California Oaks and Fire: A Review and Case Study[1]

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Abstract

California has a fire-prone Mediterranean climate, and many of its nine species of native oak trees are thought to have evolved with fire. Little has been widely published about the role of fire in the oak recruitment and mortality in the western United States, and there has been some debate about how to reintroduce fire into oak woodlands. We present here a review, synthesis, and analysis of the literature on fire and California oak species. This literature review suggests high overall survival of oaks after fire, although smaller individuals often experience topkill (death of all above-ground stems, followed by recovery via sprouting of basal shoots from the root crown). We then provide results from a case study of a controlled burn on the survival of 5-year-old valley oaks (*Quercus lobata*) at a restoration research site near Davis, CA. One-half of the trees at our site were exposed to a set of prescribed burns in summer 2003, and another half were left unburned as a control. Prior to burning, measurements were taken on each tree's height, diameter, and understory grass biomass. Fire temperatures were measured using temperature-sensitive paints on ceramic tiles hung on each tree. Only 3 percent of the oaks died as a result of the fire, although 85 percent were topkilled. Smaller trees, trees exposed to higher fire temperatures, and trees with higher levels of understory biomass suffered more damage. About one-third of trees over 200 cm tall escaped being topkilled. Our investigation of the effects of fire on young valley oak trees indicates that saplings of this species, similar to the saplings of most western oak species, are resilient to fire, especially if managers are willing to accept the temporary setbacks associated with topkill.

Keywords: Basal sprout, coppice, prescribed burn, prescribed fire, Quercus lobata*, topkill, valley oak, wildfire.*

Introduction

California has a fire-prone Mediterranean climate, and many of its nine species of native oak trees are thought to have evolved with fire (Pavlik and others 1991). Native Americans were known to set fires in many oak communities, and fires before the mid-1800s were probably fairly frequent and of low intensity (Lewis 1982). With the advent of the gold rush in 1848, fires in California initially increased in frequency and then, starting in the 1940s, were almost completely suppressed (Biswell 1989, McClaran and Bartolome 1989).

Some of California's oak communities have not been experiencing normal recruitment in recent decades; although oak stands contain many mature individuals, young trees and saplings are often rare or absent (Bolsinger 1988, Griffin 1976). It may be that changes in California's fire regime have contributed to this lack of regeneration, although there are other potential causal factors, including increases in deer and rodent populations and the introduction of domestic livestock and invasive

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annual plants (Pavlik and others 1991). Little is known about the role of fire in oak recruitment and mortality (Barbour and Minnich 2000), and there has been some debate about the proper way to reintroduce fire into oak woodlands (Bartolome and others 2002, Biswell 1989).

The effect of fire on valley oak trees (*Quercus lobata*) is of particular interest to restoration efforts in California's Central Valley. Valley oak trees are the dominant members of California's low-elevation riparian oak woodlands (Pavlik and others 1991), and are some of the most threatened communities in California because of flood control and agriculture activities (Vaghti and Greco *in press*). It is estimated that only 6 percent of the historic riparian forest remains in California's Central Valley (Katibah 1984). Many restoration efforts focus on valley oak restoration, and it is one of the most frequently planted trees at restoration sites in the Central Valley (Young and Evans 2005). Newly-restored valley oak communities often have serious invasions of understory non-native grasses and thistles. Although prescribed burning can be an effective control for these exotics, managers may be reluctant to use fire if it causes substantial mortality of sapling valley oak trees.

We reviewed and analyzed the literature on fire and California oak species. Although some species have been investigated in a number of studies, particularly blue oak (*Q. douglasii*) and coast live oak (*Q. agrifolia*), the effects of fire on other oak species, including valley oaks, have only been minimally addressed. We therefore present preliminary results from a case study of a controlled burn on valley oak saplings at a research restoration site near Davis, CA.

Statistical Review of Previous Research

We identified studies on the effects of fire on California oak species by searching the electronic database BIOSIS Previews with various combinations of the following keywords: oak*, lobata, valley oak*, burn*, fire*, prescribed, California, west*, and advance regeneration (where * is a truncation symbol). Proceedings from the 1979, 1986, 1990, 1996, and 2001 Symposiums on Oak Woodlands published by the USDA's Forest Service Pacific Southwest Research Station were also searched for relevant articles. As articles were identified for inclusion in our study, their cited literature was scrutinized for additional references. Although our statistical analysis was restricted to studies that investigated the effects of fire on oak species native to California, if relevant, results from other areas of North America are mentioned in the discussion.

A total of 14 studies on seven different species were identified, although three did not report data in a form that allowed for inclusion in our analysis. Many of the studies addressed multiple species and/or multiple sizes (seedling, sapling, mature); therefore, a total of 26 cases were included in our analysis. One-way ANOVAs or t-tests were used to analyze the effect of predictor variables (tree size, fire season, and oak species) with respect to tree response to fire (death or topkill). Homogeneity of variance was checked with Levene's tests and, if necessary, non-parametric tests were used.

Due to low replication of studies within species, it is not clear whether the differing results described in the following sections are due to differences in species, sites or experiments. Nonetheless, some consistent patterns emerge.

Potential Benefits

Fire may reduce competitive pressures from species that are more fire-sensitive than oaks. Managers of senescent oak forests in the southeastern United States have long used prescribed burning to reduce the densities of certain oak competitors, such as maple (*Acer*) and gum (*Nyssa*) trees (Arthur and others 1998). These species have come to dominate their communities with the advent of fire suppression, and prescribed fire restores oak dominance (McCarty 1998). Many non-native understory species have invaded oak woodlands, particularly in California, and fire has been used as a restoration tool to control common understory exotics, such as Scotch broom (*Cytisus scoparius*), yellow star thistle (*Centaurea solstitialis*), and various annual grasses (Bossard and others 2000).

Fire may promote acorn germination and growth, possibly by reducing competitive pressure from understory vegetation, releasing soil nutrients, reducing litter-born pathogens, or improving contact with mineral soils. Kauffman and Martin (1987) found that densities of black oak (*Q. kelloggii*) seedlings were up to nine times greater in burned plots than unburned plots. Oregon white oak (*Q. garryana*) acorns planted in fire-charred soil had a significantly higher emergence rate than those planted in unburned soil (Regan and Agee 2004). No similar increase in recruitment, however, was found for acorns of blue oak (Allen-Diaz and Bartolome 1992) or valley oak (Swiecki and Bernhardt 1998).

There may also be broader community benefits to burning. Haggerty (1994) noted that the previously abundant oak mistletoe (*Phoradendron villosum*) was completely eliminated after a wildfire in a stand of blue oak and interior live oak (*Q. wislizeni*), suggesting that the current abundance of mistletoe may be an artifact of fire suppression. Dagit (2002) found an increase in native species' cover in the understory of a coast live oak woodland after a wildfire, although natives were gradually being replaced by exotics as time since fire increased. More research on such effects is needed.

Potential Risks

Many species of mature oaks are relatively tolerant to fire. However, even large oaks can die as a result of fire exposure, and sapling and seedling oaks are at greater risk. Our survey of studies investigating the effects of fire on California oak species found that mortality rates generally ranged between 1 to 11 percent for mature oaks, 2 to 10 percent for sapling oaks, and 17 to 52 percent for seedling oaks (*table 1*). Larger trees were significantly more likely to survive fire than were smaller trees and seedlings (Wilcoxon $p = 0.01$, *fig. 1*).

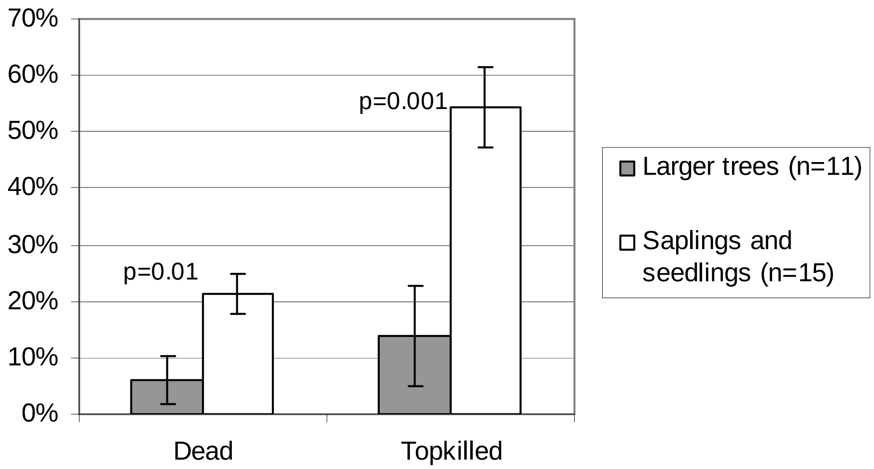

Figure 1—Comparison of death and topkill rates between large and juvenile oaks exposed to fire, based on a review of the literature (*table 1*). Bars represent one standard error. Sample sizes are the number of cases in each size class.

Even though fire does not usually completely kill sapling oaks, it topkills them 75 to 90 percent of the time (*table 1*). “Topkill” means that the above-ground portions of an individual sapling die, but that recovery occurs via sprouting of new basal shoots (coppices) from the tree’s root crown. Two studies of seedling oaks exposed to fire (Schwan and others 1997, Lathrop and Osborne 1991) reported topkill levels from five to 52 percent – levels much lower than those found for sapling trees. It is hard to determine the topkill status of very small oaks because their branches are small enough to be completely consumed by fire, and subsequent regrowth makes it difficult to find evidence of a dead main leader (personal observation). It may be that in some cases the topkill rates reported for seedling oaks are artificially low due to the difficulty of distinguishing dead main leaders.

In our sample of studies, saplings and seedlings were significantly more likely to be topkilled by fire than were larger trees (t-test $p = 0.001$, *fig. 1*). Topkilled trees, although often capable of complete recovery, may be more susceptible to further damage from deer browsing or subsequent fires until the basal shoots grow up through susceptible height classes (Bartolome and others 2002, Swiecki and Bernhardt 2002).

Fire Characteristics

Several different fire characteristics can influence the damage and mortality response of oak trees, including fuel load, fire frequency, and fire season. The amount of understory litter, brush, and downed wood (fuel load) is often high in areas with low fire frequency, and differences in fuel loads can have a dramatic effect on fire damage. Fire-induced mortality in black oak stands with high fuel loads was about twice that of moderate-fuel load areas (Kauffman and Martin 1987). Blue oak saplings were significantly more likely to escape being topkilled if they were located in areas with light fuel loads, rather than medium or heavy fuel loads (Tietje and others 2001).

In other parts of the United States, multiple fires within a short period of time have been found to increase oak mortality rates (Dey and Hartman 2005, Peterson

Table 1—*Summary of research publications on the effects of fire on California oak species.*

Species	#	Fire type/season	Dead	Topkilled[a]	Citation
Mature trees					
Q. agrifolia	90	wildfire, Nov	4%	not specified	Dagit 2002
Q. douglasii *Q. kelloggii* *Q. lobata*	208	prescribed, June	1%[b]	none noted	Fry 2002
Q. douglasii	119	wildfire, June	6%	8%	Haggerty 1994
Q. wislizeni	29	wildfire, June	11%	24%	Haggerty 1994
Mixed-age					
Q. agrifolia (>7.5cm dbh)	165	wildfire, Aug	5%	11%	Plumb 1980
Q. chrysolepis	239	prescribed, Nov	<15cm dbh 47%[c] >15cm dbh 10%[c]	included in dead	Paysen and Narog 1993[d]
Q. chrysolepis (>7.5cm dbh)	156	wildfire, Nov	2%	63%	Plumb 1980
Q. douglasii	100	wildfire, summer	2%[b]	seedling 50% others 8%	Horney and others 2002
Q. garryana	874	prescribed, spring prescribed, fall prescribed, 2x	spring 94/ha[c] fall 91/ha[c] 2x 523/ha[c]	included in dead	Regan and Agee 2004[d]
Q. kelloggii	?	prescribed, various	high fuel 55-91% mod. fuel 22-65%	none noted	Kauffman and Martin 1987[d]
Q. kelloggii	72	wildfires, various	13%	24%	Plumb 1980
Q. lobata	266	wildfire, Aug	20%	not specified	Griffin 1980
Saplings					
Q. agrifolia	90	wildfire, Aug	2%	88%	Plumb 1980
Q. agrifolia	18	prescribed, Oct	<5%	74%	Tietje and others 2001
Q. chrysolepis	10	wildfire, Nov	10%	90%	Plumb 1980
Q. douglasii	38	prescribed, Oct	<5%	78%	Tietje and others 2001
Q. douglasii	67	wildfire, Sept	9%	82%	Swiecki and Bernhardt 2002
Q. douglasii	48	prescribed, July	<10%	>90%	Bartolome and others 2002
Seedlings					
Q. agrifolia	89	prescribed, June prescribed, Nov	June 46% Nov 52%	June 50% Nov 36%	Lathrop and Osborne 1991
Q. agrifolia[e] *Q. douglasii*[e] *Q. lobata*[e]	558	wildfire, July	QUAG 44% QUDO 17% QULO 17%	5%[b]	Schwan and others 1997
Q. engelmannii	699	prescribed, June wildfire, Aug prescribed, Nov	June 45% Aug 34% Nov 22%	June 53% Aug 52% Nov 50%	Lathrop and Osborne 1991

[a]Death of all above-ground stems, followed by recovery via sprouting of basal shoots.
[b]Study addressed either multiple species or multiple sizes of oaks; results not provided individually.
[c]Topkilled trees included in numbers reported for dead trees.
[d]Study did not report data in a form that allowed for inclusion in statistical analysis.
[e]Most trees in study were seedlings, although some sapling–sized trees were also included.

and Reich 2001). Hutchinson and others (2005), however, found lower mortality at more-frequently burned sites, perhaps because their more-frequently burned sites experienced lower-intensity fires. Regan and Agee (2004) found that two prescribed burns in Washington within a 5-year period increased Oregon white oak mortality more than five-fold over single burns. We found no studies on the effects of multiple fires on oaks in California.

The seasonal timing of fires is also believed to affect the extent of tree damage. Increased susceptibility to summer fires may be because higher ambient temperatures cause internal tree temperatures to increase to mortal levels during fire much more rapidly than do lower ambient temperatures (Hare 1965) or because low fuel moisture creates more intense fire conditions (Whelan 1995). Some trees may be more sensitive to spring fires, however, because higher moisture content in bark can increase thermal conduction (DeBano and others 1998). It is likely that historical fires in California were more likely to occur in the late summer and fall (Lewis 1985). Many controlled burns now occur in the spring and early summer, either to better kill non-native weeds or to provide more controlled conditions for fires.

Only a few studies have specifically addressed burn response by season, and their results have been somewhat conflicting. Ferguson (1957) found that several Texas oak species were more likely to survive winter or spring burns than summer burns, as have studies from the eastern United States (Brose and Van Lear 1998, Cain and Shelton 2000). In contrast, Lathrop and Osborne (1991) found that Engelmann oak (*Q. engelmannii*) seedlings in Southern California had higher survival rates for both summer and fall burns compared with a spring burn. Although the trend was for late-season burns to have more severe impacts than spring burns (*fig. 2*), the studies of California oak species we reviewed showed no significant differences among burn seasons in either mortality (ANOVA $p = 0.98$) or topkill (ANOVA $p = 0.13$).

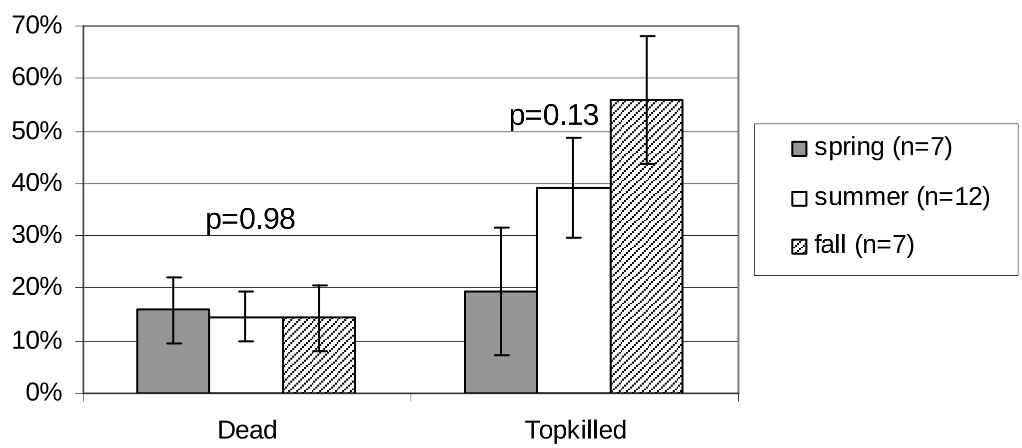

Figure 2—Comparison of death and topkill rates of oaks after fires that occurred at different times of year, based on a review of the literature (*table 1*). Bars represent one standard error. Sample sizes are the number of cases in each season class.

Species-Specific Fire Response

Fire response appears to vary among California's oak tree species. Plumb (1980) found that coast live oak tolerated fire better than black oak, while canyon live oak (*Q. chrysolepis*) was extremely fire sensitive. Blue oak has been shown to be more fire resistant than interior live oak (Haggerty 1994), and Engelmann oak is more resistant than coast live oak (Lathrop and Osborne 1991). Differences in bark are posited to be the primary factors responsible for varying fire responses among tree species (DeBano and others 1998). Several bark characteristics, including increased thickness, non-flaky texture, and high density, reduce the negative effects of fire by minimizing heat transmission to the underlying cambium cells (Hare 1965, Plumb 1980). Snow (1980) found that Engelmann oak seedlings recovered from fire faster than coast live oak seedlings. He identified Engelmann oak's bark thickness, which was twice that of coast live oak's, as the likely explanation.

Our review of seven different California oak species (black, blue, canyon live, coast live, Engelmann, interior live, and valley) found no significant difference in either death (Kruskal-Wallis $p = 0.32$) or topkill (Kruskal-Wallis $p = 0.24$). However, this is likely due to the low replication of case studies within species (three or less for five of the seven species), which limited our ability to separate species effects from the effects of other differences in individual studies.

Prediction of Survival

Logistic regression and discriminant analysis models have been used to predict which oak trees will be damaged or killed by fire. Some of the tree characteristics analyzed include height, diameter, crown height, crown width, and bark thickness. Most studies have found that larger, older trees are significantly less likely to be damaged by fire (Fry 2002, Horney and others 2002, Paysen and Narog 1993, Regan and Agee 2004, Swiecki and Bernhardt 2002), although one study of wildfire in a mature stand of blue and interior live oaks found no significant difference attributable to tree size (Haggerty 1994). Swiecki and Bernhard (2002) used their model to propose critical threshold levels, suggesting that blue oak saplings more than 2-meters tall are likely to avoid being topkilled by fire, while those under 1-meter tall are more likely to be completely killed. Increase in fire damage (parameters analyzed include percent bole char, height of bole char, char severity, and percent crown scorch) has also been found to be predictive of subsequent topkill and mortality (Fry 2002, Haggerty 1994, Horney and others 2002, Paysen and Narog 1993, Regan and Agee 2004).

Recovery of Height

Results from several studies indicate that blue oak saplings topkilled by fire can experience a period of accelerated growth from one to several years after the fire. That growth significantly exceeds the growth of less damaged or unburned trees (Bartolome and others 2002, McClaran and Bartolome 1989, Swiecki and Bernhardt 2002). Schwan and others (1997) found accelerated growth in coast live oaks after a wildfire, although growth of valley and blue oaks was stagnant or negative. Studies of oaks in the eastern United States have found evidence of increased postfire growth (Brose and Van Lear 1998). In most cases, however, accelerated growth has not resulted in burned trees returning, within a few years, to the full height they would have been had they not been burned (in other words, not full compensation). In a

Missouri forest with dense canopy cover, lack of height recovery was presumably due to shading from overstory trees, which reduced photosynthesis (Dey and Hartman 2005). Slow height recovery has also been found in areas with large deer or livestock populations, since topkilling returns saplings to heights accessible to browsing animals (Bartolome and others 2002, McClaran and Bartolome 1989).

A Case Study: Effects of a Prescribed Burn on Valley Oak Saplings of Different Sizes

Our review of the literature on fire and California oak trees revealed that very few studies have examined the effects of fire on valley oak trees in general, and none have comprehensively addressed sapling-aged valley oaks. This is unfortunate, since prescribed fire can be an important management tool at restoration sites in the Central Valley, many of which include newly planted valley oaks. Fire effectively controls exotic annual grasses and thistles, but can be used only if young valley oaks are reasonably fire-tolerant. In light of the potential for differences in species-specific fire response, more study on the effect of fire on young valley oaks is needed. We conducted a prescribed burn in a field of sapling valley oaks for the purpose of (1) investigating valley oak response to prescribed fire; (2) determining critical thresholds for mortality and topkill; and (3) identifying factors that are predictive of fire response.

Methods

Our study site is a 2-hectare research field near Davis, California. The site was planted with several hundred valley oak acorns and seedlings in the winter of 1999 as part of an unrelated restoration experiment (Hobbs and Young 2001, Young and Evans 2001, 2005). The original experiment concluded in 2001, and 278 trees remained at the site by summer 2003. None of the trees received supplemental irrigation after summer 2000. There is no overstory canopy layer at the site, and the understory layer is dominated by nonnative annual grasses (*Bromus*, *Avena*, *Lolium*, and *Hordeum* species) and yellow star thistle.

The site was subdivided into plots of approximately 72 m^2 each, with an average of 10 trees per plot. Nine plots were burned in the summer of 2003 and nine were left unburned as a control. The plots assigned to burning treatment were regularly interspersed with the controls. Each plot had oaks that differed substantially in size, and our analysis combined all trees of a particular height, across all plots. There were substantial differences in tree size due to the previous restoration experiment, and plots were stratified to more evenly distribute tree size.

In April 2003, the height and stem diameter at 30 cm was measured for each tree. For those trees in the burn treatment, the grass biomass under each tree was assigned a density level of one (low) through three (high). Ceramic tiles painted with six different temperature-sensitive welding paints (ranging at regular intervals from 79 ˚C to 399 ˚C) were hung at a height of 30 cm on each tree. Three weeks after the burn, the height of the top of the scorch level was measured for each tree. Three months after the burn, the survivorship of each tree’s main leader was assessed, and the number of basal sprouts and height of the tallest sprout were measured.

The burn was conducted on July 16, 2003, from 12:00 p.m. until 4:00 p.m. Dry bulb temperatures averaged 34 ˚C during the burn and relative humidity was 37 percent. As recorded by the ceramic tiles, fire temperatures reached a high of 204 ˚C with a mean of 95 ˚C. Most of the litter and understory herb layer was consumed in the fire, although some patchiness was evident with small areas of litter only lightly charred. Fire carried into the crowns of many of the saplings, and 26 percent of them experienced 100 percent crown scorch, although leaves and small twigs were only rarely completely consumed by the fire.

Results

The burn resulted in three levels of tree response, with the most severe being entire tree death, followed by topkilled trees with dead main leaders but vigorous sprouting from the root crown, and trees whose main leaders survived (*table 2*). Only three percent of the valley oak saplings died as a result of the fire; however, 85 percent of the burned trees were topkilled. Two years after the fire, most of the burned trees appeared quite robust, and even the topkilled trees were approaching the height of the control trees.

Table 2 — *Proportions of valley oak saplings in each treatment, by fire response*

	Trees in burned plots	Trees in unburned plots
Dead	0%	3%
Topkilled, coppicing	0%	85%
Alive	100%	12%
N	96	88

Tree height, fire temperature and understory biomass density all contributed to the severity of tree response to fire. Smaller trees, trees exposed to higher fire temperatures, and trees surrounded by denser understory biomass were more likely to experience death or topkill in response to the fire (*figs. 3, 4, 5*). All three trees that died in the fire were under 150-cm tall. Although there were no height classes that completely avoided being top-killed by the fire, increasing proportions of trees above 200 cm escaped topkill. In the largest height class (251-350 cm), one-third of the trees avoided being topkilled.

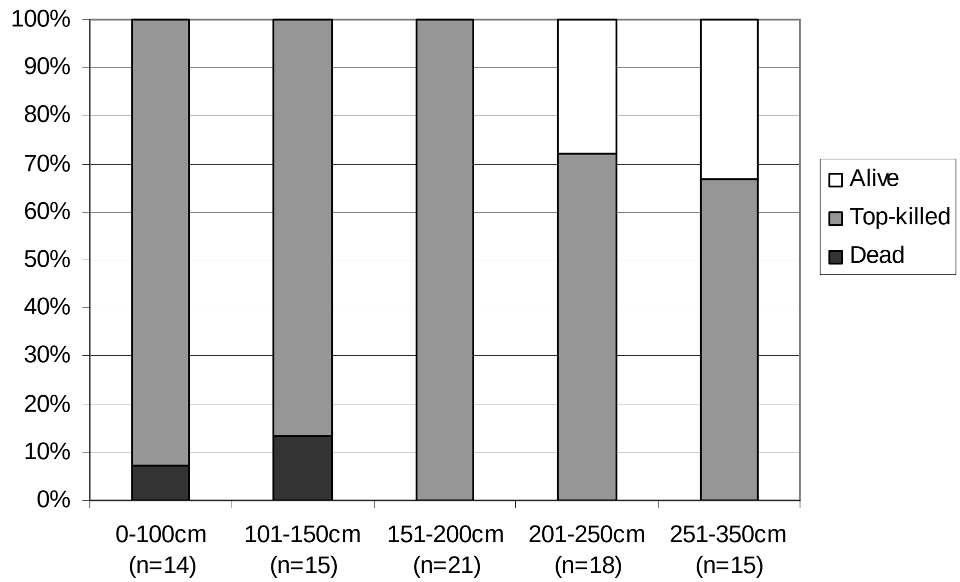

Figure 3—The proportions of valley oak saplings of different heights that experienced different fates after a prescribed burn. Sample sizes are the numbers of individual trees in each height class.

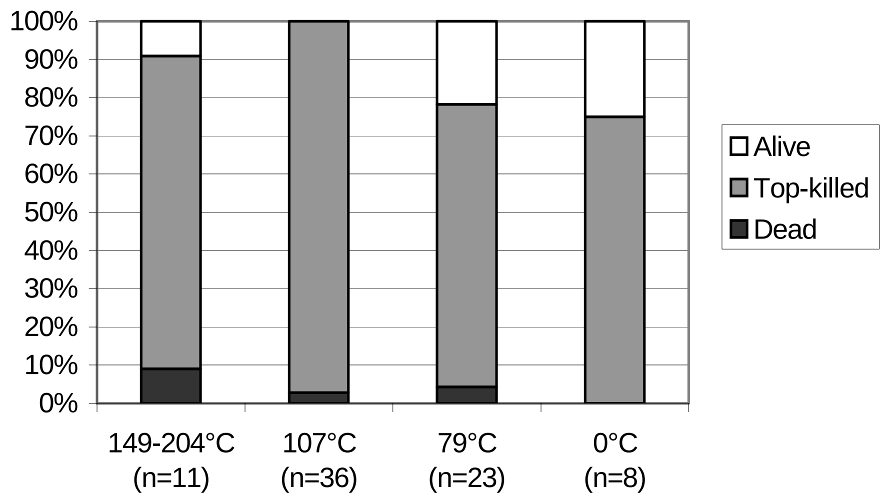

Figure 4—The proportions of valley oak saplings exposed to different minimum fire temperatures that experienced different fates after a prescribed burn. Sample sizes are the numbers of individual trees in each temperature class.

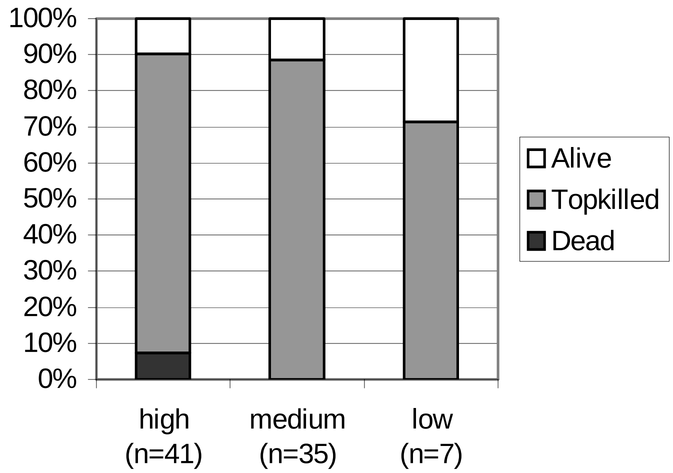

Figure 5—The proportions of valley oak saplings with different understory biomass density levels that experienced different fates after a prescribed burn. Sample sizes are the numbers of individual trees in each understory biomass density class.

Discussion

Our case study results indicate that valley oak saplings exposed to a low-intensity prescribed fire experience very low mortality rates but high topkill rates, similar to the fire responses found for several other sapling California oaks species. Three previous studies on other sizes of valley oak trees also found high survival after fire. A prescribed burn conducted by Fry (2002) in a mature stand of valley, blue, and black oaks resulted in less than 1 percent mortality. Griffin (1980) found a more variable response in a mixed-age stand of valley oaks exposed to wildfire; crown-fire killed 48 percent of the trees, severe ground-fire killed 18 percent, and moderate ground-fire killed 3 percent. Schwan and others (1997) studied the effects of a wildfire on 159 mostly seedling valley oaks and found a 17 percent mortality rate but only a 5 percent topkill rate. We have found that it is difficult to determine the topkill status of very small valley oaks, since the main leader is likely to be consumed by fire and the regrowth is rapid and vigorous. It may be that the topkill rate reported by Schwan and others was artificially low due to the small stature of their trees.

Although all three of the saplings completely killed by fire in our study were under 150-cm tall, most trees in the smaller height classes did not die. There does not, therefore, appear to be a critical height threshold for fire-induced mortality of valley oak saplings. Since none of our height classes reliably avoided being topkilled, we cannot propose a specific height above which valley oak saplings escape topkilling. Our data does show, however, that as saplings exceed 200 cm they become less likely to be topkilled.

Previous studies have identified several tree and fire characteristics that are predictive of oak trees' fire responses. Our case study found that tree size, fire temperature and fuel load all contribute to the severity of sapling valley oaks' fire response. Fire temperature and fire residency time are inversely proportional to each other in causing plant cell death (Bond and van Wilgen 1996), and cells can survive higher temperatures when the time of exposure is shorter. The larger saplings in our study presumably had thicker bark that more effectively insulated the underlying cambium layer, reducing the amount of time living cells were exposed to potentially lethal temperatures. Higher-density understory biomass not only provides more fuel, thereby increasing fire temperatures, but may also serve as a fuel ladder, carrying flames into tree crowns and increasing the potential severity of a fire's effects.

Two years after the fire, the trees burned in our experiment were approaching the height of unburned control trees and appeared healthy and robust. Our research site, although subject to rodent and hare herbivory, experienced very little deer browse pressure. Studies in areas with large deer or livestock populations have found that topkilled saplings experience slow height recovery because of browsing (Bartolome and others 2002, McClaran and Bartolome 1989).

Conclusion

Although there are some differences in fire sensitivity among oak species, most California oaks, even saplings, appear to be resilient in their ability to survive at least one-time burns, especially if managers are willing to accept the temporary setbacks associated with topkill. Land managers interested in using prescribed fire in young oak tree stands may want to minimize potential fire damage by addressing factors that have been shown to be predictive of severe fire response. Fire temperatures can be lowered by conducting burns when ambient temperatures are low and when relative humidity and fuel moisture is high; for example, either in early morning or early season. Understory biomass around sapling oaks can be reduced through the use of weed control fabric or via aggressive weed-whacking within the canopy line of individual sapling oaks immediately before burning.

Although the effects of fire on valley oak saplings has not been comprehensively addressed in previous research, the results of our case study indicate that valley oak saplings are capable of surviving fire with very little mortality and appear quite robust within a few years after fire. The presence of valley oak saplings does not therefore appear to preclude the use of a single low-intensity prescribed burn to control understory invasive plants in recently-planted restoration sites, particularly if the saplings are over 300-cm tall and measures are taken to reduce fire temperatures.

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