

The population growth rate cannot be directly estimated as the recruitment rate into the tree size class is unknown. The sapling data associated with this monitoring may help us calculate that rate in the future. Currently, the percent of trees with saplings has decreased, from 38 to 31 percent, in the last decade as a result of the recent drought. A similar decline in the total number of saplings from 1,700 to 1,150 was also observed. Even following the decline of saplings in the last decade there was an average of 2 saplings per adult tree in 2013, down from 3 saplings per tree in 2003. These are similar to the numbers of late stage seedlings and saplings per adult tree recently found for *Q. lobata* and *Q. douglasii*, in Santa Barbara County, California, which ranged from roughly 2 to 57 per tree (Pearse and others 2014). As the definition of sapling used in this study includes both saplings and a portion of their larger late stage seedlings, it is likely that the estimates of saplings per tree would be closer if similar definitions had been applied. As saplings occur clustered around 31 percent of the trees at SY and SRP, a shift in the distribution of adult oaks may occur within individual woodlands. The trees with saplings contained an average of 6.8 saplings per adult tree, providing each with a good opportunity to at least replace itself.

Based on the pattern of saplings present in 2003 and 2013, with respect to the number of recent fires, it does not appear fires greatly decrease their presence on the landscape. At SRP, in both 2003 and 2013, the percentage of trees with saplings was highest in areas exposed to more than one fire. At SY, the percentage of trees with saplings was higher in areas burned once compared to unburned areas. It is likely that much of the variability in the distribution of saplings is unrelated to fire and it is more likely that areas with the greatest density of saplings are, by chance, the areas that have burned most frequently. The relatively high survival rates of *Q. engelmannii* saplings exposed to fire would allow saplings to persist following these fires. Depending on fire damage, survival rates of saplings exposed to fire range from 60 to 95 percent, while survival rates for saplings receiving low levels of fire damage (which are likely typical of saplings with grass understories) were found to be >80 percent (Lawson 1993, Principe 2002). In this study, the persistence of saplings in areas exposed to the highest frequency of fires demonstrate that these areas support capacity to maintain *Q. engelmannii* woodlands in the future.

In conclusion, both wildfire and prescribed burns reduce the survival of all size classes of *Q. engelmannii*. Fires also increase the occurrence of basal scars, which appear to increase mortality when trees are exposed to subsequent fires. The overall impact of fires on the long-term viability of *Q. engelmannii* populations is, however, unknown and would require demographic modeling to help tease out its influence. For areas where there is concern over the viability of the population, the use of prescribed fire should be considered carefully as mortality of all size classes will likely be increased unless protective measures are taken. Based on observations made following prescribed fires at SRP and large wildfires in San Diego County in 2003 and 2007, the influence of fire appears site specific. At many locations in San Diego County, following wildfires, there appears to be high tree mortality, similar to that observed in the chaparral and sage scrub at SY, but limited numbers of saplings. As a result, some stands appear to have been substantially reduced in spatial extent. This is in contrast to most areas of SRP where, even after repeated fires, tree mortality is low and saplings are relatively abundant. At SRP, it is also common to observe multiple saplings being released from the sapling bank with rapid growth following the fire-induced death of their nurse/parent tree. More information is needed to gain a better understanding if the indirect effects of fire on the environment of *Q. engelmannii* (decreased abundance of non-native annual grasses following fires on seedlings and sapling recruitment and growth rates) outweigh the increase in mortality.

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