Fire Behavior in Beetle-killed Stands:

A brief review of literature focusing on early stages after beetle attack

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Background

The Pacific Southwest Region recognized that the historically unprecedented tree mortality event currently occurring in California is resulting in altered fuel characteristics with potential effects on wildfire behavior. As stated by the Deputy Regional Forester "What is the actual fire behavior in tree mortality areas?" An understanding of fire behavior is necessary to address time critical needs of fire mangers to make decisions regarding firefighting strategies and tactics.

In 2016, the Fire Behavior Assessment Team (FBAT) collected direct observations and measurements of fire behavior in bark beetle-caused tree mortality on the Cedar Fire. However information from this one case study does not alone adequately answer the question of "What is fire behavior in tree mortality areas?" FBAT is prepared to collect a larger number of observations in 2017 to better describe actual fire behavior in areas with significant bark beetle-caused tree mortality, however, beetle-killed stands are changing rapidly. Some beetle-infected trees which were in the red stage (needles dead, attached and orange/red colored) last year are already losing needles and transitioning to the grey stage (most needles off, branches remain).

The purpose of this brief literature review is to outline and make available current research and case studies on fire behavior in forests with bark beetle-caused tree mortality to supplement field observations and measurements. Much of the literature and case studies available come from the U.S. and Canadian Rockies in lodgepole pine or Englemann spruce which may not be directly applicable to Sierra Nevada mixed-conifer due to differences in stand structure and fuel arrangement. Some information based on modeling results are noted because there is a paucity of direct observation of fire behavior, however, these results should be considered in light of the limitations of the models used. Note that this is a brief review covering information relevant to fire managers in the Sierra Nevada tree mortality zones, and a fair number of manuscripts have not been directly included or cited.

Field Case Studies and Anecdotal Observations

Few fully-documented case studies of fire behavior in forests with bark beetle-caused tree mortality exist in the literature, and of those available, most are from the Rockies where tree mortality has occurred in past years. Several case studies are documented below, however, most are not from the Sierra Nevada.

- Perrakis et al. (2014) estimated rate of spread in 16 mountain pine beetle-killed lodgepole pine stands (1-5 years since peak attack) in British Columbia using photographs from aircraft, airborne measurements of wildfire spread, and experimental burns. They analyzed their observations based on weather and found that fires spread **2.7** times faster and had more crown fire than expected than fires in areas without beetle kill.

- On the 2012 Halstead Fire in southwestern Idaho, 'crews observed a rapid transition from surface to crown fires where mixtures of green and red needles existed in the canopy. Unusual fire behavior was observed including passive, active and independent crown fire and spotting capable of igniting canopy fuels in the absence of surface fire' (Jenkins et al. 2014).
- Bond et al. (2009) analyzed trends in fire severity in the San Bernardino Mountains for fires occurring during red phase mortality, however, no observations of fire behavior were noted. Additionally, the tree mortality in this area was patchier and at lower levels than the current mortality in the southern Sierra Nevada.
- Average rates of spread for August 18th on the 2016 Cedar Fire, Sequoia National Forest, CA, which included areas of red phase tree mortality, were estimated at 8-12 ch/hr over 8 hours and 18 ch/hr over 12 hours as estimated from aerial imaging and webcam imagery (Reiner et al. 2016). Estimated intra-day fire perimeters in WFDSS for August 17th indicate that rates of spread during peak burning periods could have been even higher. (Weather at the Johnsondale RAWS, near the Cedar Fire, for August 18th at 1300 was 89° F; relative humidity 6%; windspeed (gusts) 4 (13) mi/hr.)
- Page et al. (2014) compiled case studies of fire behavior observations in stands with bark beetle-caused tree mortality during the red stage and noted several differences between healthy stands and beetle-affected stands:
    - In spruce budworm-killed balsam fir in Ontario, peak fire behavior potential occurred 5-8 years after mortality due to a combination of crown breakage and windthrow. Modeled rates of spread were 2.5 to 3.6 times greater than in healthy stands (Stocks 1987, Alexander and Cruz 2013).
    - Fire behavior on wildfires in recently attacked lodgepole pine in British Columbia showed 'increased probabilities of ignition, a lower surface fire intensity threshold to initiate crowning' and long distance spotting in low wind conditions (Armitage 2004).
    - Post-hoc model runs simulating the beetle-attacked lodgepole pine on the 2005 Valley Road Fire, Idaho, in stands with a significant amount of red foliage and some gray, showed predicted rates of spread of 4.5 ch/hr for a 'very dry' scenario compared with observed rates of spread in excess of 60 ch/hr (Simard et al. 2011).
    - In mountain pine beetle-attacked lodgepole stands on the 2011 Saddle Complex, Idaho, in red and gray foliage, active crown fire was observed at 68 - 81 ch/hr, whereas predicted spread for that day based on the dwarf conifer fuel models (TU4) was 21 ch/hr (Church et al. 2011).

Figure 1. The lower branches of a red phase tree in background begin to torch on the Cedar Fire. Photo courtesy of Tim Sexton.

Fuel Moisture

Foliar moisture has been found to be lower in bark beetle attacked trees, which effectively lowers the amount of heat required to ignite the foliage of attacked trees, suggesting that 'crown fire potential may be higher in attacked stands as long as foliage is retained on the tree' (Jolly et al. 2012). Jolly et al. (2012) found that fuel moistures of lodgepole pine foliage from Colorado and western Montana were an average of 12% for red needles and 109% for green. Page et al. (2012) found similar moisture (13%) for red needles of lodgepole in eastern Idaho. Field data from Engelmann spruce in northern Utah showed that foliar moisture in new green foliage was 325% in June and 125% in September, dropping to 75-100% in green trees infested with beetles and 25-50% moisture (June-July) in yellow needles (Page et al. 2014). The Fire Behavior Assessment Team (FBAT) found foliar moistures from red-stage ponderosa pine and incense-cedar to be 7% which was within the range of predicted fine dead fuel moisture for burn periods during the 2016 Cedar Fire, CA. FBAT also found foliar moisture from recently dead incense cedar, similar to yellow stage, was 30% (Reiner et al. 2016). The lower foliar fuel moistures of trees in the red stage allows the transition of fire from the surface to crowns 'when such a transition would otherwise be unlikely if the stand contained only live and healthy foliage' (Page et al. 2014).

Fuel Arrangement

The arrangement of fuels changes with beetle attack. As trees shed needles, surface fuels increase (Page et al. 2014, Hicke et al. 2012). Solar radiation and wind are higher in more open canopies. Both of these factors could act in concert to increase drying and the total amount of fine dead fuels on the surface, potentially increasing surface fire behavior compared to pre-attack conditions (Jenkins et al. 2014, Hicke et al. 2012). Fire managers have noted that shrubs with needle drape are expected to have higher flame lengths (B. Skaggs pers. com. 2017).

The time it takes needles to fall after attack is different between species, and is not documented in the literature for Sierra Nevada mixed-conifer species at the time of this report. Jenkins et al (2014) notes that needles can fall in as little as one year in Engelmann spruce and 1-3 years in lodgepole pine. Aerial detection surveys have shown some mortality beginning in 2014 in California and widespread mortality in 2015 in the southern Sierra Nevada. Parts of the southern Sierra Nevada have trees which have shed some or all of their needles at the time of this writing (spring 2017), leading to the assumption that Sierra Nevada mixed-conifer species may shed needles in as little as 2 years if exceptionally stormy winters are involved such as the winter of 2016-2017.

Fire modeling case studies

Several attempts have been made to model fire behavior in beetle-killed stands, however, results are mainly in lodgepole pine forests, are not all congruent, and are subject to the limitations of the models. Predicted surface fire rates of spread and intensities (from empirical models) were higher in mountain pine beetle-infested (epidemic levels of infestation) lodgepole pine stands due to increased fine fuels (Page and Jenkins 2007). Simard et al. (2011) found lower active crown fire in mountain pine beetle-affected lodgepole stands due to lower canopy bulk density. Schoennagel et al. (2012) suggest that active crown fire may not be qualitatively different between different stages of beetle-killed lodgepole under extreme burning conditions. Hoffman et al. (2012) used the Wildland-Urban Interface Fire Dynamics Simulator to model fire in mountain pine beetle-attacked lodgepole pine and found that crown fire intensity increased with increasing bark beetle-caused tree mortality.

Model predictions of fire behavior in trees with dead foliage are weak due to the limitations of the models. Alexander and Cruz (2012) evaluated five fire behavior models (Van Wagner, Albini, Lindenmuth and Davis, Rothermel, and FCCS) and noted that 'none were ever intended to be applied to dry, dead canopy foliage and it is quite clear they would not be appropriate for such use.' The limitations of the empirical models includes 'a clear under-prediction bias when the onset of crowning and crown fire rate of spread is determined' and the assumption of homogenous fuels. The physics-based models may overcome some of these assumptions and limitations, however, 'field validation is limited, especially in conifer forests' (Jenkins et al. 2014).

Differences between Sierra Nevada mixed-conifer and Rocky Mountain Forest Types

Understanding the differences in stand structure and fuels arrangement between Sierra Nevada mixed-conifer and Rocky Mountain forest types can help in applying information on fire behavior in Rocky Mountain forest types to the Sierras. Lodgepole pine can grow in associations with Engelmann spruce, subalpine fir and other tree species, as well as in single-species stands. Lodgepole pine often grows in dense stands, reflective of its tendency toward stand-replacing fire regimes. Dense stands of lodgepole compete with understory vegetation, reducing grasses and forbs, however, older stands with windthrow or disease can have high quantities of large downed woody material (Anderson 2003). Forests and canopy fuels can be more heterogeneous in Sierra Nevada mixed-conifer than in lodgepole pine stands. Sierra Nevada mixed-conifer forests have a more variable forest structure due to more frequent and mixed-severity fire regimes, with patches of young trees in openings as well as larger, fire-resistant trees (van Wagtendonk and Fites-Kaufman 2006). The patchy character of Sierra Nevada mixed-conifer canopies would likely slow down crown fire, similar to fuels treatments on the landscape, relative to the more homogeneous canopy fuel of lodgepole pine stands. It may not follow that crown fire in tree mortality would always be slower in the Sierra Nevada than in the Rockies, because the potentially higher grass, forb and shrub understory fuels of the Sierra Nevada would tend to increase surface fire intensities and transition to crown fire.

Summary

Although some information exists in the literature pertaining to fire behavior in tree mortality, not all of it is directly applicable to forest types in the Sierra Nevada or should be relied on without considering its limitations. Despite a great wealth of literature on tree mortality ***due to fire*** in the Sierra Nevada, there is almost no literature on the effects of tree mortality ***on fire behavior***. The heterogeneity of forest fuels would tend to slow crown fires compared to more homogeneous canopy fuels, however, the presence of relatively high grass, forb and shrub fuel loadings make it difficult to compare potential crown fire rates of spread between Sierra Nevada mixed-conifer and the Rockies. Fire mangers in California have noted fires transitioning to crown fuels more readily and fire behaving more erratically in tree mortality zones.

As of May 2017, many trees in the southern Sierra Nevada have lost needles and are moving from 'red phase' to 'grey phase.' As more trees on the landscape drop their needles, the canopy fuels available will decrease. Pockets of grey phase mortality could act as 'stumbling blocks,' effectively slowing crown fire runs. However, as fine fuels and larger fuels build up, and as canopies thin and allow more solar radiation and wind to reach surface fuels, potential ***surface*** fire behavior will increase. While red phase mortality exists on the landscape, the potential for these trees to torch will be high. During times when fuels are receptive to spots, fire growth due to spotting could be prevalent in tree mortality areas.

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