Modeling Fire Behavior in Mountain Pine Beetle Affected Stands
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In the past ten years, millions of acres of lodgepole pine and ponderosa pine across the interior west have been attacked and killed by bark beetles. Once a tree has been attacked and killed by the beetles the tree goes through three distinct stages, Green Attacked, Red Needled and Gray. At each stage there is a potential change to fire behavior due to the changes occurring in chemical composition of the needles, foliar moisture content and moisture content of the standing bole in the gray stage. There has been limited published research on the affects of the bark beetle on fire behavior. Published literature on fire behavior in these affected stands is mixed on the potential risks and changes to fire behavior in these stands. In British Columbia, Canada, the pine beetle epidemic has been ongoing longer than in the US. Fire managers there saw unprecedented fire behavior in stands of lodgepole pine that were in the green attacked and red needle stages. The Canadians developed triggers for their fire fighters based on weather parameters to help with situational awareness and fire fighter safety.

Fire seasons in the Northern Rockies since the bark beetle epidemic began have been light. When fires have been detected in these dead and dying stands fire behavior variables were moderate and initial attack was successful or weather conditions changed shortly after a fire escaped leading to containment of the fire. Fires this year have provided researchers the conditions to begin documenting altered fire behavior in these affected forests. Dr. Matt Jolly from the Missoula Fire Laboratory in Missoula Montana has been studying conditions on fires this summer. Using the computer program "FARSITE" he has been able to model observed fire growth very closely.

This summer there were fires in Montana and Idaho that burned through stands that had attacked by the bark beetle. Extreme fire behavior occurred on several that were above anticipated behavior. These fires provided an opportunity to work with existing fire models to see if they could be calibrated to model the observed fire behavior.

The Saddle Complex fires (a combination of the Stud and Saddle fires) started burning on the Salmon/Challis National Forest. On August 22, 2011 fire weather created conditions for the fires to become active and make a five mile run to the east out of Horse Creek in Idaho and down both Beaver Creek and Woods Creek in Montana. The fire burned through timber stands that had been attacked by the mountain pine beetle. It was estimated that approximately 40% of the lodgepole in these stands were in the red needle stage and 40% was in the gray stage. Fire behavior was predominantly plume dominated crown fire. Through much of the area, almost all surface fuels were consumed during the initial flaming front passage.

The computer programs FlamMap and FARSITE were used to model fire growth during this event, as well as the spatial fire behavior prediction tools in WFDSS. Using the existing landscape did not model
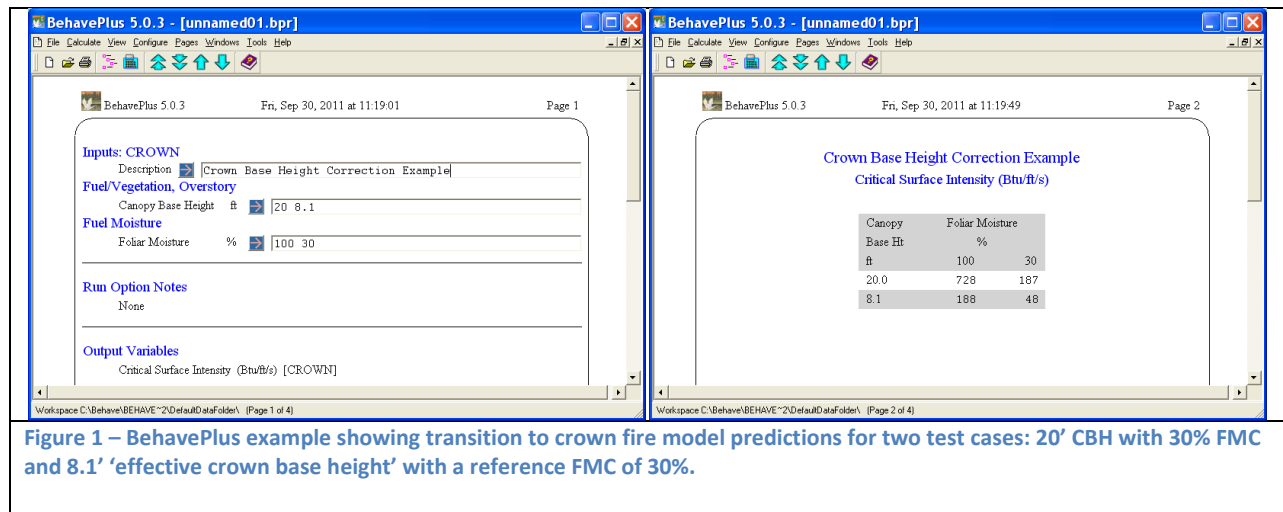
the growth of the fire. To begin making adjustments to inputs Dr. Jolly made several adjustments to the landscape to begin the calibration process.

Aerial detection surveys from 2007 – 2010 were used to create landscape masks for the beetle attacked areas. Two masks were created: one for red stage and one for gray stage trees. The assumptions used for these masks were: Areas that were mapped in 2007 and 2008 as being affected were considered to now be in the gray stage. A grey stage mask was created that reduced canopy cover by 50%, effectively increasing surface wind speeds in those stands.

Those areas that were affected and mapped in 2009 and 2010 were considered to be in the red stage. The fuels characteristic most dramatically changed in the red needle stage is the foliar moisture content. None of the existing landscape-scale fire behavior assessment tools allow users to enter spatial variations in foliar moisture content (FMC), yet this is a key factor in predicting expected fire behavior in attacked mountain pine beetle-attacked stands. However, the transition to crown fire model used by the fire behavior models, uses both FMC and Crown Base Height (CBH) as inputs. It is therefore possible to derive an 'effective crown base height' that compensates for a reduction in FMC in attacked stands. This can be derived as follows:

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

Where $CBH_{effective}$ is the 'effective crown base height' that compensates for lower foliar moisture contents. FMC_{Green} is the moisture content of healthy green foliage (usually ~100%) and FMC_{Red} is the moisture content of the red needles. The key to this approach is that modeled crown fire transition potential is equivalent to keeping the CBH unchanged and only changing the foliar moisture content. We can verify this by using BehavePlus to predict the Critical Surface Fire Intensity, which is the surface fire intensity that must be exceeded to initiate torching or crowning. If we assume that our reference CBH is 20', our green FMC is 100% and our red FMC is 30% (the lowest value allowed in BehavePlus), then we can calculate our $CBH_{effective}$ to be 8.1' from the equation above. From the results in Figure 1, we can see that stands with 100% moisture content (the default for most spatial fire behavior prediction systems) at our corrected CBH of 8.1' has an almost identical critical surface fire intensity to a stand where at the original CBH but with an FMC of 30%. This allows us to 'correct' our landscape models for spatial variations in FMC by simply multiply CBH by the correct factor to reflect changes in FMC.

Figure 1 – BehavePlus example showing transition to crown fire model predictions for two test cases: 20' CBH with 30% FMC and 8.1' 'effective crown base height' with a reference FMC of 30%.

The Crown Bulk Density values found in the landscape layers were found to be too low to permit active crown fire behavior under less than extreme wind speeds. CBD is a key crown fire model input that determines the Critical Crownfire Rate of Spread that must be exceeded before active crown fire is predicted. CBD values derived from the LANDFIRE 2008 refresh data were significantly lower than field measured CBD values reported in the Fire Behavior Field Reference Guide. As such, CBD values were tripled and these increased values produced more realistic CBD ranges.

All of these landscape corrections were made as a series of landscape rules in Analysis section of the WFDSS.

The daily burn period used in fire behavior modeling is an important value in predicting fire behavior and movement. The length of the burn period used by different analysts is based on personal observations and knowledge. Usually the analyst has some rules of thumb that they have used successfully when modeling fire growth. Dr Jolly has developed a mathematically based method that provides the analyst with a qualitative means of estimating the daily burn period using temperature, relative humidity and wind speed. These three variables all affect fire behavior. As generalities it is accepted that when temperature goes up, relative humidity drops or wind speeds increase fire behavior increases. Using this thought process you can use the three variables to calculate an ordinal ranking. Temperature and Relative Humidity have an inverse relationship. Increased temperatures and decreased RH are associated with increases in fire behavior. Temperature is divided by Relative Humidity. Higher wind speeds tend to increase fire behavior as well. Multiply the temperature/RH value by the wind speed to calculate a ranked value.

$$Burn\ Period\ Score = \frac{Temperature}{Relative\ Humidity} * Wind\ Speed$$

Applying this formula to hourly RAWS observations you can graph the calculated values with a line graph. By comparing the graph to observed fire behavior an analyst can then define a threshold value that can be used for quantifying the daily burn period. One can then simply count the number of

occurrences each day where the Burn Period Score exceeds some threshold and this will provide a repeatable estimate of daily burn periods.
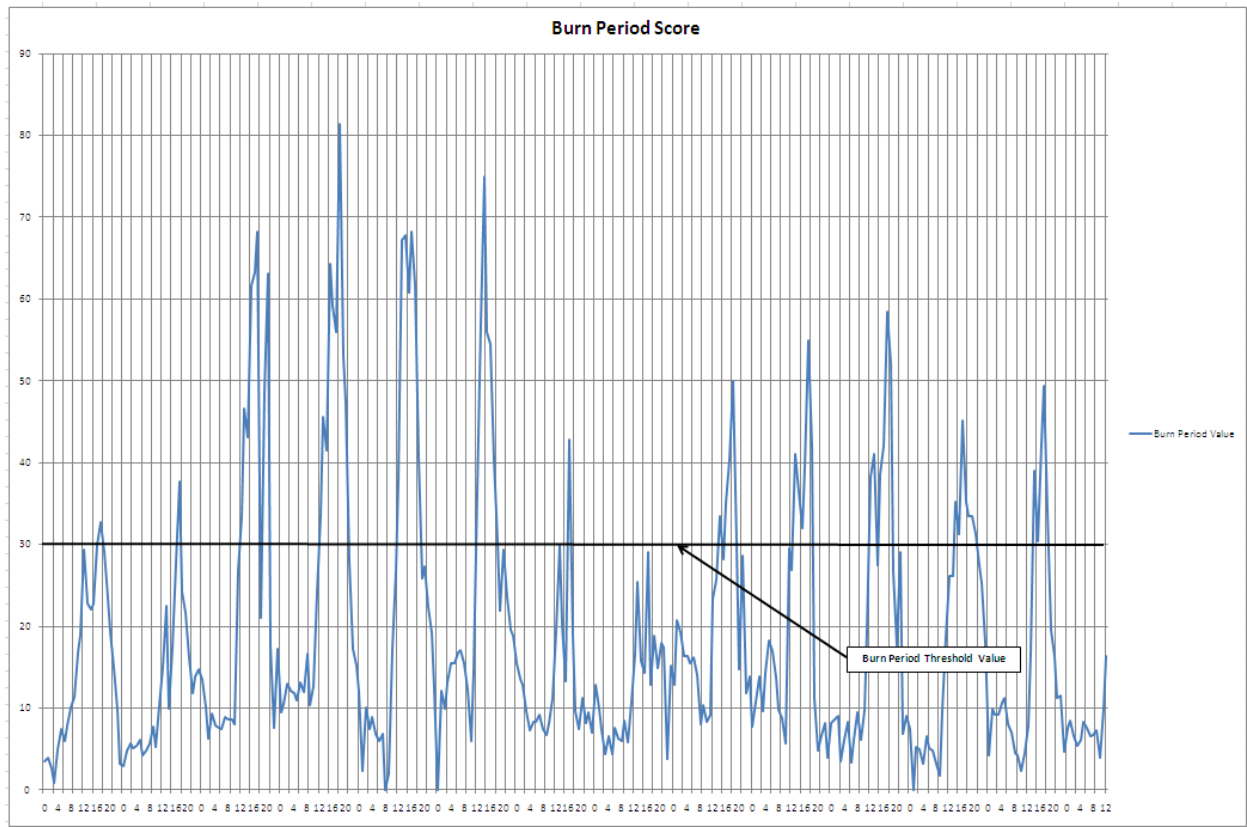

Figure 2 – Example of hourly Burn Period Scores derived from hourly RAWS data.

The calibration steps described here were used in fire behavior projections on the Salt and Saddle Complex Fires with very good results.

For more detailed information on the use of these calibration steps contact Dr Matt Jolly (406) 329-4848 or e-mail him at: mjolly@fs.fed.us.