Damage and Mortality Assessment of Redwood and Mixed Conifer Forest Types in Santa Cruz County Following Wildfire

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Abstract

On August 12, 2009, the Lockheed Fire ignited the west slope of the Santa Cruz Mountains burning approximately 7,819 acres. A mixture of vegetation types were in the path of the fire, including approximately 2,420 acres of redwood forest and 1,951 acres of mixed conifer forest types representative of the Santa Cruz Mountains. Foresters and land managers were left with tough decisions on how to treat tree damage and mortality compounded by the Pine Mountain Fire which occurred in the same area in 1948. Big Creek Lumber Company (BCL), Cal Poly's Swanton Pacific Ranch (SPR) and other professionals familiar with this region of redwood teamed up to develop a method for evaluating damage and mortality. Qualitative criteria for evaluating stand damage focused on historic defect, cambial death, root damage, and associated fire intensity. Quantitative damage criteria was used to contrive three mortality assessment tables, broken up by diameter class (1 through 8, 9 through 16, 17+), for all tree species and tested against 83, 1/5th acre fixed plots from SPR's Continuous Forest Inventory. Since the initial mortality evaluation using the new tables in fall of 2009, each of the 2877 trees have been re-evaluated in spring 2010 and spring 2011. Accuracy against the initial evaluation is 89.3 percent.

Key words: damage, hardwood, mortality, redwood

Introduction

What should be harvested to encourage regeneration of selectively-managed forestland in the Southern Subdistrict of the Coast Forest District following wildfire? What determines tree mortality for the purpose of amending the sustainability analysis (SA) of a Non-industrial Timber Management Plan (NTMP) following wildfire? Charged with managing and maintaining the health and vigor of the forest ecosystem, foresters and land managers need an accurate way of field-evaluating damage and mortality in conifers and hardwoods immediately following wildfire. These questions and many others not related to forest health, loomed for the local forestry community following the Lockheed Fire. This paper is a case study to provide other foresters and land managers with information and knowledge gained through our experiences following the Lockheed Fire to help make decisions about damage and mortality in conifers and hardwoods as a result of wildfire.

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Seasonal context

The time of year and prevailing wind direction during the Lockheed Fire was very similar to conditions during the Pine Mountain Fire, which is the last recorded and mapped fire perimeter within the Lockheed Fire area. The Pine Mountain Fire burned in September 1948, 61 years ago, and consumed 15,899 acres. The Lockheed Fire also took place in late summer, a season when historically lightning strikes have caused fires in the Santa Cruz Mountains; although the Lockheed Fire was human-caused. Other large historic fires are known to have occurred in the vicinity of the Lockheed Fire near the turn of the 19th century associated with logging and power generation projects in the Scotts Creek watershed.

Damage assessment

The land management goals of the large Timber Production zoned parcels are for timber production and protection of associated resources such as wildlife, fisheries, and watershed. The mission of the landowners affected by this fire was to determine the level of defect and remove some of the most damaged wood to bring defect down to an acceptable level for future management.

Consider the accounting for a timber harvest conducted a few years ago in an area heavily hit by the Pine Mountain Fire, where the defect was 23 percent, about 11 percent higher than "average" for the Santa Cruz Mountains. The loss of net return to the landowner was about $71,500 for approximately 1 million board feet harvested.

Fire intensity

In order to understand burn intensity patterns, fire behavior was estimated for the day the fire started under the prevailing weather and fuel conditions. Five different fuel models, representing five vegetation types, were used in the BehavePlus computer simulation to estimate fire behavior. The BehavePlus fire modeling system is a collection of models that describe fire behavior, fire effects and the fire environment.

Burn severity analysis was conducted initially by a Risk Assessment Team put together by Cal-Fire. The team used a Burned Area Reflectance Classification (BARC) satellite-derived map of post-vegetation condition made by comparing satellite near and mid infrared reflectance values. This data was evaluated in several ways. Some team members flew over the fire area on the first clear day and photographed post-fire conditions. Other team members made ground-based observations over the fire area while assisting with suppression and suppression repair efforts. Burn severity across the entire burn area was estimated to be 14 percent very high, 37 percent high, 43 percent moderate, and 6 percent low.

Research

Foresters working in the burned area began researching what to expect from the various levels of burn damage. Little research or literature is available relative to wildfire impacts on redwood defect and mortality, especially in this region. Several papers about fire damage and anticipated mortality from prescribed burns in mixed-conifer forests were helpful. One paper emerged with practical insights on tree mortality and wildfire from Willis W. Wagener in 1961 (Wagener 1961), called "Guidelines for Estimating the Survival of Fire Damaged Trees in California."

Following a literature review, many conversations occurred with other foresters and land managers throughout the state to learn from their experiences. Contacts included:

- Mike Jani and John Anderson from Mendocino Redwood Company, with experience the year prior conducting salvage operations on the Lightning Complex Fire.
- Lathrop Leonard from California State Parks with experience in prescribed burning.
- Rich Casale, District Conservationist, USDA Natural Resources Conservation Service.
- David Van Lennep and Mike Duffy from Redwood Empire Sawmills. We toured the Summit Fire area that has been salvage logged by them the year prior.
- Dale Holderman, Chief Forester emeritus for Big Creek Lumber Company, with significant experience in defect levels in the Santa Cruz Mountains.

Repeatedly other land managers stated that the salvage operations undertaken in burned areas did not remove enough of the damaged timber. Significant loss of future commercial value is expected as a result of the persistent fire-scar defect.

Cambium death, root damage and crown scorch

Determining the level of internal defect from the external visual indicators on the tree immediately post-fire was very difficult. The methodology evolved over the course of months investigating the extent of the burn and initiating salvage operations in the most severely burned areas, and is still ongoing. Foresters started out chipping into the bark of trees with a hatchet to see what types of bark characteristics are indicative of damage to the cambium layer. Immediately after the fire as the cambium was dying, that layer appeared very dry compared to live cambium which oozed resin. Dying cambium also sometimes appeared grey versus red or pink for live cambium. A particularly useful tool turned out to be delivering a sound kick to the tree. A hollow sound would indicate that the cambium had died and the wood separated from the bark.

On some trees bark burned completely through exposing the wood underneath. Other trees had cracks in the bark showing the wood indicating that the cambium had been burned. Other trees had hollowed-out bases where large quantities of roots had been burned. Reduced root mass affects the tree's growth rate and if the damage is substantial, it can affect the trees stability and slow the rate of recovery. Many scorched trees that experienced crown fire lost all of their needles during the first winter, which provided a good carpet of mulch on the ground.

Trees with cambium damage in multiple quadrants were considered to be substantially damaged, especially when occurring in conjunction with previous scars. Although redwood compartmentalizes rot as it grows over it, the dead cambium will rot wood interior to it. The effects of dead cambium introducing defect are immediate. As the water transport cells break down, the sapwood dries out and is therefore susceptible to dry rot and termite attacks.

As the trees began to grow, the cracks in the bark where cambium had burned began to separate. Now, 2 years after the fire, the bark plates have separated where cambium died and you can see the cambium growing over the dead wood layer and re-sealing the perimeter of the tree. Badly burned trees developed a variety of fungus and lichen on the scorched bark, giving clues about the extent of internal damage.

There was increased burn damage in certain environmental settings such as: where ladder fuels were present, next to a more flammable vegetation type, on ridges, in topographic chimneys, in dense stands of un-thinned trees and where there was a heavy duff layer, legacy stumps, or lots of downed wood. Canopy damage ranged from an un-phased crown to all but the biggest limbs completely consumed in a crown fire. Severely burned trees did not re-sprout from the limbs, but only from the bole, like a bottle-brush. Where new limbs or tops are formed, the dead wood will be subsumed in the new growth, creating a weak spot in the wood.

Most second growth redwood trees that have experienced an intense wildfire in the past have an interior cylinder of rot. Using the U.S. Department of Agriculture, Forest Service Log Scaling and Grading Rules, that defect is “squared out” in order to account for waste when manufacturing dimensional lumber. The quality of the wood going into the mill is very important for the end result of producing sound building materials. Compounded defect from multiple fires would severely impact the manufacturing of high grade lumber. Experience dictates that defect levels elevated above 20 percent have dramatic consequences for the net return of a timber harvest for the landowner.

Adaptive management

During the first fall after the fire, a small area (4 ac) was salvage logged with ground based equipment to see the extent of the burn damage. Initiating the salvage effort offered an opportunity for foresters to verify the external indicators used to determine defect. Once the trees were cut, the dead cambium sections were discernible in the cross-section because the usually fuzzy, fibrous inner bark becomes smooth and sometimes separated from the wood when it is dead.

The rot from the fresh fire scars had already started. Landowners wishing to grow sound trees for sustainable harvest had to react. More damage was sustained to the timber resource than was recouped in the salvage. Trees left with fire scaring and dead wood are more vulnerable to fire and insect attack going into the future. Due to the practice of leaving the healthiest residual trees to retain structure for wildlife and maintain microsite characteristics, many trees were left. It was not inexpensive to log, nor did it produce windfall profits. Compounding the loss, the low profitability in Douglas-fir markets necessitated that many thousands of dead Douglas-fir trees be left standing. Redwood seedlings were under-planted in some of these areas.

Helicopter salvage harvest

Multiple land managers elected to proceed with a salvage harvest by helicopter. Helicopter harvesting is extremely expensive, but avoids the ground disturbance of conventional harvest methods such as tractor logging. The salvage operation was a long-term land management decision to "cut the losses" and establish better wood quality in the future. Helicopter harvesting affects the bottom line, but weighing all decision-making factors, it made sense for the initial salvage effort due to the resource protection it affords as a result of the minimal ground impact. Other factors affecting the decision to fly included the relative inaccessibility of the ground, seasonal restrictions for sensitive species, the helicopters availability, and the desire to recover the damaged wood quickly.

Mortality assessment

The SPR NTMP was approved in June of 2008. Encompassed in this document is the sustainability analysis (SA) required by the Forest Practice Rules to demonstrate movement toward a fully regulated state of harvest over time. In essence, this means a "cut what you grow" type system focused on the long term sustained yield of forest products. Once the Lockheed Fire burned over the majority of the SPR NTMP area, the SA had to be re-evaluated. What determines tree mortality for the purpose of amending the NTMP's sustainability analysis following wildfire?

Mortality assessment method

SPR's Continuous Forest Inventory (CFI) samples approximately 2 to 3 percent of the forested area, probably considered by most to be a lower sample for most forest inventories. Where the SPR CFI system excels is in sampling intensity within the plot, measuring all trees in the plot down to one inch Diameter at Breast Height (DBH). Each tree is numbered and has a distance and bearing recorded to plot center so it can be tracked over time. Last re-measurement of the 83 CFI plots in the burn area was 2008 and 2003. This means an excellent record of tree condition prior to the fire now exists.

The purpose of the mortality assessment was to test a set of guidelines based on professional opinion and available scientific literature for the forester or land manager to utilize to evaluate conifer and hardwood mortality levels immediately following wildfire.

The mortality assessment began with an initial evaluation in fall of 2009. The data listed below was gathered on each tree in the plot and applied to *tables 1*, *2* and *3* (below) to evaluate tree mortality:

1. Percent of crown remaining on each tree to 1 inch DBH
2. Percent of crown sprouting on each tree to 1 inch DBH
3. Basal sprouting? Y/N
4. Percent of root system and cambium quadrants (four possible) destroyed by fire (not recorded, but evaluated)
5. Will the tree live or die? Y/N
6. 10th acre plot regeneration less than 1 inch DBH
7. Plot photos in cardinal directions

The tables below state the characteristics that were assessed on each tree to determine whether the tree would live or die. For example, look at *table 2*, Tanoak:

- zero percent canopy remaining
- less than 5 percent canopy sprouting

- missing more than 66 percent of its root system
- Two quadrants of cambium destroyed by fire
- The tree was considered dead.

Table 1—*Thresholds for determining tree mortality*: *1 – 8 inch DBH classes* (*1.0" – 8.9"*).

Tree Species	Percent canopy remaining	Percent canopy sprouting	Percent of root system missing	Cambium quadrants destroyed by fire
Redwood (RW)	0%	10%	33%	1
California nutmeg (CN)	0%	10%	33%	1
Live oak (LO)	0%	10%	33%	1
Tanoak (TO)	0%	10%	33%	1
Red alder (RA)	0%	10%	33%	1
California bay laurel (CL)	0%	10%	33%	1
Pacific madrone (PM)	0%	10%	33%	1
Big leaf maple (BM)	0%	10%	33%	1
Douglas-fir (DF)	70%	N/A	33%	1
Monterey pine (MP)	70%	N/A	33%	1
Knobcone pine (KP)	70%	N/A	33%	1

Table 2—*Thresholds for determining tree mortality: 9 – 16 inch DBH* (*9.0" – 16.9"*).

Tree Species	Percent canopy remaining	Percent canopy sprouting	Percent of root system missing	Cambium quadrants destroyed by fire
Redwood (RW)	0%	5%	66%	2
California nutmeg (CN)	0%	5%	50%	2
Live oak (LO)	0%	5%	66%	2
Tanoak (TO)	0%	5%	66%	2
Red alder (RA)	0%	5%	50%	2
California bay laurel (CL)	0%	5%	50%	2
Pacific madrone (PM)	0%	5%	50%	2
Big leaf maple (BM)	0%	5%	50%	2
Douglas-fir (DF)	60%	N/A	33%	1
Monterey pine (MP)	60%	N/A	33%	1
Knobcone pine (KP)	60%	N/A	33%	1

Table 3—*Thresholds for determining tree mortality: 17.0+ inch DBH classes* (*17.0"+*).

Tree Species	Percent canopy remaining	Percent canopy sprouting	Percent of root system missing	Cambium quadrants destroyed by fire
Redwood (RW)	0%	0%	66%	3
California nutmeg (CN)	0%	0%	50%	2
Live oak (LO)	0%	0%	66%	3
Tanoak (TO)	0%	0%	66%	3
Red alder (RA)	0%	0%	50%	2
California bay laurel (CL)	0%	0%	50%	2
Pacific madrone (PM)	0%	0%	50%	2
Big leaf maple (BM)	0%	0%	50%	2
Douglas-fir (DF)	60%	N/A	33%	2
Monterey pine (MP)	60%	N/A	33%	2
Knobcone pine (KP)	60%	N/A	33%	2

Each tree was evaluated, qualitatively, around these guidelines, but if the tree met all of the thresholds by DBH category it was considered dead.

Mortality assessment results

The mortality assessment began with an initial evaluation in fall of 2009 These same 83 plots (2,877 trees) were re-evaluated in spring of 2010 and spring of 2011 to determine whether the initial mortality assessment in fall of 2009 was correct. Overall weighted average for percent accuracy to date is 89.3 percent. See *tables 4*, *5*, and *6* below for more detailed information on species, diameter class, percent accuracy and sample size.

Table 4—*Accuracy of tree mortality assessment: 1 – 8 inch DBH.*

Tree Species	Percent accuracy	Sample size
Redwood (RW)	90.4%	470
California nutmeg (CN)	58.3%	12
Live oak (LO)	85.9%	207
Tanoak (TO)	88.0%	302
Red alder (RA)	62.5%	8
California bay laurel (CL)	84.0%	119
Pacific madrone (PM)	77.0%	61
Big leaf maple (BM)	0.0%	2
Douglas-fir (DF)	96.2%	290
Monterey pine (MP)	82.3%	17
Knobcone pine (KP)	0.0%	0
Weighted average	**88.7%**	1488

Table 5—*Accuracy of tree mortality assessment: 9 – 16 DBH.*

Tree Species	Percent accuracy	Sample size
Redwood (RW)	93.2%	223
California nutmeg (CN)	80.0%	5
Live oak (LO)	88.0%	150
Tanoak (TO)	83.9%	181
Red alder (RA)	0.0%	0
California bay laurel (CL)	66.0%	50
Pacific madrone (PM)	73.0%	15
Big leaf maple (BM)	0.0%	0
Douglas-fir (DF)	97.5%	122
Monterey pine (MP)	78.9%	19
Knobcone pine (KP)	100.0%	3
Weighted average	**88.1%**	768

Table 6—*Accuracy of tree mortality assessment: 17.0+ inch DBH.*

Tree Species	Percent accuracy	Sample size
Redwood (RW)	97.7%	271
California nutmeg (CN)	66.0%	3
Live oak (LO)	89.1%	74
Tanoak (TO)	95.4%	66
Red alder (RA)	28.6%	7
California bay laurel (CL)	55.0%	9
Pacific madrone (PM)	50.0%	6
Big leaf maple (BM)	0.0%	0
Douglas-fir (DF)	90.5%	180
Monterey pine (MP)	100.0%	2
Knobcone pine (KP)	100.0%	3
Weighted average	**92.4%**	621

Mortality assessment discussion

The mortality assessment was led in the field by the same SPR forestry technicians for all three evaluation periods maintaining continuity in an assessment that had a manageable level of subjectivity.

Following the initial evaluation of the 83 plots in fall 2009 portions of the burn area were salvaged harvested in 2010 and harvested under the SPR NTMP in 2011. Forestry technicians were very systematic at determining if trees evaluated in 2009 were affected by harvesting activities. If so, those trees were removed from the sample for the purposes of this test.

Accuracy for the mortality assessment tables in the first two evaluation periods (spring 2010 and spring 2011) following the initial evaluation in fall 2009 at 89.3 percent was strong, but the mortality assessment table faltered a little in the thinner bark species; California nutmeg, red alder, California bay laurel, Pacific madrone, and big leaf maple in the mid (9” to 16” DBH) and upper (17.0+” DBH) diameter classes. Based on the data set, reducing the “Cambium quadrants destroyed by fire” to “one” in both the mid and upper diameter classes would increase accuracy. These trees did not withstand as much cambial damage as expected.

The mortality assessment showed very strong results in redwood, tanoak, live oak, Douglas-fir, Monterey pine, and knobcone pine to date. Adjustments to increase accuracy for these species would likely require additional data on other burn characteristics such as scorch height and bark thickness.

Conclusion

A combination of factors affected the decision making process in regards to what trees were harvested to encourage regeneration of managed forestland following wildfire. One or more of the following criteria affecting an individual tree were reason to suspect substantial damage and sustained negative impacts from the fire: cambium damage on multiple sides of the tree, extensive root damage with voids under the tree, extensive crown consumption or scorching that kills limbs, and significant prior defect combined with damage. This is an ongoing learning experience that will be refined as time passes and managed forestland continues to burn and be harvested.

The process of damage evaluation provided significant direction to determine an applied set of quantitative criteria to develop the mortality assessment. It is clear that more years need to pass to understand the full effects that the Lockheed Fire, compounded by the Pine Mountain Fire, had on the forested area in the Scotts Creek watershed. Follow-up surveys will re-visit the 2,877 trees each spring to see if the mortality assessment table continues to hold its accuracy. There is also movement from Cal Poly San Luis Obispo to begin sampling scorch height and bark thickness in addition to the mortality assessment in an attempt to create a local wildfire mortality equation.

References

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