AN OVERVIEW OF THE FIRE AND FUELS EXTENSION TO THE FOREST VEGETATION SIMULATOR

Sarah J. Beukema, Systems Ecologist
ESSA Technologies Ltd., Suite 300, 1765 W. 8th Avenue, Vancouver, BC, Canada V6J 5C6
Phone: (604) 733-2996
E-mail: sbeukema@essa.com

Elizabeth D. Reinhardt, Research Forester
USDA Forest Service, Rocky Mountain Research Station, P.O. Box 8089, Missoula, MT 59802
Phone: (406) 329-4760
E-mail: ereinhardt/rmrs_missoula@fs.fed.us

Werner A. Kurz, Senior Systems Ecologist
ESSA Technologies Ltd., Suite 300, 1765 W. 8th Avenue, Vancouver, BC, Canada V6J 5C6
Phone: (604) 733-2996
E-mail: wkurz@essa.com

Nicholas L. Crookston, Operations Research Analyst
USDA Forest Service, Rocky Mountain Research Station, 1221 South Main, Moscow, ID 83843
Phone: (208) 883-2317
E-mail: ncrookston/rmrs_moscow@fs.fed.us

ABSTRACT

The Fire and Fuels Extension (FFE) to the Forest Vegetation Simulator (FVS) has been developed to assess the risk, behavior, and impact of fire in forest ecosystems. This extension to the widely-used stand-dynamics model FVS simulates the dynamics of snags and surface fuels as they are affected by stand management (of trees or fuels), live tree growth and mortality, and fires. It offers all the standard silvicultural options available in FVS as well as various fuel treatments and prescribed burns. In addition to the standard output provided by FVS, the FFE produces indicators of snag size and species distributions, fuel loading, and potential fire behavior and effects. The extension can also simulate the effects of fires on various stand components, using user-provided weather conditions and model-predicted fuel loading. An overview of the model, including some sample results, is provided here.

Keywords: fire effects model, snag model, fuels, coarse woody debris

INTRODUCTION

Fire is an important component of many forested ecosystems. Fire and fuel managers are increasingly asked to predict the consequences of their management actions at a larger scale and longer time frame than the immediate effects on the forest and fuel levels. Models exist that simulate the dynamics of the forests, the dynamics of fuels, fire behavior, and the effects of fires, but few combine more than one or two of these components. The goal of the Fire and Fuels Extension (FFE) was to create a model that linked changes in forest vegetation due to growth, natural or fire-based mortality, and management, with changes in fire behavior, using existing models and information wherever possible. Snag and surface fuel dynamics were included in the FFE because they closely link vegetation and predicted fire intensity.

The FFE is designed to be a tool that managers can use to quantitatively assess consequences of various management options. Using the model, managers can examine the trade-offs between both timber values from FVS, such as merchantable volume available for harvest, and non-timber values such as the density of large snags. The results can be shown to stakeholders or policy-makers in various intuitive display formats.

THE MODEL

The model chosen to simulate the vegetation dynamics was the Forest Vegetation Simulator (FVS, Wykoff, W. et al. 1982). FVS is a distance-independent individual tree growth model that is used by multiple agencies across the US and is fully supported by the US Forest Service. This model is able to simulate and is responsive to common management actions, including both the immediate effect of the action (e.g., density reduction) and the secondary effects (e.g., reduced mortality, or increased growth of the remaining trees). FVS normally operates on a 5-10 year time-step or "cycle." It requires only basic stand exam data, e.g., species and dbh of sample trees, to start a simulation, and produces numerous output tables that describe, in various levels of detail, the stand conditions in each cycle.

The FFE represents three components that are not part of FVS, namely snags or standing dead trees, surface fuels including fallen dead trees, other coarse woody debris, litter, and duff, and fire effects. The FFE simulates the dynamics of the snags and fuels, including their creation and depletion, through management, fire, or decay. Fire's actual effects on trees and fuels can be simulated or the potential intensity as it changes over time can be reported. Each of these components is discussed in more detail below.

The FFE operates on an annual time-step within the multi-year FVS cycle. When the FFE is being used, it always simulates the snag and fuel dynamics. The fire component, however, is only active if the user has specifically requested options such as simulating the effect of a fire or calculating the potential fire intensity.

The initial design of the FFE was developed using a workshop process with numerous experts. This process determined the most appropriate existing models to meet the analytical objectives. It also defines the scope and boundaries of the model. Temporally, the FFE is designed to operate at no shorter than an annual time step, and spatially, it operates on an entire stand. It does not simulate the spread of a fire, or the probability of a fire occurring. Thus, this model will not simulate the fine-scale spread of a fire through part of a stand, or the effects in the days immediately following a fire. By linking the FFE to FVS, the FFE operates on forested lands only, and is not the appropriate choice for simulating the effects of a fire on a rangeland or an open woodland where shrubs are an important component of fire dynamics.

Snags

The snag component of the FFE tracks standing dead trees over time. Snags are created from the death of the living trees simulated by FVS, independent of the cause of death. They are removed through user-specified management, such as salvage logging, or by falling. While fire does not directly remove snags, it consumes their crowns and increases their rate of fall. In the absence of fire, snags experience gradual crown and height loss and decay. Falling, height loss and crown loss gradually move material from the snag component of the model into the fuels component. Each of the processes is defined by species-specific parameters that can be controlled by the user.

By default at the beginning of a simulation, no snags are present unless they were initialized as part of the tree information given to FVS. Users can add additional snags if their characteristics are known. Information about the snags in the model is available in three formats. Two reports are specifically for snags: a detailed report and a summary report. Both reports combine the snag information into six user-defined size classes. The detailed report then lists the complete characteristics of the snags in that size class: species, current height, current hard and soft volume, and the current density of hard and soft snags. This report is printed at a user-defined interval. The summary report simply lists the current density of hard and soft snags in each size class, for all species combined, in each FVS growth cycle. The amount of material contained in snags and their crowns is also reported in the detailed fuel output table (described below).

Fuels

The fuels component tracks litter, duff, and woody surface fuels. The woody debris is classified into six different size classes and four different decay rate classes, based on the species and diameter of the wood at the time it was added to the forest floor. The movement of fuel components between these size classes is not simulated in the model. Each fuel pool, including litter and duff, decays at a potentially different rate. As the fuels decay, a portion becomes duff and a portion goes into the atmosphere. Duff decays only to the atmosphere. Input to the fuels comes from snags (as mentioned above), the crowns of live trees, and management slash. Fuels are removed through decay, management, or fire. Users can control the decay rates, the amount of the decayed material that becomes duff, fuel management options, and, to some degree, the amount of slash that is created at the time of a stand entry.

The model contains default fuel levels based on stand cover and age which are used to initialize the various fuel pools. The user can overwrite these pool sizes with other values, where known. The fuels component produces a detailed output report at a user-specified interval that gives the amount of fuel in each size class, as well as in live and dead trees and canopies.

Fire

The fire component consists of two parts. One part allows users to simulate the first and second order effects of a fire on the stand. First order effects include fuel consumption (Brown, J. K. et al 1985, Ottmar, R. D. et al 1993), tree mortality (Ryan, K. C. and E. D. Reinhardt 1988), crown consumption, smoke production (Reinhardt, E. D. et al 1997) and mineral soil exposure. Second order effects include the reduced growth of scorched living trees, increased fall rate of some snags, and potentially altered growth, mortality or regeneration prediction by FVS. The second part, instead of simulating the effect of the fire, reports various characteristics that can be used to assess the potential impact of a fire on the stand, the risk of the stand to severe fire, and the effect of different management regimes on these indicators. For example, this report produces information, for two different weather scenarios, about the potential flame length, the type of fire (e.g., surface fire or crown fire), and the potential basal area mortality of the stand. In both cases, the model must calculate surface fire intensity (Rothermel, R. C. 1972, Albini, F. A. 1976) and the related flame length or scorch height and the type of fire based on user-defined environmental conditions and the modeled stand characteristics.

Unlike the snag and fuel components of the FFE, the fire component is only active if the user has specifically requested options such as simulating the effect of a fire or calculating the potential fire intensity. In addition, the FFE simulates only those fires that have been requested by the user, using times and parameters defined by the user. Users can schedule fires with different weather conditions or management conditions to occur at different points in time or when the stand reaches a given stand condition. For example, users can specify that they want a fire to occur under very dry moisture conditions if there is more than 100 tons per acre of surface fuels, or they can specify that they would like to do a prescribed burn under very still, wet conditions 10 years after the simulation began. The model is not designed to predict when a fire will occur, the probability of fire, or the spread of a fire between stands.

The fire component optionally produces three tables at the time that a fire is simulated. These tables provide the user with information on the conditions at the time of the fire: fuel moisture, wind speed, flame length, and scorch height; the fuel consumption by size class, including smoke production and mineral soil exposure; and the tree mortality by size class and species. A fourth table is produced by the part of the FFE that calculates the potential fire intensity and effect and includes, for two different user-defined wind and moisture scenarios, the potential flame length, whether the fire would be a surface fire, an active crown fire, or a passive crown fire, the percent basal area mortality that would be experienced, the current crown base height and crown bulk density, and the wind speeds that would be required to produce torching or crowning (Scott, J.H. and E.D. Reinhardt in prep.) under the first of the weather scenarios. Users can control the frequency and duration of the production of this table.

EXAMPLE RESULTS

To demonstrate some of the abilities of the FFE, we simulated an example stand under three different scenarios. The purpose of this example is to show how the model can be used to compare different alternatives, using some of the options and output that are readily available.

The simulated stand contains approximately 2700 trees per acre or 300 sq. ft. per acre of basal area of a mixture of lodgepole pine, Douglas-fir, grand fir, and subalpine fir. After about five years of normal growth, and in successive years, a wildfire in the stand would cause a complete stand replacement. We thus compared the effects of three treatments applied 15 years into the simulation: 1) do nothing, 2) thin from below and remove the thinned stems from the stand, and 3) conduct a prescribed burn on the stand. The thinning was designed to reduce the stand to the same basal area as the burn, in both cases from approximately 250 sq. ft. per acre to 110 sq. ft. per acre.

From the numerous indicators that are available, we have chosen two. The first one is potential basal area mortality, which is the percent of the available basal area that would be killed if a wildfire occurred under very dry conditions in the stand. The second indicator is the total amount of dead surface fuels other than litter or duff, henceforth referred to as woody surface fuels.

After the first five years, the predicted percent basal area mortality from the wildfire is 100 percent (Figure 1). If no treatment is applied, this percentage remains unchanged for the remainder of the simulation period because the stand would always experience a complete crown fire. The prescribed burn causes a slight reduction in the predicted mortality. In contrast, the thinning creates an immediate partial reduction in the potential mortality, which then continues to decrease.

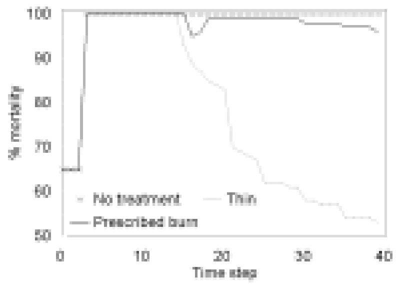

Figure 1. The potential percent basal area mortality that would occur from a wildfire under very dry conditions.

Mortality is a function of the size and species of trees in the stand, the environmental conditions, and fuel loads. In all cases, the environmental conditions are the same. The size and species distribution of the trees varies, as do the fuel loads. The patterns of change in the coarse woody debris pools, i.e., those surface fuels that are not litter, duff, snags, or alive, explain some of the differences in behavior. Both the scenario with no treatment, and the scenario with a burn show high amounts of fuels (Figure 2), which increases the severity of the fire and thus helps to cause the increased mortality. The greater increase in fuel loads after the burn is caused by the breaking and falling of the numerous snags created from the prescribed burn.

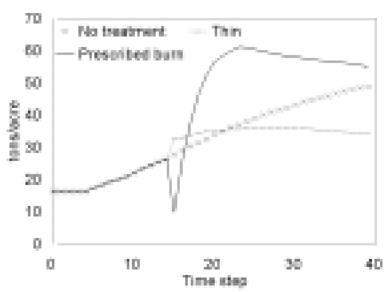

Figure 2. The surface woody fuels in the stand under the three different scenarios.

Conversely, the thinning removed many of the trees that may later have died and thus reduced the source of some of the input to the fuel pools in later years. The immediate increase in fuels after the thinning is caused by the slash from the crowns of the trees that were harvested. These decompose relatively quickly, however, so their effect is short-lived.

The biggest difference between the runs, and the second source of differences between the three scenarios is in the stand structure (Figure 3). With no treatment, the predicted fire is always able to become a complete crown fire, and kill all trees in the stand. The thinning creates a more open stand allowing the trees to grow relatively well, which leads to bigger, more fire-resistant trees. In addition, there few small trees in the understory in this scenario, which reduces the chances of a crown fire, thus further reducing the potential mortality. The prescribed burn removes fewer trees than the thinning, and at a wider variety of sizes. Thus, more trees would be killed directly from the flames, and, while the stand would not have a complete crown fire, many trees experience torching and die.

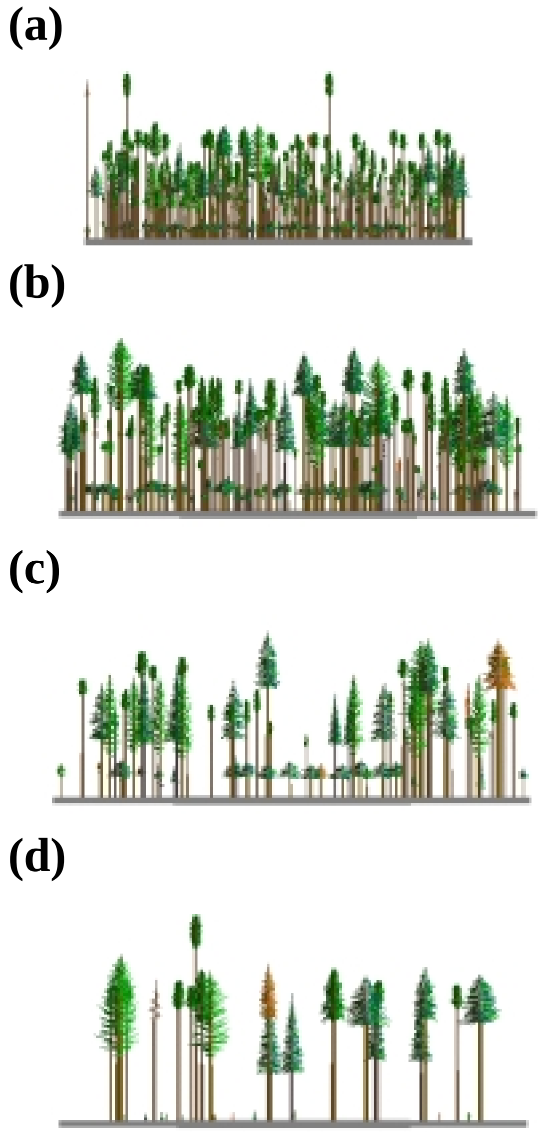

Figure 3. A schematic diagram of the stand. A) before any treatment, B) 20 years later with no treatment, C) 20 years after the burn, D) 20 years after the thinning. All figures were produced using the Stand Visualization System (SVS, McGaughey, R.J. 1997).

This set of scenarios was chosen for example purposes only because it shows some of the interactions between the different parts of the FFE. This stand is clearly not a good candidate for a prescribed burn to reduce fuel loads and future risk of fire because of the density of small trees and the impact of the mortality resulting from the burn. Thinning, if the stems of the thinned trees are removed, reduces the fuel loads and reduces the risk of the stand to a stand-replacing fire.

SUMMARY

The FFE is a powerful tool that can allow the user to explore a wide variety of scenarios of the interactions between tree growth, snags, fuels, management, and fire severity. It is able to simulate snag and fuel dynamics without simulating fires. The FFE can, if desired, produce reports of changes in various indices of potential fire severity as a result of the changing stand characteristics, or predict the first and second-order effects of the fire on the various stand components.

The FFE is currently linked to the Northern Idaho variant of FVS and is available from the USFS web site at: http://www.fs.fed.us/fmsc/variants.htm. Previous experience with FVS is recommended. Calibration for the Southern Oregon / Northeastern California region is in progress, and we plan to complete the calibration of the FFE for all western US variants within the next two years. In addition, we are exploring the linkage of this model with FCCs (Sandberg and Ottmar 1999) and FARSite (Finney 1998).

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