FIRE BEHAVIOR MODEL CALIBRATIONS AND ADJUSTMENTS ACCOUNTING FOR FUEL MODEL CHANGES BASED ON INSECT ACTIVITY

Introduction/Background

Over the past two decades insect activity, including mountain pine beetle, spruce beetle, pinyon ipp, and a variety of other bark beetles, have affected more than 41.7 million acres of forest including; ponderosa pine, lodgepole pine, limber pine, Engelmann spruce, Colorado blue spruce, jack pine as well as subalpine fir (2) (7). While bark beetle infestations are a natural occurrence and infestations have occurred at various times dating back as far as 12,000 years, the current infestation seems to be more extensive than past outbreaks. The current outbreak includes National Parks and National Forests throughout the intermountain west as well as areas where bark beetles haven't been previously seen, such as the 37 million acre infestation in British Columbia (6). This is due to several factors, including decreased winter larvae mortality, and homogenous, overstocked, and drought-weakened forests (6).

Impacts to Vegetation

The direct effects to vegetation vary by insect, but in the case of Mountain Pine Beetle, the effects can be detected by changes in stem moisture in as little as two weeks post-infection (9). Once a tree has been successfully attacked, it enters the green attack stage, a condition in which its chemical state is essentially frozen, but the outward appearance of the tree will not change until the following year when the needles redden (9). It is over this next year that the foliar moisture will decline until the foliar moisture nears the 1-hr fine dead fuel moisture (FDFM). The next stage is the red stage in which the needles are retained on the tree for 2-3 years and the foliar moisture generally follows fluctuations in the 1 hour fuel moisture. Once the red needles are shed and become part of the surface fuel bed, the grey stage begins. The grey stage is characterized by standing dead trees without needles. Following the grey stage is an accumulation of 1000-hour and larger fuels in the surface fuel strata.

The red stage results in a foliar moisture at or below typical1-hr FDFM values, and green attacked trees may have a foliar moisture as low as 35-40% (9). This means that the intensity threshold to initiate crown fire (both active and passive) is much lower than in a stand with healthy trees where the foliar moisture would typically be 90-120% (9). As a result, Rate of Spread (ROS) and fire type (crown fire vs. surface fire) in beetle infested areas typically exceed modeled estimates. In stands where there is a mixture of red stage, green attack, grey stage, and healthy trees, a cascade of crown fire initiation can occur where the easily initiated crown fire of red stage can quickly preheat and initiate crown fire in the green attack trees, which can in turn preheat and initiate crown fire in healthy trees. The cumulative effect of the fire in the red stage, green attack, and healthy trees, can then preheat the grey stage trees. This cascade of crown fire results in a fire that is sustained more easily and for a longer period of time. This effect is more easily understood when looking at the figures below (9).

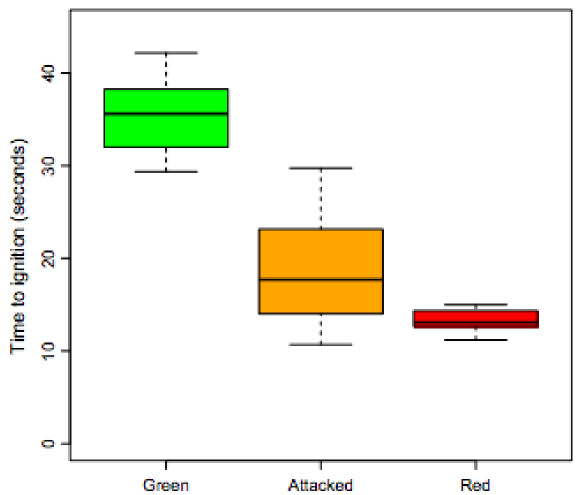

Fig. 4. Box plot of ranges of time to ignition of lodgepole pine foliage across three early stages following a MPB attack. Boxes represent the interquartile range and horizontal lines within the boxes indicate the medians for each category. Upper and lower whiskers are displayed as 1.5 times the interquartile (1.5 IQR). Open circles are observed values that fall outside of the 1.5 IQR ranges.

Figure 1: Box plot of ranges of time to ignition of lodgepole pine foliage across three early stages following a MPB attack

Table 3
Growing season averages and extremes of the time to ignition for lodgepole pine foliage across the early stages of a MPB attack. Mean time to ignition varied significantly between attack categories (ANOVA, $p < 0.001$, $F = 91.268$, $n = 48$).

Tree condition	Seasonal minimum time to ignition (s)	Seasonal maximum time to ignition (s)	Seasonal mean and standard deviation of time to ignition (s)
Green	29.4	42.2	35.3 (4.1)
Attacked	10.7	29.8	18.7 (5.1)
Red	11.2	15.0	13.3 (1.2)

Figure 2: Time to ignition for lodgepole pine foliage across the early stages of an MPB attack.

Impacts on Fire Behavior Modeling and Potential Adjustments

There are options for calibrating fire behavior models to simulate spread and fire behavior in beetle killed stands; however, analysts should always document these calibrations in detail to demonstrate an understanding of model limitations and assumptions (consider using the Notes section when modeling with WFDSS tools).

Issues to Consider

The main limitation of the WFDSS-based models (BFB, STFB, NTFB, & FSPRO) in relation to this issue, is that the foliar moisture has one value for the entire landscape (LCP), which precludes simply adjusting the foliar moisture for the affected stands. Additionally the foliar moisture value used by the model is limited to a range of 70-130%, which is well above the value needed to represent insect attack affected stands. For more information on how foliar moisture is used in the models, consult the publication Foliar moisture content of Pacific Northwest vegetation and its relation to wildland fire behavior by Agee et al. A solution to this issue is to use a modified Canopy Base Height (CBH), Canopy Bulk Density (CBD), and/or Canopy Cover (CC) as surrogates for a lower foliar moisture as well as to reflect the actual physical changes to the canopy that have resulted from the insect attack. In order to make adjustments that aren't applied to the entire LCP, locate a shapefile of each of the areas needed to create a mask to modify the LCP. This is especially important where the tree mortality varies in intensity across the landscape, and modifications to landscape file will need to vary as well.

In addition to the calibrations to represent the physical modifications of the insect affected stands, occasionally it may be necessary to modify the burn period (BP) to better represent the daily spread of the fire. One method is to divide the maximum dry bulb temperature by the minimum relative humidity and multiplying this value by the maximum 20' wind speed for the hour. Examine the results of this index to determine the threshold for adding or removing that particular hour to the burn period. If you lack hourly observations, you may follow a similar process using the daily observations. If you do this you will have to class your thresholds so that a particular range of values would be associated with a burn period length. For example a range of 60-79 = 3 hour BP, 80-99 = 4 hour BP, etc.

For details on how to adjust the BP, CBD and CC as well as some potential data sources for shapefiles that can be used as landscape masks, see the "Modeling Adjustments in Beetle Kill Handout" written by Dr. Matt Jolly.

A Process to Incorporate Insect Activity in Fire Modeling

The following process outlines some of the potential steps necessary to incorporate insect activity in analyses.

NOTE: It is assumed that before you begin following the steps below you have already run the model(s) and have found that the calibrations you have made are inadequate so far as representing fire spread through insect affected areas. As you proceed through the steps it is crucial that as you modify each parameter you do it one at a time, so that you can assess the effect each change makes.

To this end, you should be running the model following each step.

1. Obtain any shape files that you can use to mask the landscape as you make landscape changes. These shapes may include ADS shapes, fuel treatments, or any other shapes that represent insect attacked areas you would like to adjust. A few data sources are available in the Modeling Adjustments in Beetle Kill Handout written by Dr. Matt Jolly. An alternative to using pre-existing shapefiles is creating your own shape either in the analysis map or by using a photograph or field drawn map to create a KML or KMZ shape in Google Earth and then converting that file to a shapefile for upload into WFDSS.
2. In the case of beetle affected stands, use the foliar moisture surrogate adjustments to CBH. See the table below from Modeling Adjustments for Bark Beetle Infested Stands by Dr. Matt Jolly.

Corrected Foliar Moisture Content (%)	CBH Correction Factor (assuming 100% reference FMC)
100	1.000
90	0.915
80	0.830
70	0.745
60	0.660
50	0.575
40	0.490
30	0.405
20	0.320
10	0.235

$$CBH_{effective} = CBH * \frac{1}{\left(\frac{460 + 26 * FMC_{Green}}{460 + 26 * FMC_{Red}}\right)}$$

FMC_{Green} – Reference Foliar Moisture Content (usually 100%)
FMC_{Red} – Corrected Foliar Moisture Content

Figure 3: Foliar moisture surrogate adjustments to CBH

3. If the level of mortality is known you can use the table and equation below, (developed by Dr. Matt Jolly) to adjust the CBD. PCTMORT is the percent mortality and the CBD is from the table.

   CBDNEW = CBD * PCTMORT * CBDModifer + CBD * (1 – PCTMORT)

Time Since Attack	CBD modifier (multipler)
0	1
1	1.33
2	1.7
3	2.07
4	1.8
5	1.53
6	1.07
7	0.73
8	0.4
9	0.2
10	0.17
11	0.13
12	0.1
13	0.07
14	0.03
15	0.03

Figure 4: Table and equation to adjust CBD when the level of mortality is known

4. Depending on the stage, make appropriate adjustments to CC to areas with landscape masks.
5. Examine wind and weather observations from a representative RAWS and calculate the hourly burn period index using Dr. Jolly's equation (shown below). Determine the threshold for fire growth by going back through the growth of the fire and finding those days when the fire was most active and tying that to the resulting value of Jolly's Burn Period Index equation. Once your active fire threshold value is determined you will be able to determine how many hours per day to allow fire growth based on that value, and in the case of Near Term Fire Behavior, which hours in particular to model fire growth. In cases where hourly data isn't available you can apply the same concept on a daily basis.

$$\textbf{Burn Period Index} = \frac{Dry\ Bulb\ Temperature}{Relative\ Humidity} * Windspeed$$

Figure 5: Burn Period Index Calculation

6. If your calibrations are still inadequate you can try switching from the default, Finney crown fire model to the Scott & Reinhardt crown fire model, which should give much more crown fire across the landscape due its lower crown-fire initialization thresholds.
7. Following the adjustment to the crown-fire model or sometimes in lieu of switching crown fire model you may want to adjust the fuel models of some of the insect affected stands. In many of the insect affected stands in the red stage, fuel model 164 or 165 does a good job of simulating ROS and crown fire. Slash fuel models 201 and 202 also do a good job in late grey stage where surface fuel loadings are elevated. Remember to use an appropriate fuel model that matches the arrangement of the fuels but also matches the fire behavior. Document your choices and their corresponding reasoning in the analysis notes.
8. Check with the local unit on dead, live and foliar moistures of both the un-attacked and attacked areas. Make appropriate adjustments to foliar, live and dead fuel moisture to match real-world values in unaffected stands. In affected stands you may need to switch to a different fuel model specifically for the purpose of lowering the live fuel moistures in those areas resulting in a lower threshold for crown fire initiation.
9. A last resort is the adjustment of the spotting probability. As you adjust spotting probability it should be done in small increments (.01) so that the effect of each adjustment can be assessed. It is also important to note that if you decide to switch between crown fire models as you are making spotting probability adjustments, the effect of a (.01) adjustment is an order of magnitude greater in its effect in Scott & Reinhardt (.1). For more information on spotting refer to this document by Tonja Opperman.

Figure 6 shows one potential calibration order, annotated with the effects on fire behavior outputs each calibration could have.

	BFB/STFB	NTFB	FSPro
Dead & Live Fuel Moistures	1 · RFC	1 · RFC	1 · R
WX Station/Wind Speeds	2 · RFC	2 · RFC	2 · R
CBH & CBD	3 · RFC	3 · RC	3 · R
CC (Sheltering & Shade – Includes cloud cover)	4 · RFC	4 · RC	4 · R
Burn Period Length	5 · R	5 · R	5 · R
Burn Period Times	/	6 · RFC	/
Crown Fire Model	6 · RFC***	7 · RFC***	/
Fuel Model	7 · RFC	8 · RFC	6 · R
Spotting Probability	8 · R	9 · R	7 ·R

Calibration influence on fire behavior output–

R – Rate of Spread

F – Flame Length

C – Crown Fire Activity

**** If calibrating for transfer to FSPro SKIP*

Figure 6: Potential Calibration Order with Annotations

References:

1. Rocky Mountain Region, Forest Health Protection. 2010. Field guide to diseases & insects of the Rocky Mountain Region. Gen. Tech. Rep. RMRS-GTR-241 Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 336.

2. NPS Rocky Mountain National Park. Forest Heath, Mountain Pine Beetle Epidemic from Canada to Mexico.
3. USDA Rocky Mountain Region. Mountain Pine Beetle, Aggressive bark beetle of western pines.
4. USDA. Spruce Beetle.
5. USDA Medicine Bow-Route National Forest and Thunder Basin National Grassland. Mountain Pine Beetle Epidemic.
6. Dr. Diane Six. 2014. Mountain Pine Beetles Expansion in the West. http://www.americanforests.org/
7. USDA. USDA Bark Beetle Fact Sheet.
8. Hicke et al. 2012. Effects of bark beetle-caused tree mortality on wildfire. Forest Ecology and Management. 271: 81-90.
9. Jolly et al. 2012. Relationships between moisture, chemistry, and ignition of Pinus contorta needles during the early stages of mountain pine beetle attack. Forest Ecology and Management. 269: 52-59.
10. Agee et al. 2002. Foliar moisture content of Pacific Northwest vegetation and its relation to wildland fire behavior. Forest Ecology and Management 167: 57-66.