Forest Restoration at Redwood National Park: Exploring Prescribed Fire Alternatives to Second-Growth Management: a Case Study[1]

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Abstract

Almost half of Redwood National Park is comprised of second-growth forests characterized by high stand density, deficient redwood composition, and low understory biodiversity. Typical structure of young redwood stands impedes the recovery of old-growth conditions, such as dominance of redwood (*Sequoia sempervirens* (D. Don) Endl.), distinct canopy layers and diverse understory vegetation. Young forests are commonly comprised of dense, even-aged Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and redwood stump sprouts, with simple canopy structure and little understory development. Moreover, many of these young stands are believed to be vulnerable to disturbance in the form of drought, disease and fire.

Silvicultural practices are increasingly being employed by conservation agencies to restore degraded forests throughout the coast redwood range; however, prescribed fire treatments are less common and potentially under-utilized as a restoration tool. We present an early synthesis from three separate management-scale prescribed fire projects at Redwood National Park spanning 1to 7 years post-treatment. Low intensity prescribed fire had minimal effect on overstory structure, with some mortality observed in trees smaller than 30 cm diameter. Moderate to high intensity fire may be required to reduce densities of larger Douglas-fir, the primary competitor of redwood in the Park’s second growth forests. Fine woody surface fuels fully recovered by 7 years post-burn, while recruitment of larger surface fuels was quite variable. Managers of coastal redwood ecosystems will benefit by having a variety of tools at their disposal for forest restoration and management.

Introduction

Redwood National and State Parks (RNSP) are best known as having the most spectacular examples of old-growth coastal redwood forests, but approximately 45 percent of RNSP is composed of second-growth forests. Typical structure of young redwood stands impedes the rapid recovery of old-growth conditions, such as dominance of redwood (*Sequoia sempervirens* (D. Don) Endl.) distinct canopy layers and diverse understory vegetation (O'Hara et al. 2010, Teraoka and Keyes 2011). Young forests are commonly comprised of dense, even-aged Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and redwood stump sprouts, with simple canopy structure and little understory development. Under these conditions the relatively shade-intolerant Douglas-fir is expected to exclude redwood from the upper canopy until large gaps are formed, a process that may take centuries (Thornburgh et al. 2000). Moreover, many of these young second growth stands are believed to be vulnerable to disturbance in the form of drought, disease and fire (fig. 1). While the presence of second-growth redwood forest presents a management challenge, it also provides an opportunity for landscape restoration, an important theme in the 1978 Redwood National Park Expansion Act (USDI 1999).

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Figure 1—Dense second growth forest conditions in Redwood National Park.

Figure 2—Fire-scarred redwood cross-section from Redwood National Park.

Wile the understanding of fires role in redwood forest development is somewhat ambiguous, tree ring evidence suggests fires were historically quite frequent resulting from a combination of Native American and lightning ignition sources (Lorimer et al. 2009; fig. 2). Fire history research in Del Norte and northern Humboldt counties has reported historical fire return intervals of about 10 years at a site east of Prairie Creek State Park (Brown and Swetnam 1994), 11 to 26 years in Del Norte Redwoods State Park (Norman 2007), and up to 500 years at humid coastal sites in RNSP (Veirs 1980). While fire surely played a role in the development of many old growth stands, second growth redwood forest structure differs drastically from old growth (e.g., smaller trees, more of them, sprouts surrounding rotten stumps), and limited information is available on the effects of fire in second growth redwood stands.

The RNSP currently uses silviculture (i.e., mechanical thinning) as the primary tool to meet the forest restoration objectives in the park, which include: decrease stand density; increase spatial heterogeneity in the forest canopy; alter tree species composition to give redwood a competitive advantage; increase understory diversity; and increase forest vigor. Silvicultural methods have a long history of success in commercial and non-commercial settings (Bauhus et al. 2009, Teraoka and Keyes 2011), however the use of silviculture in ecological restoration is generally a novel approach to park management and was first used by RNSP Ecologist Stephen Veirs in the early 1980s (but has since increased in scale and scope). Prescribed fire may have utility in the restoration of second growth redwood forests in RNSP, especially in low-accessibility stands. Prescribed fire may also offer unique benefits over mechanical treatments (e.g., fuels reduction, understory vegetation response, snag and cavity creation, nutrient cycling, etc.). In this article we present and discuss results from three prescribed fires that were conducted to help restore second-growth forests in RNSP, dating back to 2006. The three case studies demonstrate both low-intensity and moderate-intensity treatments, and we discuss management implications and long term monitoring.

Methods

We present monitoring results from three prescribed fires located in the Bald Hills area of Redwood National Park (fig. 4). The Dolason-Airstrip (DA) unit (12.1 ha, 30 ac) was treated in the fall of 2007 with a low-moderate intensity burn. Monitoring plots were installed pre-burn and re-measured 1 year post-burn and 7 years post-burn. A total of 21 plots were installed and overstory trees ≥ 20cm (7.9

inches) diameter at breast height (DBH; 1.37 m) were assessed on $1/25^{th}$ ha plots while pole trees < 20cm DBH were assessed on 1/100 ha plots. One Browns Planar Intercept fuels transect was installed at each plot (Brown 1974). The Dolason Trailhead (DTH) unit (3.2 ha, 8 ac) was treated in the fall of 2006 with a moderate- high intensity burn. Eight monitoring plots were installed immediately post-burn (no true "pre" data were recorded) and assumptions were made concerning the pre-burn live/dead status of trees; plots were re-assessed 7 years post-burn. One Browns fuels transect was installed at each plot. Similar plot sizes were utilized for overstory and pole trees in the Dolason-Airstrip and Dolason Trailhead burn units. The Lower Airstrip Expansoin (LAE) unit (20.2 ha, 50 ac) was treated with low-intensity fire in the fall of 2013. Nine small plots ($1/50^{th}$ ha) were utilized for pole trees < 20 cm (7.9 in) DBH and fuel loading (one transect per plot), while two, 1 ha large plots were installed to capture treatment effects on overstory trees ≥ 20cm DBH. Plots were assessed pre-burn and 1 year post-burn. Both LAE and DA had a mixed composition of Douglas-fir, tanoak (*Notholithocarpus densiflorus* (Hook. & Arn.) P.S. Manos, C.H. Cannon, & S.H. Oh), and redwood, while the Dolason Trailhead unit lacked redwood, but was dominated by Douglas-fir and tanoak. All stands within these units were 40 to 45 years of age at time of treatment. All units had a combination of crown volume scorch and/or bark char height assessed post-burn.

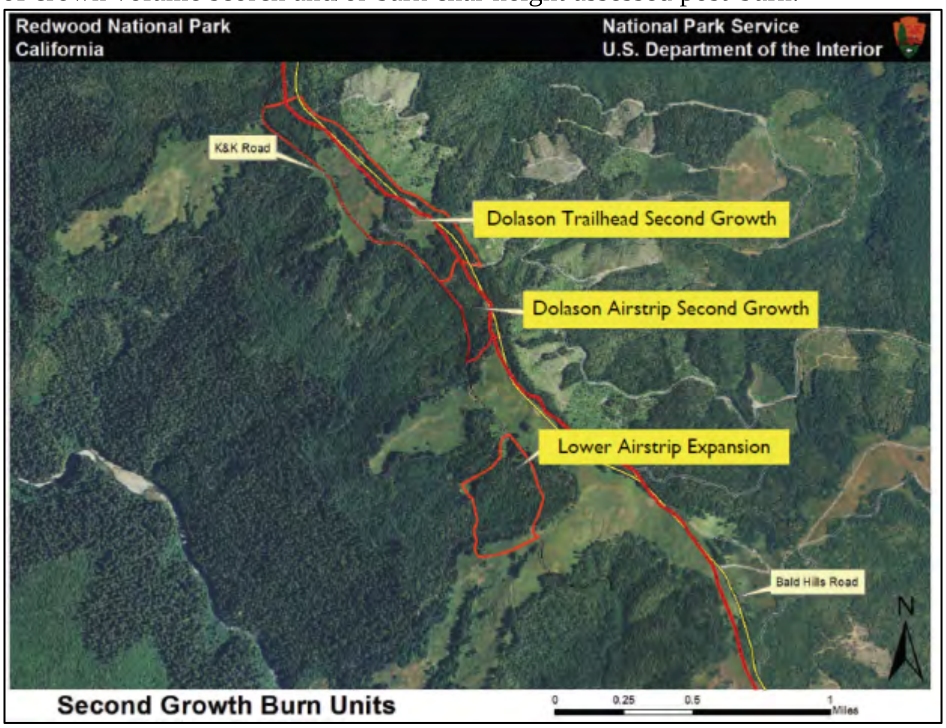

Figure 3—Second-growth burn units in the Bald Hills of Redwood National Park.

Results and Discussion

Outcomes for each of the three burns are presented individually below. Table 1 displays the primary forest attributes monitored for these projects at each measurement, including stand density (trees per hectare [TPHa] and basal area [m^2ha^{-1}, BAHa]), overstory species composition, and fuel loading (fine fuels [1-100Hr] < than 7.6 cm (3 inches) diameter; heavy fuels [1000Hr] > than 7.6 cm diameter). Measures of fire severity, including percent crown volume scorched (excluding DTH where it was not measured) and bole char height, are presented in fig. 4.

Table 1—Results for forest attributes measured for each case study (PRE = prior to fire treatment.; YR-1 and Yr-7 = 1 and 7 years post-treatment, respectively; POST = post burn same season of burn; species composition is in percent)

	Low intensity		Moderate intensity		Mod/high intensity	
Attribute	**LAE PRE**	**LAE YR-1**	**DA PRE**	**DA YR-7**	**DTH - Post**	**DTH YR-7**
TPH*a*	1533	1206	1638	948	469	143
BAHa[b]	86.8	83.5	76.4	76.3	120.4	91.5
Fine fuel TPA	5.3	3.6	4.8	5.9	1.0	7.0
Heavy fuel TPA	11.9	17.7	35.5	28.0	16.7	22.7
Species composition (%)						
Redwood TPHa	13.7	14.1	17.4	23.5	-	-
Redwood BAHa	39.0	39.6	19.5	20.4	-	-
Douglas-fir TPHa	30.9	34.2	29.2	31.5	75.3	91.3
Douglas-fir BAHa	36.5	36.6	49.2	51.2	99.5	99.99
Tanoak TPHa	45.0	40.9	51.2	44.2	24.7	8.7
Tanoak BAHa	21.0	20.2	30.8	28.0	0.5	0.001

[a] TPHa = Trees per hectare; [b] BAHa = Basal Area, square meters per hectare.

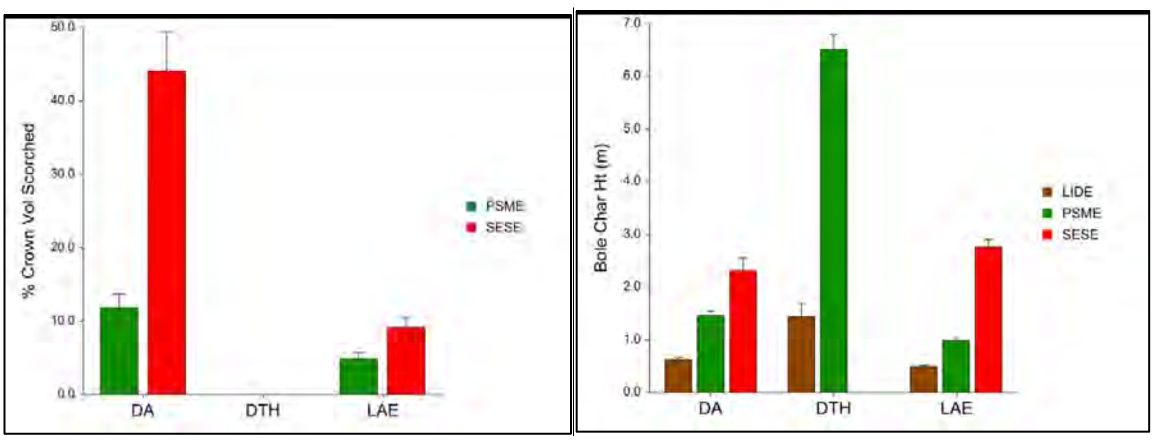

Figure 4—Crown volume scorch (%) (Left) and bole char height (meters) (Right) by species for each of the three prescribed fires. PSME = Douglas-fir, SESE = redwood, LIDE = tanoak.

Case Study #1: Dolason-Airstrip Burn Unit 2007 - Low/Moderate Intensity Prescribed Fire

The Dolason-Airstrip Burn Unit (fig. 5) is a mix of second-growth forest and conifer-encroached prairie. Dominant tree canopy cover is Douglas-fir followed by tanoak and redwood. There had been no prior management of the unit by the Park until the 2007 prescribed burn; monitoring plots were re-measured 1 year post-burn and again in 2014 (7 years post-burn). Fine fuel loading was reduced by about 40 percent immediately following the burn; however by 7 years post-burn, fine fuels recruited 23 percent above pre-burn condition (fig. 6). Heavy fuels remain 21 percent below the pre-burn condition after 7 years.

Figure 5—Fire spread in the Dolason-Airstrip Rx burn.

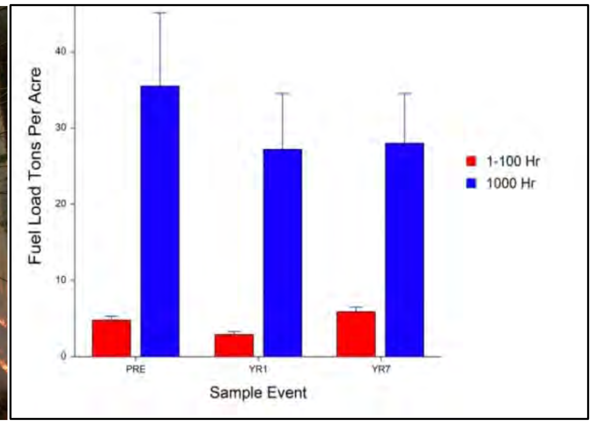

Figure 6—Fine (1-100 hr RED) and heavy (1000 hr BLUE) fuel loading pre-burn, 1 year post-burn, and 7 years post-burn.

Prior to treatment, there was an average of 1,638 trees per ha and 76.4 m^2 of basal area per hectare. Seven years after treatment, there was an average of 948 trees per hectare (42 percent decrease), and 76.3 m^2 of basal area per hectare (no substantial change). Tree mortality was concentrated in the smaller size classes (below 30 cm DBH; fig. 7). Prior to the prescribed burn, there were 68 percent more Douglas-fir trees than redwood trees, and 152 percent more Douglas-fir basal area than redwood basal area. Seven years following the burn entry, there were 34 percent more Douglas-fir trees than redwood; basal area remained unchanged (from 152 to 151 percent) (see table 1 and fig. 7).

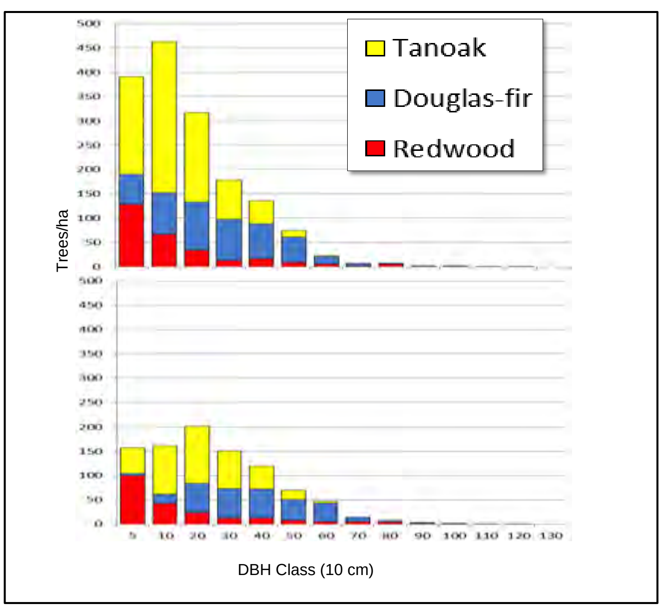

Figure 7—Diameter distribution pre-burn (Top) and 7 years post-burn (Bottom). Bars represent number of trees per hectare (by species) in each 10 cm diameter size class.

Figure 8—Photo-point depicting tree canopy (Top) and understory condition (Bottom) pre-burn (Left), immediate post-burn (Center), and 7 years post-burn (Right). Note resprouting of redwoods from the bole and crown in areas with high crown scorch.

Case Study #2: Dolason Trailhead 2006 - Moderate/High Intensity Prescribed Fire

The Dolason Trailhead burn unit demonstrates the use of moderate-high intensity prescribed fire in Douglas-fir and tanoak forest (fig. 10, fig. 13). Due to circumstances, monitoring plots were installed immediately post-burn, so no true pre-burn data are available. However, at the immediate post-burn sample, the pre-burn stand condition (e.g., living/dead status of trees) was assumed, based on presence/absence of scorched foliage. No pre-burn fuels data are presented. Dominant tree canopy cover is Douglas-fir, followed by a minor understory tanoak component. There had been no prior management of the unit by the Park until the 2006 prescribed fire; monitoring plots were re-measured in 2013.

Fine fuel loading increased by 600 percent between the immediate post-burn sample and the 7 year post-burn sample (table 1, fig. 9). Heavy fuel loading increased by 36 percent between the immediate post-burn sample and the 7 year post-burn sample.

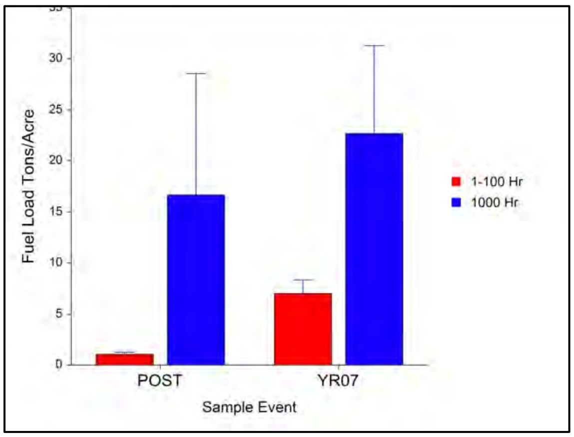

Figure 9—Fine fuel loading (1-100 Hr; Red) and heavy fuel loading (1000 Hr; Blue) immediately post-burn and at 7 years post-burn, Dolason Trailhead Prescribed burn.

Prior to treatment, we assumed there was an average of 469 live trees per hectare and 120.4 m^2 of basal area per hectare (assumption based on estimated live/dead tree status at the immediate post-burn sample event; table 1). Immediately post-treatment, there were 206 live trees per hectare and 103.5 m^2 of basal area per hectare. Seven years after treatment, there was an average of 143 live trees per hectare (69 percent decrease from pre-burn), and 91.5 m^2 of basal area per hectare (24 percent decrease from pre-burn). Tree mortality was concentrated in the size classes below 60 cm DBH. Tanoak dominated the small size classes (< 30 cm DBH); all but one died immediately following the burn, the single survivor perished by year 7 (fig. 11). Most top-killed tanoak currently exhibit 1 m tall basal sprouts (fig. 12).

Figure 10—Moderate to high intensity fire in the Dolason Trainhead Precribed Burn.

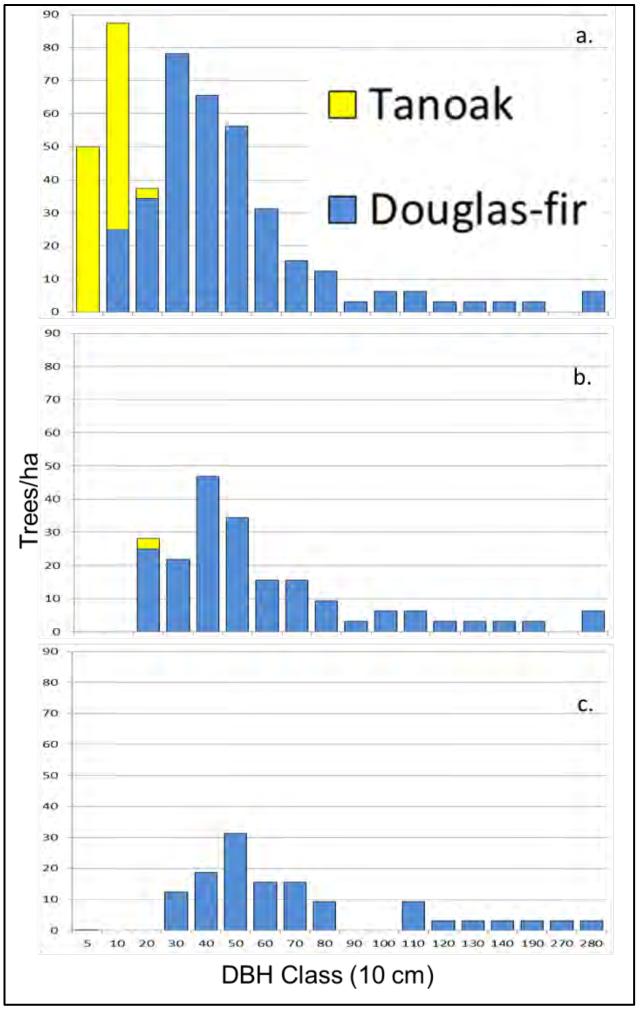

Figure 11—Diameter distribution pre-burn (a) immediately post-burn (b), and 7 years post-burn (c). Bars represent the number of trees per hectare (by species) in each 10 cm diameter size class.

Figure 12—Tanoak mortality and basal sprouting in the Dolason Trailhead Prescribed Burn.

Figure 13—Evident canopy mortality in a high-intensity patch of the Dolason Trainhead Prescribed Burn.

Case Study #3: Lower Airstrip Expansion 2013: Low Intensity Prescribed Fire

The Lower Airstrip burn unit is mostly second-growth forest dominated by Douglas-fir, with lesser amounts of tanoak, redwood, and other hardwoods. There had been minimal management to the unit by the Park until the 2013 prescribed burn. Monitoring plots were re-measured 1 year post-burn.

Fire spread was intermittent throughout the Lower Airstrip Prescribed Burn due to moist fall conditions, and mostly low intensity, with flame lengths typically less than 0.3 m (1 ft) (fig. 14), though there were small pockets (~1/20th ha) of high-intensity fire where fuels, topography, and ignition patterns aligned. 1000 hr fuel moisture was sampled pre-burn and ranged from 27 to 47 percent (mean = 34 percent). Many areas with green vegetation (ferns) or short-needle litter (Douglas-fir fuelbeds) carried fire poorly and resulted in a patchy burn pattern (fig. 15). At 1 year post-burn, fine fuels (1, 10, and 100 hr) were reduced by 33 percent, while heavy fuels (1000 hr sound and rotten) increased by 48 percent.

Figure 14—Low-intensity fire behavior in the Lower Airstrip burn, concentrated in redwood leaf litter.

Figure 15—Heterogeneous burn pattern in the Lower Airstrip Expansion unit resulting from moist fall conditions.

Almost 1400 living and dead trees were sampled in the monitoring plots pre-burn. Overall tree mortality was low at 1 year post-burn, as expected given the low-intensity fire behavior observed during the burn. For overstory trees ≥ 20 cm DBH, the 1 year post-fire mortality rate for redwood was 1.4 percent, 2.1 percent for Douglas-fir, and 2.2 percent for other species (tanoak and California laural [*Umbellularia californica* (Hook. & Arn.) Nutt.]); in other words, overstory composition didn't change much following the burn. Trees smaller than 20 cm DBH exhibited an overall mortality rate of 58 percent for redwood, 25 percent for Douglas-fir, 36 percent for tanoak, and 21 percent for laurel (fig. 18). Mortality of redwood was mostly concentrated in trees smaller than 10 cm DBH, many of which re-sprouted. The greater mortality of redwood compared to other species may be biased since areas with redwood were more likely to burn than areas without (e.g., Douglas-fir dominated patches) under the damp fall conditions.

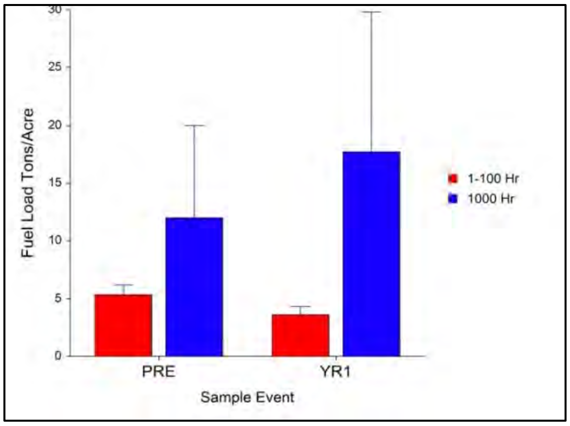

Figure 16—Fine fuel loading (1-100 Hr) and heavy fuel loading (1000 Hr) pre-burn, and at 1 year post-burn. Lower Airstrip Prescribed Burn Unit.

For overstory redwoods, 29 percent of the stems had new basal sprouts at 1 year post-burn, with a mean sprout height of 38.1 cm. Redwood poles had an even more vigorous sprouting response, with 73 percent re-sprouting from the base (mean sprout height of 35.6 cm) and 27 percent from the bole (epicormic). Areas with higher fire intensity appeared to have a more vigorous sprouting response (fig. 17). Portions of the stand with more redwood litter (surface fuel) burned with greater fuel consumption and continuous fire spread due to the flammable redwood leaf litter.

Figure 17—Basal and epicormic sprouting on redwood in the Lower Airstrip Expansion Burn Unit.

If tree mortality and crown scorch data for the DA and LAE burn units are pooled together (both of which had redwood in the overstory), redwood appear to have a greater tolerance for crown scorch than Douglas-fir (fig. 19). For example, Douglas-fir trees killed by fire had an average crown volume scorch close to 40 percent, while redwood killed by fire had an average crown volume scorched over 80 percent. Additionally, there were 52 individual redwoods that suffered 90 percent crown scorch or more; out of these 52 trees, only 26 died, and all but one of those were 15 cm (6 in) DBH or smaller.

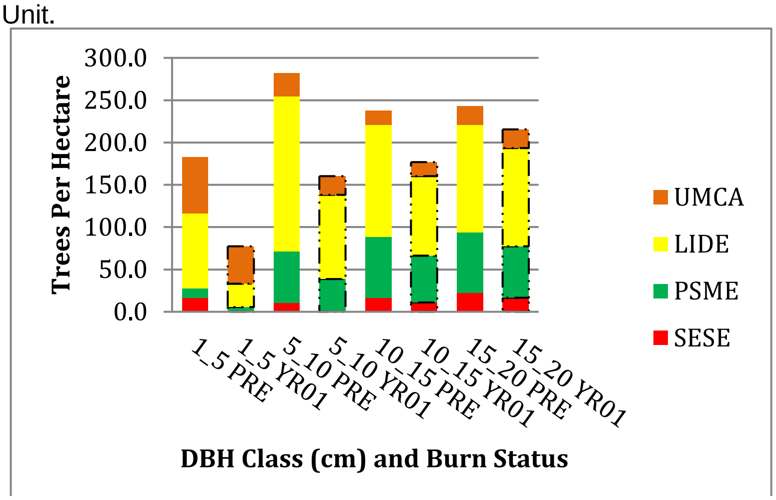

Figure 18—Small tree (< 20 cm DBH) diameter distribution by 5 cm size classes and paired pre-burn and YR-1 condition. Colors represent species. UMCA = California Bay, LIDE = tanoak, PSME = Douglas-fir, SESE = Redwood.

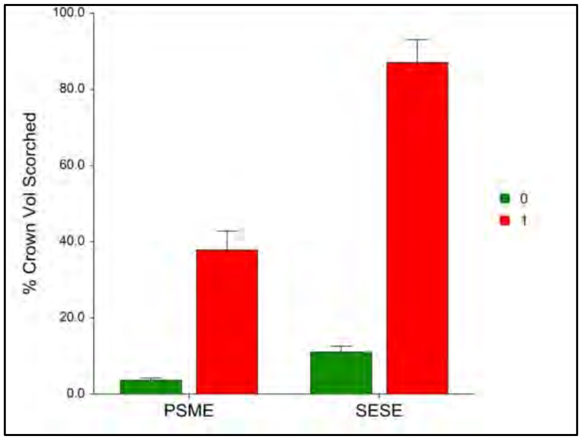

Figure 19—Crown volume scorch (%) and mortality status (0 = living, 1 = dead) for Douglas-fir (PSME) and redwood (SESE) trees in the DA and LAE burn units.

Conclusions

Forest Structure

The low-intensity prescribed fire resulted in relatively small changes to overstory forest structure, with some mortality of smaller trees concentrated below 20 to 30 cm DBH. Moderate to high intensity fire may increase mortality in Douglas-fir up to 60 cm DBH, and top-kill understory tanoak (e.g., DTH burn). Redwoods appear to have a higher tolerance for crown scorch, and with the ability to resprout from the crown and bole, may have a competitive advantage in high-intensity patches. Redwood's main competition—Douglas-fir in the larger classes—may not be affected by low-moderate intensity fire and may require follow-up mechanical thinning to achieve forest restoration objectives. Burning initiates a vigorous sprouting response (basal and epicormic) on pole and overstory redwoods and tanoak, which will result in new cohorts of trees.

Fuels and Fire Behavior

Redwood leaf litter is quite flammable and areas dominated by redwood were observed to burn at a higher intensity and with greater fuel consumption than areas dominated by Douglas-fir. While small redwoods may be susceptible to mortality, competitors are likely to suffer greater injury, and the ability of redwood to resprout may give the species an advantage over Douglas-fir. Fine fuels fully recover, even exceed pre-burn load by 7 years post-burn, suggesting re-entry may be required to maintain low fuel loading. Heavy fuels may remain unchanged (low intensity burns) or increase or decrease (moderate-high intensity burns) by 7 years post-burn.

Management Implications

Prescribed fire may be a viable second growth management tool, with some notable differences to standard silvicultural methods. The application of prescribed fire:

- returns a key process to fire-adapted landscapes and may have unique effects;
- may promote redwood, but with less control over outcomes;
- may not always achieve large Douglas-fir mortality goals while remaining in prescription, requiring mechanical thinning to remove large trees.

The use of prescribed fire in second growth forests warrants further study to assess patterns in tree mortality under hotter burn prescriptions, the role of redwood stump smoldering and consumption in redwood mortality, and understory vegetation recovery following fire.

Acknowledgments

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