2B.3 STEM MORTALITY IN SURFACE FIRES. PART III, LINKING STEM HEATING WITH TISSUE RESPONSE FOR PLANNING PRESCRIBED BURNS

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1. INTRODUCTION

Tree injury/mortality due to stem heating can be an important issue in the planning and execution of prescribed burns, which are used for management of forest stands. Currently there are no physics-based models for managers to use in predicting thermally induced mortality when developing prescriptions. Empirical models have previously been developed for the prediction of stem heating mortality (Peterson and Ryan 1986). Based on correlated field data, they are restricted to the range of species and conditions under which the empirical correlations were developed. A physics-based utility for the prediction of thermally induced mortality is desired.

This abstract summarizes work on a model coupling a previously developed stem heating model (Jones *et al.* 2003) to the species-specific cell mortality model of Dickinson (2002) and Dickinson and Johnson (2003). Predicted kill depths are compared to corresponding measurements in experiments for three species: Ponderosa Pine (*Pinus ponderosa*), Red Maple (*Acer rubrum*), and Chestnut Oak (*Quercus prinus*).

2. STEM HEATING MODEL

The numerical heat transfer model used in this research is described in detail elsewhere (Jones *et al.* 2003). It is a one-dimensional heat conduction model in cylindrical coordinates, which is driven by heat flux as a function of time at the boundary. The model includes various temperature dependent phenomena including desiccation, devolatilization, charring, and bark swelling (where appropriate). Since these phenomena represent energy absorption mechanisms, an accurate accounting of energy transfer into the stem requires that they be included. While the model can simulate a temperature boundary at the stem surface, a heat flux boundary condition at the stem surface is needed if the model is to be eventually coupled to existing fire behavior models, which cannot directly predict the surface temperature but which may be used to derive the surface heat flux as a function of time.

3. TISSUE NECROSIS MODEL

Past modeling work has assumed that there exists a certain lethal temperature for vascular cambium necrosis. A threshold of 60ºC is typical (Van Wagner 1973, Peterson and Ryan 1986, Brown and DeByle 1987, Stewart *et al*. 1990, Gutsell and Johnson 1996). The lethal temperature concept is based on data showing that physiologically active plant tissues can survive only short exposures to temperatures of around 60ºC (*e.g.*, Nelson 1952, Kayll 1963). While lethal temperatures may give a rough method for predicting tissue necrosis, they are not realistic and their usefulness is limited. Dickinson (2002) and Dickinson and Johnson (2003) have presented a model for trees in which thermally induced cell mortality predictions are based on temperature regime and resulting species-specific rate parameters which describe the decline in tissue viability. Tissue impairment is modeled explicitly as tissues are heated in contrast to previous models based on empirical descriptions of time-to-necrosis at a range of fixed temperatures.

The stem heating model is capable of predicting temperatures as a function of time for discrete numerical grid points within the tree stem. At each time step in the stem heating model, the viability at each radial location is recalculated. As the fire heats the stem, tissue necrosis occurs in grid points near the surface, followed by grid points deeper within the stem. Thus, the result of the combined stem heating and tissue necrosis model is a local prediction of which stem radial locations have been killed, and which have survived. If the tissue necrosis goes beyond the cambium there are implications with regard to overall tree mortality.

4. EXPERIMENTAL METHODS

The combined stem heating and cell mortality model was evaluated by comparison with experimental data designed to illustrate the extent of thermal damage on stems. The thermal mortality model was evaluated by comparison with experimental data in three different species: Red Maple (*Acer Rubrum*), Chestnut Oak (*Qercus Prinus*), and Ponderosa Pine (*Pinus Ponderosa*). The experiments and results are presented in detail elsewhere (Jones 2003).

The moisture distribution within the stem is a critical parameter, as it affects strongly the heat transfer into the stem and resulting temperature response to the heating. A generic moisture profile is used with profile parameters specified from experimental measurements for each species. The moisture content was determined from experiment for the stem samples tested by sectioning the bark into inner and outer regions, and making careful weight measurements on the inner bark before and after drying.

For the experiments on Red Maple and Chestnut Oak it was possible to use a chemical stain (tetrazolium trichloride) to determine the depth-of-kill incurred by the experimental fires (this technique was not effective in

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the softwood tests). TTC reveals respiring (live) cells with a reddish color.

5. MODEL VALIDATION

Figure 1 shows the results of predicted and measured kill depth in the 21 Red Maple experiments. If, in the figure, both the measured and predicted values of normalized depth-of-kill are on the same side of unity, the model predicts stem survival/mortality correctly. Further, two measured kill depths were taken for each experiment: one at 10 cm height, and one at 20 cm. These two values of measured depth-of-kill are shown as error bars, with the data point being the average of the two measurements. This gives some idea of the uncertainty of depth-of-kill measurements.

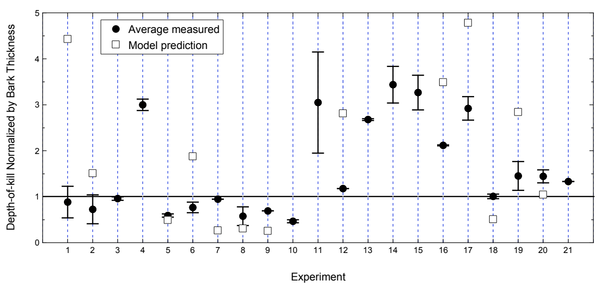

Figure 1. Normalized depth-of-kill predictions and measurements for Red Maple. For experiments without accompanying modeling results, the predicted values are omitted because they are above the maximum value on the plotting scale.

Figure 1 reveals that cambial death/survival is correctly predicted in 15 of 21 cases. If the variance in kill depth experimental measurements is accounted for, and if predictions and measurements very near the cambium are, based on uncertainty, considered correct, there are perhaps 19 of 21 correct predictions.

Validation was equally encouraging for the other species, lending confidence in the combined stem heating/tissue necrosis model methodology.

6. CONCLUSIONS

The stem heating model of Jones *et al*. (2003) has been coupled to a discretized form of the tissue necrosis model of Dickinson. Experiments were conducted for comparison with the model's predictions of cambial necrosis. The results show that the model correctly predicts cambial necrosis for the majority of cases modeled. These results give a reasonable degree of confidence in the model's application to the prediction of tree mortality from stem heating.

7. REFERENCES

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8. ACKNOWLEDGMENTS

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