Modeling Fuel Succession

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Surface fuels data are of critical importance for supporting fire incident management, risk assessment, and fuel management planning, but the development of surface fuels data can be expensive and time consuming. The data development process is extensive, generally beginning with acquisition of remotely sensed spatial data such as aerial photography or satellite imagery (Keane and others 2001). The spatial vegetation data are then crosswalked to a set of fire behavior fuel models that describe the available fuels (the burnable portions of the vegetation) (Anderson 1982, Scott and Burgan 2005). Finally, spatial fuels data are used as input to tools such as FARSITE and FlamMap to model current and potential fire spread and behavior (Finney 1998, Finney 2006).

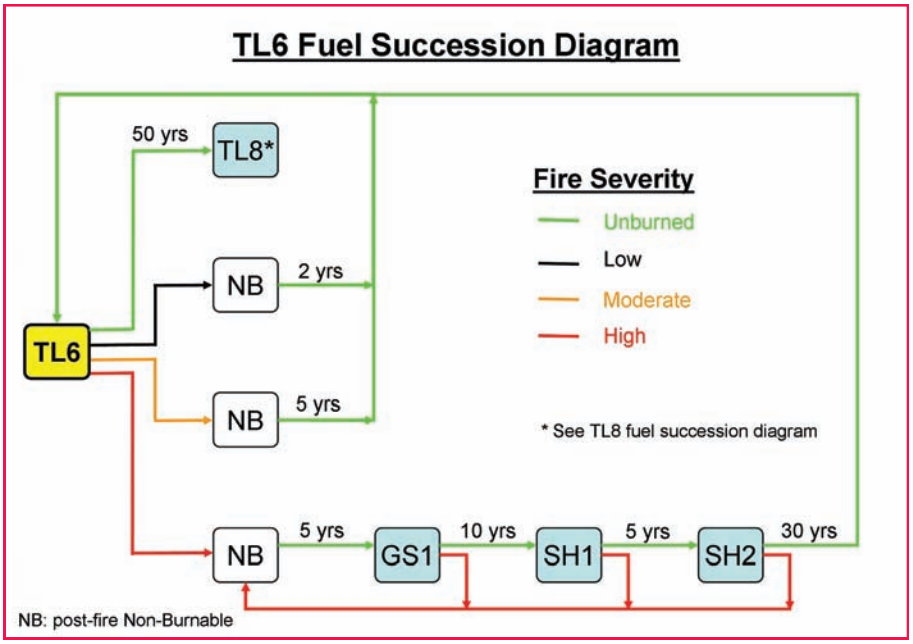

Figure 1—*Successional pathway diagram for the Timber Litter 6 (TL6) fire behavior fuel model.*

The capture date of the remotely sensed data defines the period for which the vegetation, and, therefore, fuels, data are most accurate. The more time that passes after the capture date, the less accurate the data become due to vegetation growth and processes such as fire. Subsequently, the results of any fire simulation based on these data become less accurate as the data age. Because of the amount of labor and expense required to develop these data, keeping them updated may prove to be a challenge.

In this article, we describe the Sierra Nevada Fuel Succession Model, a modeling tool that can quickly and easily update surface fuel models with a minimum of additional input data. Although it was developed for use by Yosemite, Sequoia, and Kings Canyon National Parks, it is applicable to much of the central and southern Sierra Nevada. Furthermore, the methods used to develop the model have national applicability.

Fuel Model Development

To characterize fuels and fuel succession, we started with the fire behavior fuel models described in “Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel’s Surface Fire Spread Model” (Scott and Burgan 2005). These models provide a more detailed representation of fuels than the standard 13 Northern Forest Fire Laboratory (NFFL) fuel models (Anderson 1982) and, therefore, gave us the flexibility to depict different successional stages. We then developed crosswalks between current vegetation data and fire behavior fuel models in a series of collaborative meetings with fuels experts from the parks and the U.S. Geological Survey (USGS). Among

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Table 1—*Fuel models represented in Yosemite, Sequoia, and Kings Canyon National Parks.*

Fuel Model	Description
Grass 1 (GR1)	Short, sparse, dry climate grass
Grass 2 (GR2)	Low load, dry climate grass
Grass 4 (GR4)	Moderate load, dry climate grass
Grass-Shrub 1 (GS1)	Low load, dry climate grass-shrub
Grass-Shrub 2 (GS2)	Moderate load, dry climate grass-shrub
Shrub 1 (SH1)	Low load, dry climate shrub
Shrub 2 (SH2)	Moderate load, dry climate shrub
Shrub 5 (SH5)	High load, dry climate shrub
Shrub 7 (SH7)	Very high load, dry climate shrub
Timber Litter 1 (TL1)	Low load, compact conifer litter
Timber Litter 2 (TL2)	Low load, broadleaf litter
Timber Litter 3 (TL3)	Moderate load, conifer litter
Timber Litter 4 (TL4)	Small downed logs
Timber Litter 6 (TL6)	Moderate load, broadleaf litter
Timber Litter 7 (TL7)	Large downed logs
Timber Litter 8 (TL8)	Long needle litter
Timber Understory 1 (TU1)	Low load, dry climate timber-grass-shrub
Timber Understory 5 (TU5)	Very high load, dry climate timber-shrub

the three parks, we classified vegetation into 18 unique surface fuel models (table 1) and then we developed successional pathways for each (fig. 1).

Our end result is a deterministic model of fuel succession, based on expert local knowledge, that accounts for both fuel accumulation and consumption. The model predicts how fuels—represented by the fire behavior fuel models—can be expected to change over time. Rules governing transitions from one fuel model to another reflect our best judgment about how quickly fuels accumulate and how different vegetation types respond to fires of various severities.

Fire Severity: The Major Model Input

Fire severity and time since last fire are the key inputs that dictate which successional pathway the model will follow. We defined fire severity as the degree of post-fire change that would be seen from a remotely sensed (aerial) perspective, a definition compatible with Normalized Burn Ratio techniques for assessing fire severity (Key and Benson 2005, Thode 2005, Miller and Thode 2007). Sequoia and Kings Canyon National Parks have used delta Normalized Burn Ratio (dNBR) (Thode 2005) and Yosemite National Park has used Relative delta Normalized Burn Ratio (RdNBR) (Miller and Thode 2007) data to obtain estimates of fire severity on most of their larger fires for fires that have burned in the past 30 years. We used these estimates of fire severity, usually classified into low, moderate, high, and unburned categories, to model post-fire transitions among fuel models.

Fuel Model Transitions

For each of the 18 unique surface fuel models developed for park vegetation types, we created a state-and-transition model, represented by a successional pathway diagram (fig. 1). A "state" is a standard fire behavior fuel model, and "transitions" are the changes to the fuel model that occur as a result of either fuel accumulation or low, moderate, or high severity fire. Transition times associated with each state represent the waiting period before the current state changes to the subsequent state (fuel model) in the absence of fire. We based the state, transition, and transition time selections on the distribution of the underlying vegetation for each fuel model assigned in the crosswalk.

There are two general categories of fuel model transitions: (1) transitions resulting from low, moderate, or high severity fire, and (2) transitions resulting from fuel accumulation. Transitions resulting from fire are to a temporarily unburnable state—several years may be required before enough fuel accumulates to support another fire and thereby transition back to a burnable fuel model. Transitions based on fuel accumulation reflect the rate of post-fire recovery or fuel accumulation that occurs in the absence of fire; these rates vary with the severity of the fire and the accumulation potential of the post-fire vegetation. For example, if the Timber Litter 6 (TL6) fuel model burns in a moderately severe wildfire, it becomes unburnable for 5 years. After 5 years, enough fuel will have accumulated for it to transition back to the original TL6 fuel model (fig. 1).

We developed 22 diagrams, one for each of the 18 original fuel models plus four "special cases" (see below). Most diagrams are self-contained, reflecting successional pathways that are either circular or dead-end in a "final" fuel model (fig. 2). But in a few cases, a fuel model transition reflects an underlying vegetation type change that necessitates a transition to a new succession diagram. For example, if fuel model TL6 burns in a high severity fire, it will eventually become a Grass-Shrub 1 (GS1) fuel model and continue to follow the successional path illustrated in the TL6 diagram (fig. 1). On the other hand, if it remains unburned for 50 years, it will transition to fuel model Timber Litter 8 (TL8) as a result of an underlying vegetation type change, and the succession model will then follow the successional pathways in the TL8 diagram.

The four "special cases" represent situations where multiple vegetation types were similar enough in their expected fire behavior to be crosswalked to a single fuel model but were markedly different in their accumulation rates or response to fire. In these special cases, we developed multiple distinct successional diagrams for the fuel model. For example, fuel model Timber Litter 2 (TL2) was crosswalked from evergreen oaks (Quercus spp.) as well as a variety of deciduous tree species. These two vegetation types have very different fuel accumulation rates and responses to fire, and, therefore, separate succession diagrams were developed for each type (fig. 3, fig. 4).

Updating Fuels Data

The Sierra Nevada Fuel Succession Model provides a simple, practical, and easy way to keep surface fuels data current. It extends the useful life of these expensive and labor-intensive data and should improve the predictive accuracy of fire modeling tools such as FARSITE and FlamMap. To keep fuels data current, the model should be run each year at the end of the fire season, starting the first year after the creation of the fuels data (generally the vegetation data's capture date). Model outputs include a fuel model grid representing the next year's fuels (prior to next year's fire season) and inputs for the following year's succession run.

Conclusions

One must keep in mind that, like all models, the Sierra Nevada Fuel Succession Model is subject to the quality of the underlying data and the accuracy of the predictions of the fire and fuel modeling experts. It is also subject to all assumptions of the models and classification systems used to generate its inputs, specifically the vegetation and severity classifications based on remotely sensed imagery. In addition, fire is the only landscape-scale process modeled—the roles of other processes such as insects, diseases, blow-downs, or avalanches are not accounted for in this version of the model.

As the Sierra Nevada Fuel Succession Model is put into use at Yosemite, Sequoia, and Kings Canyon National Parks, the transitions and transition times in the successional pathways will be vali-

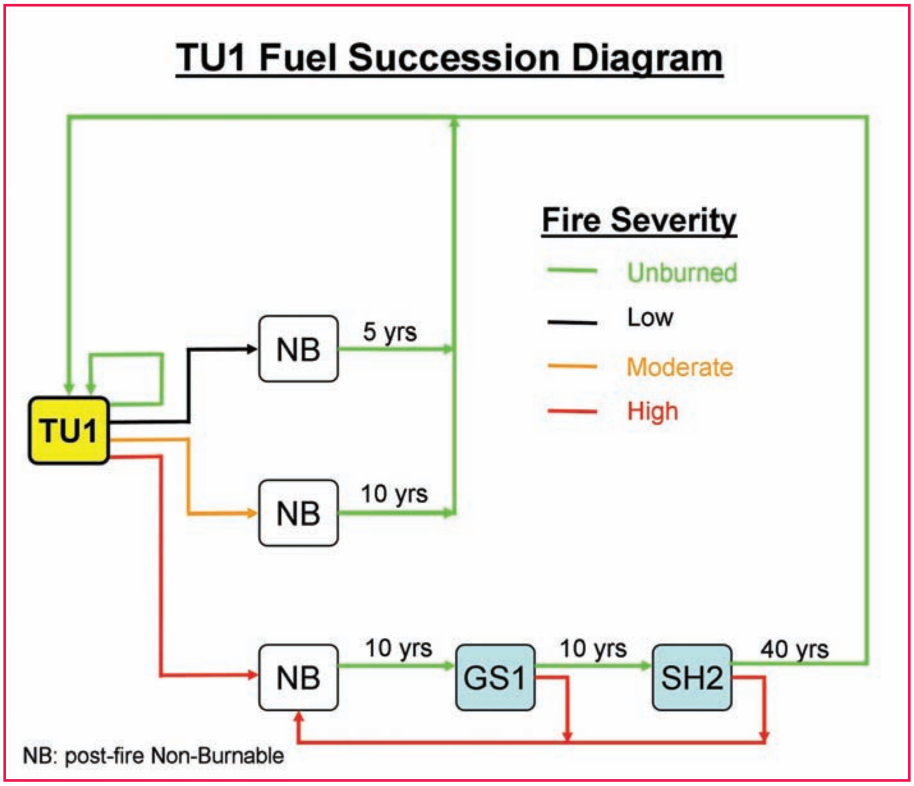

Figure 2—*Fully self-contained successional pathway diagram for the Timber Understory 1 (TU1) fire behavior fuel model.*

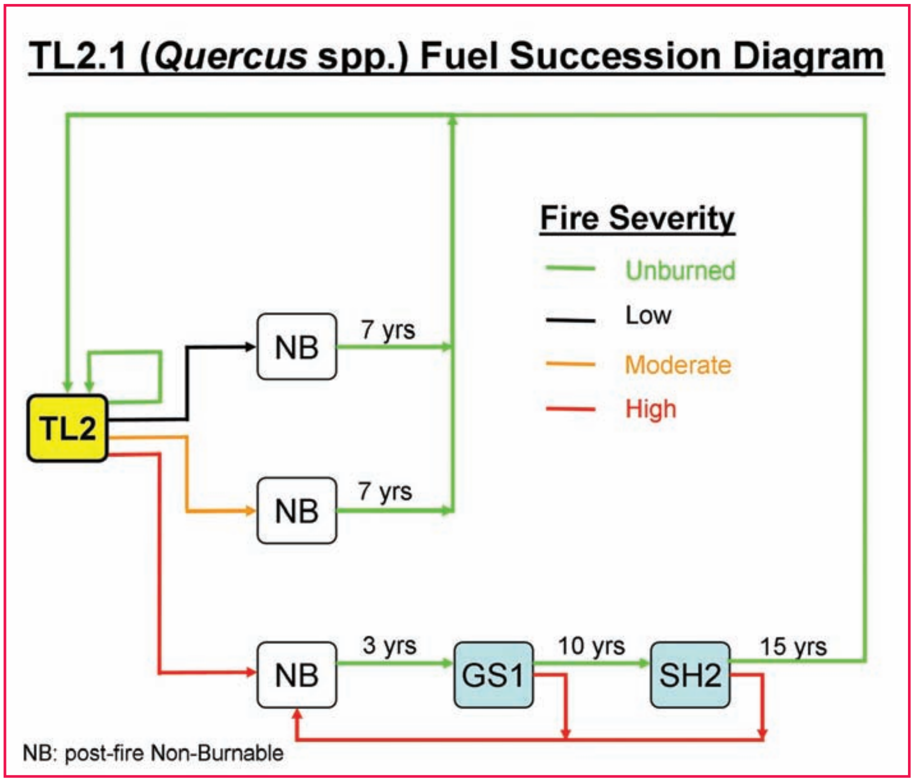

Figure 3—*Successional pathway diagram for the Timber Litter 2.1 (TL2.1 - evergreen oaks) fire behavior fuel model.*

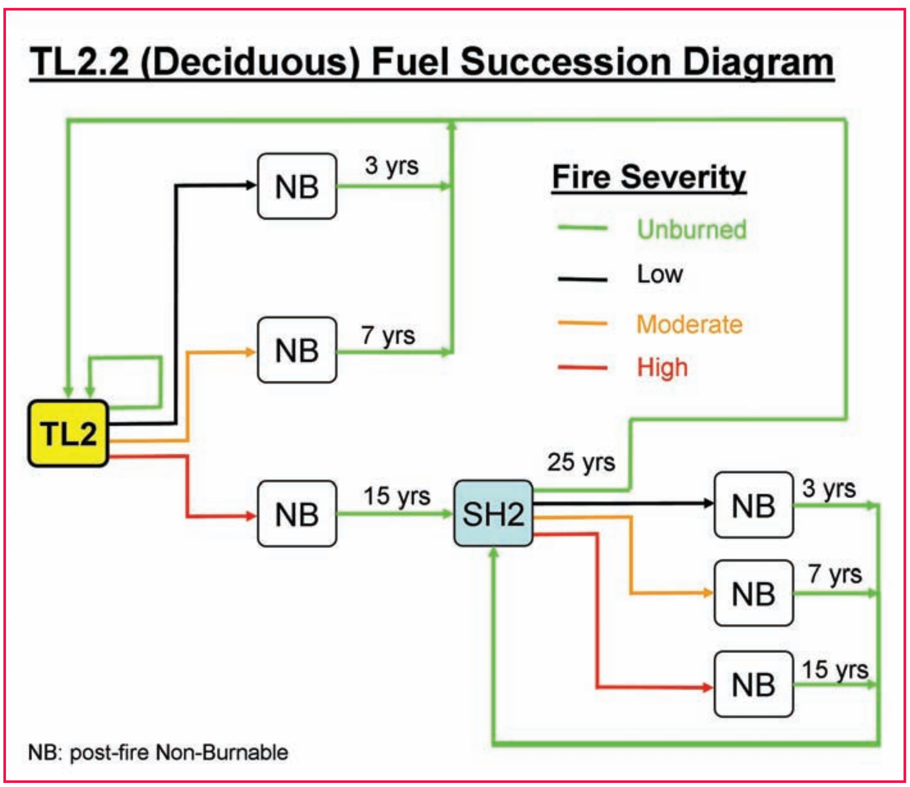

Figure 4—*Successional pathway diagram for the Timber Litter 2.2 (TL2.2 - deciduous) fire behavior fuel model.*

dated and adjusted in response to field observations. Currently, the model is only applicable to the central and southern Sierra Nevada, but the techniques should be generally applicable to any fire-prone landscape.

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