Joint Fire Science Program

Fire Science Brief

RESEARCH SUPPORTING SOUND DECISIONS

Crews igniting a prescribed burn in California. Credit: Sheri Smith.

Improving a Widely-used Tree Mortality Model: Better Predictions Change the Landscape

Summary

After wildfire and when planning prescribed burns, those who tend the land must try to predict tree death. Managers and planners need to know the level of fire intensity required to meet tree mortality objectives, decide if and which trees to salvage, and predict future post-fire stand conditions. Models play a vital role in helping take the guesswork out of predicting post-fire tree mortality.

One such model—the Ryan and Amman model—is perhaps the most widely used tree mortality model in the United States. It is used in the First Order Fire Effects Model (FOFEM), BehavePlus, and other similar software programs. Sharon Hood, along with a team of researchers that included two of the original authors of the first widely used tree-mortality model, have evaluated the Ryan and Amman model and improved it. They have created species-specific models for many western conifers that give managers more options for predicting tree mortality. With their large data set, they also evaluated the use of bark char codes for predicting cambium status. Already, FOFEM (version 5.7) has incorporated the results of their new modeling efforts, and management guidelines are available for using bark char codes.

Key Findings

- First Order Fire Effects Model (FOFEM) is now enhanced with more options. The data used in this study improved mortality predictions for 12 western conifer tree species and created a post-fire option that factors in cambium injury and bark beetle attacks.
- This work allows FOFEM and other similar programs to move towards species-specific modeling.
- Tree diameter was not significant in predicting post-fire mortality for the majority of the species modeled.
- Bark char codes are often useful for predicting cambium status after fire for species with thin bark. Further, the results of this work indicate that direct cambium sampling does not cause additional tree mortality.

Introduction

When planning prescribed burns or after wildfires, managers and planners must gauge post-fire tree death. Without a clear picture of future tree death in a burn area, managers would be reduced to simple guesswork in their ability to make plans for effective and healthy land management. It's no surprise then, that tree mortality models have become essential—and commonplace—in the fire management toolbox.

Elizabeth Reinhardt and Kevin Ryan first published their logistic regression mortality model in 1988, and it quickly found its way into fire effects modeling software. The model was updated by Ryan and Gene Amman in 1994 to the form now included in the most commonly used predictive fire behavior and effects software in the United States, including FOFEM, BehavePlus, and Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS). The Ryan and Amman model may well be the single most widely used tree-mortality model in use today, according to a Joint Fire Science Program (JFSP) Final Report by Fire Researcher Sharon Hood.

Hood is a Forester with the Rocky Mountain Research Station's Fire Sciences Lab in Missoula, Montana. Recently, she headed up a research team—which included the two original authors of the model, Ryan and Reinhardt—whose charge was to strengthen this model given both its utility and ubiquity.

"The model really needed to be tested, and if possible, improved, especially since so many managers use it in various fire behavior and effects model software programs," says Hood. "As it stood, the model's data came only from prescribed fire. Also, it didn't include information on ponderosa pine—a very common tree in most Western forests. It was only based on data from seven western conifer species."

Also, according to Hood, "The predictive accuracy of the model had not been assessed for fires outside the original study's geographic area, for wildfires, or for other tree species except ponderosa pine."

She adds, "We had data from many more trees, more species of trees, more sites, and both wild *and* prescribed fires. So we wanted to see just how effective the model actually was in predicting tree death using our independent data—and then determine whether adding more data would improve the model."

Besides Ryan and Reinhardt, the other researchers on the team were Sheri Smith, Danny Cluck, and Charles McHugh. Each had collected post-fire tree injury data using very similar variables that, when combined, created a rich data set of tree injury and mortality data for western conifer species. By the time all was said and done—three years after the initial proposal was funded by the Joint Fire Science Program—the final data set included 16,838 individual trees, from 12 western conifer species, that spanned 18 sites stretching across five western states.

Checking for cambium injury after fire. Credit: Sharon Hood.

The original Ryan and Reinhardt (Amman) model is an important scaffold. The Ryan and Amman model is free and widely available to managers, and easy to use with information on just two variables: crown scorch and diameter at breast height (DBH). "With those two variables, you can predict post-fire tree mortality for most species in the U.S. Both variables are easy to measure or predict based on expected fire behavior. We wanted to make sure any new model(s) we developed maintained this simplicity," says Hood.

Making more of a model

The team of researchers had two overarching goals. First, they wanted to check the accuracy of the current model as it stood in FOFEM, BehavePlus, and FFE-FVS at both the individual tree and stand level. "We wanted to see how well the model predicted mortality for the trees in our data set. We knew what trees had died, and could compare that with what the model predicted," says Hood.

Second, Hood's team wanted to improve the accuracy and capabilities of the model to make these software programs even more helpful in understanding post-fire

tree mortality. Their intent was to develop two models, ideally that could each be used for all 12 species in the data set. If that didn't work, they would develop two sets of species-specific models instead. The first set would only include crown scorch and DBH, like the original Ryan and Amman model. The second set would include any additional significant variables, such as cambium injury or bark beetle attacks. "Then we could compare the accuracy of the new models with the old one to see if the new ones offered an improvement."

Along with these two central objectives, the researchers also wanted to ascertain how well bark char codes can predict whether a tree's cambium is live or dead. Bark char codes may indicate cambium injury at the tree base after fire, which—if they are accurate—may allow managers to use the codes in place of direct sampling. Some have worried that cambium sampling after fire can further stress already compromised trees. "We wanted to see if this was, indeed, the case," adds Hood.

Just what did the researchers bring to the table to address these objectives? They had a large array of existing data from various fire-injury studies that recorded three-year post-fire mortality on thousands of individual trees. Other variables collected included tree species, fire date, type of fire (prescribed versus wild), DBH, crown scorch, cambium kill rating (CKR), bark char and bark beetle attack. Since data was compiled from a wide range studies, not all the variables were the same for each fire. Still, every tree was tracked each year for at least three years post-fire and there was large agreement for the majority of variables.

The team developed three-year post-fire mortality models for 12 conifer species: "white fir, red fir, subalpine fir, incense cedar, western larch, lodgepole pine, whitebark pine, ponderosa pine, Jeffrey pine, sugar pine, Engelmann spruce, and Douglas-fir." Data came from 26 different fires (both prescribed and wild) across 18 sites in Arizona, California, Idaho, Montana and Wyoming.

"We had data from 16,838 trees," says Hood, "but it is important to remember that 43 percent of those trees were ponderosa pine." As a result, some tree species are better represented in the data set than others; therefore some of the species-specific models the team created are more robust than others.

As a result of the large and varied data set, the researchers note that the majority of the data are included in all three major analyses (e.g., FOFEM evaluation, new mortality modeling, and bark char codes evaluation), but not all data are included in each analysis.

Evaluate the starting point

The first order of business was to use independent data to help determine how accurate the Ryan and Amman model in FOFEM really is. "This was really the first time anyone has used outside independent data to seriously evaluate this model," says Hood, "In fact, we really need more of this kind of work, where researchers use independent data to evaluate the accuracy and predictive power of tree mortality models. Then we could begin to understand each mortality model's limitations and strengths to know which model to use after a specific fire to predict tree mortality most accurately."

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The good news, she says, is that the Ryan and Amman model was "right about 80 percent of the time when used to predict stand level mortality."

The team published the results of that comprehensive evaluation in the *International Journal of Wildland Fire* (IJWF). The core result is that, in general, FOFEM, BehavePlus, and FFE-FVS have yielded reasonable accuracy for predicting post-fire tree-mortality.

They write in their IJWF article, "For prescribed burning purposes, the model proved to be a useful and relatively accurate method for predicting stand level post-fire tree mortality. It correctly predicted overall mortality within +/-20 percent of the observed mortality for the majority of species tested."

Credit: Sheri Smith.

But, as Hood says, "With so many different species in this one project, it's hard to generalize accuracy for all species to the project level." For example, managers can expect lower mortality than the model predicts for incense cedar, western larch, and red fir in prescribed burns. But, they can expect higher mortality than predicted when prescribed burning western hemlock stands.

The team also found that the model, as it was, was less robust when looking at tree mortality for individual fires. "Correctly predicted mortality was quite variable" from fire to fire and the accuracy of the model was lower for some fires.

The researchers also found the model was less accurate for predicting individual tree mortality and hypothesized that "other species-specific mortality models developed from individual geographic areas may be more accurate." These individual tree mortality predictions are used by managers and planners to develop post-fire salvage marking guidelines.

Perhaps most important, the team's evaluation allowed them to create a baseline from which to compare new models, including the ones they went on to develop after completing this initial evaluation of the Ryan and Amman model.

Model improvements

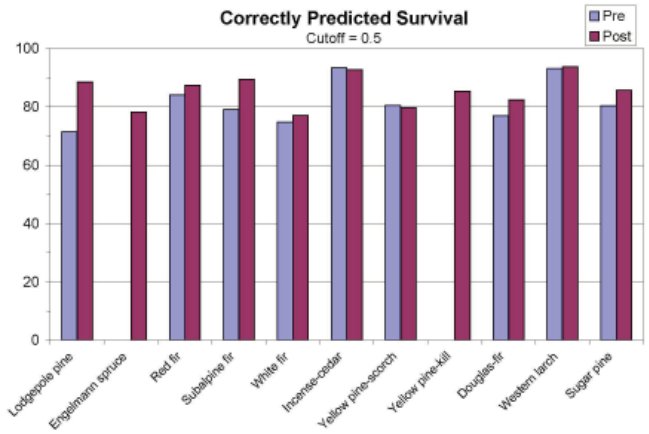
The next step, then, was to create new models using the wealth of data the researchers had collected. The new models are already available via FOFEM, and will come soon to BehavePlus. Twelve species were updated with new species-specific models. Hood says, "We quickly discovered that developing one model for all 12 species did not yield very accurate predictions, so we developed models for each species instead."

The team developed new mortality models for white fir, subalpine fir, red fir, incense cedar, western larch, lodgepole pine, whitebark pine, Engelmann spruce, sugar pine, Douglas-fir, ponderosa pine, and Jeffrey pine.

The new post-fire option allows managers to go beyond the standby variables of crown scorch and tree size. This new option allows managers to use additional data on cambium kill and beetle attack for more accurate predictions.

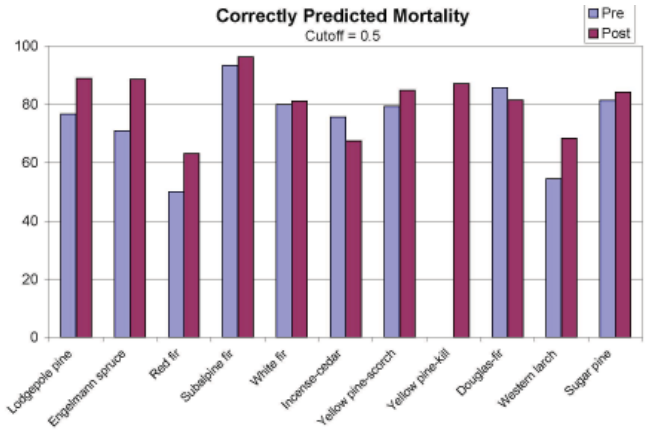
It was still true, that crown scorch was the best predictor of mortality. However, they found that both CKR and beetle attacks were consistently significant in predicting mortality in the models. Still, says Hood, "most of the models were not greatly improved by adding these additional variables, so it may not be worth the extra effort and time to collect those data. The exceptions to this were species with thin bark: Engelmann spruce, whitebark pine, and lodgepole pine. "Factoring in cambium injury, greatly improves the accuracy of these models," Hood says.

"We hope these new species-specific models make it easier for managers to develop more accurate burn plans to achieve their mortality related objectives. Also, the new post-fire option should help to develop improved marking guidelines by accounting for cambium injury and bark beetle attacks," says Hood.



Percentage of trees correctly predicted to survive 3-years post-fire by species for both sets of models developed.

"We want to see if people like the new options in FOFEM. We want to hear about whether the new species-specific models are better, and whether they use the post-fire injury option now in FOFEM. We also hope others will evaluate our species-specific models using independent data, just as we did for the Ryan and Amman model."



Percentage of trees correctly predicted to die 3-years post-fire by species for both sets of models developed.

Bark char codes, cambium, and more

Besides finding that bark char codes are often useful for predicting cambium status after fire, the results of this work also indicate that direct cambium sampling does not cause additional tree mortality. There was no difference in mortality rate for ponderosa pines whose cambium was sampled directly than those without cambium sampling. The team published these results in *Fire Ecology*.

"This is something we know people have been concerned about, and we hope our findings will ease manager's concerns about sampling cambium," says Hood. "This is the only data out there on this, so far, but we don't expect that this result would be different for other species."

Further, for thick-barked species, bark char codes are not very accurate in predicting cambium status. In particular, white fir, incense cedar, ponderosa pine, Jeffrey pine, Douglas-fir, and sugar pine are species which should be sampled directly when bark char is moderate to determine cambium status."

Still, for many species, the bark char codes were fairly accurate, and the researchers offer management guidelines (see the table on page 5) to help determine when bark char codes can be used in place of direct sampling.

"Now," says Hood, "we are working to publish the new models in a journal, and we are eager to disseminate the new models. We want managers to try the new models and see if they like them. Specifically, we are curious to see if managers will use and find valuable the post-fire injury option."

"We have really moved beyond the 'one-size fits all' approach to the species-specific models, which we hope are more useful for management," says Hood. Indeed, Hood points to a new management support document specific to Douglas-fir that resulted from their work.

The report is titled, "Assessing Post-fire Douglas-fir Mortality and Douglas-fir Beetle Attacks in the Northern Rocky Mountains." This General Technical Report describes in detail how to use and apply the different Douglas-fir models they created. "We hope it will help anyone trying to apply tree mortality models" says Hood. Also, there is a

supporting document printed on waterproof paper designed for crews to take into the field with them to help determine Douglas-fir tree injury levels," she says.

Species	Bark char code	Probable Cambium Status
Lodgepole pine Whitebark pine Western white pine Western red cedar Engelmann spruce Subalpine fir	Light, moderate, or deep	Dead
White fir Incense cedar Ponderosa pine Douglas-fir Sugar pine	Light	Alive
White fir Incense cedar Ponderosa pine (wildfire) Douglas-fir (wildfire) Sugar pine	Deep	Dead
Ponderosa pine (prescribed fire)[a]	Moderate or deep	Alive
Douglas-fir (prescribed fire)[a]	Moderate	Alive
Western larch	Light, moderate, or deep	Alive

a. If pre-fire duff mound depths are high and most of duff is consumed in fire, then the probability of cambium mortality is higher.

Recommended management guidelines for using Ryan (1982) bark char codes as a surrogate for direct cambium sampling after fire. See JFSP final report for more details.

You can download the document at http://www.treesearch.fs.fed.us/pubs/28511 or follow the link to request the free waterproof version be mailed to you.

Says Hood, "Even though it is focused on Douglas-fir, you could apply the examples to any species model, really. We've provided several examples about how to use the models to develop prescribed fire burn plans and marking guidelines—complete with a photo guide—so you could take it and use it as a springboard for modeling other species."

Indeed, this whole study serves as springboard. With their careful validation and examination of the value of the original model, followed by detailed and specific improvements—including the new species-specific pre- *and* post-fire models—managers and planners have a new gold standard when it comes to predicting tree mortality.

Further Information: Publications and Web Resources

Project website:
http://www.firelab.org/content/view/690/200/

Management Implications

- When using the original Ryan and Amman model (FOFEM prior to version 5.7), managers can expect less mortality than the model predicts when burning in incense cedar, western larch, and red fir forests. Meanwhile, they can expect higher mortality than the model predicts when planning prescribed burns in stands of western hemlock if tree boles are charred.
- Moderate bark char was not clearly associated with either live or dead cambium for thicker bark species. Cambium should be sampled directly to determine injury when bark char is moderate for these species.
- Tree injury from direct sampling of the cambium does not contribute to additional post-fire ponderosa pine tree mortality.
- FOFEM 5.7 offers improved accuracy in predicting 3-year post-fire tree mortality for white fir, subalpine fir, red fir, incense cedar, western larch, lodgepole pine, whitebark pine, Engelmann spruce, sugar pine, Douglas-fir, ponderosa pine, and Jeffrey pine.
- FOFEM 5.7 now allows users to directly enter crown scorch, cambium injury, and beetle attacks to improve model accuracy.

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Scientist Profile

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Results presented in JFSP Final Reports may not have been peer-reviewed and should be interpreted as tentative until published in a peer-reviewed source.

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