An Introduction to the Fire and Fuels Extension to FVS

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Abstract—The Fire Effects Model Extension is a new extension to FVS and the PPE that allows users to simulate the effects of fire on a number of indicators, including stand structure and composition, fuel loading, and size and density of snags. In the absence of fire, the model can be used to simulate snag and fuel dynamics resulting from tree growth and mortality and stand management. While the model produces indicators of stand risk to fire (in terms of potential flame length), the model cannot be used to simulate fire spread or the probability of a fire. A brief description of the model is given here, with some sample results showing some of the new indicators at the stand and landscape level.

Fire is an integral part of forest ecosystem dynamics and management. The Forest Vegetation Simulator (FVS) (Stage 1973; Wykoff and others 1982) is used widely by forest managers to predict future forest conditions as affected by various management actions. Up to now, fire as an ecosystem process has not been explicitly represented in FVS. Outside of FVS, several models have been developed to represent fuel dynamics (with and without fire) (Keane and others 1989), the fire itself (Albini 1976a; Rothermel. 1972), and the effects of fire (Keane and others 1989; Reinhardt and others 1997). The Fire Effects Model Extension (FEME) (Beukema and others 1996) was created from a need to link FVS with these fuel and fire models. The two main objectives for the FEME were to simulate fire effects (but not fire spread or the probability of fire), and, where possible, to use established algorithms and existing models. A joint model allows the fuel and fire model components to benefit from FVS by using FVS-generated predictions of tree growth, mortality, and regeneration as they are influenced by simulated management practices, and allows FVS components to benefit by being able to directly represent the effects of fire on species composition and stand structure. In the absence of fire, the snag model component of the FEME provides predictions on the dynamics of dead trees which are of interest to wildlife biologists and forest managers.

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Brief Description of the Fire Effects Model Extension

Model Overview

The FEME includes several submodels that take information from other components, perform calculations, and pass other information to different components (fig. 1). The three main submodels are: a snag model, a fuel dynamics model (which includes a foliage or branch model), and a burn model (which includes a fire intensity model and a fire effects model). As with the insect and disease extensions to FVS, the FEME uses the tree data generated by FVS to perform various calculations. Each of the submodels, and the information they use and generate, will be described in more detail.

Currently, the FEME is linked to the Northern Idaho variant of FVS and of the Parallel Processing Extension (Crookston and Stage 1991). This allows users to simulate fire effects at the stand and landscape level, although fires at the landscape level will not spread between stands.

Snag Model

The snag model tracks the fate of the stem and crown (foliage and branches) of standing dead trees. In the model, snags are stored in groups of trees that died in the same year and are in the same species-, diameter-, and height-class. The snags in each record are described by seven characteristics:

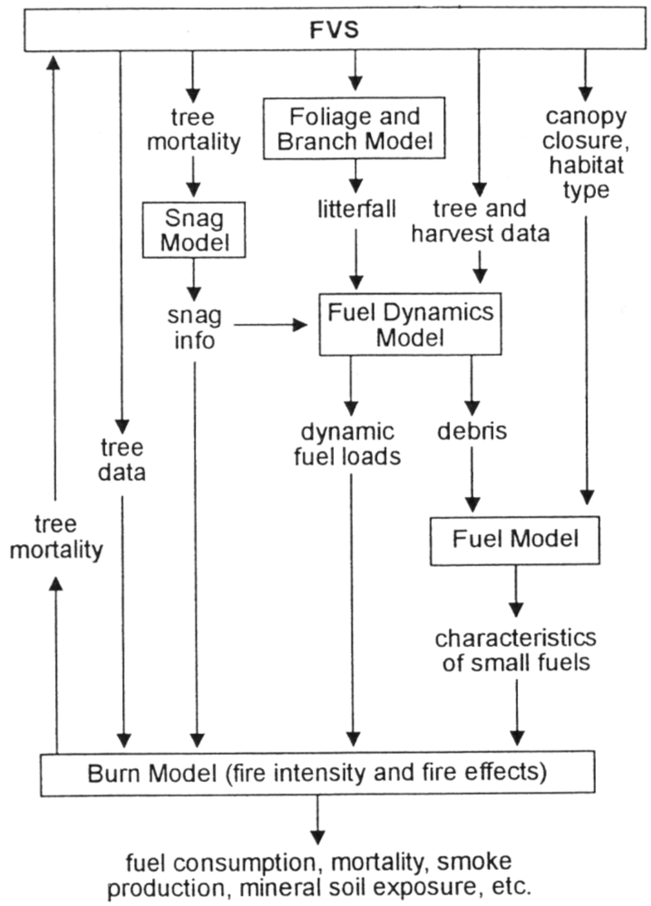

Figure 1—Overview of the components of the model and their interaction. The boxes in this figure show the main submodels while the arrows indicate the flow of information between submodels.

1. Two-inch diameter class based on the diameter at the time of death
2. Species
3. Current height
4. Height at the time of death
5. Time since death
6. Decay status (hard or soft)
7. Snag density (trees per acre)

Only four of these characteristics change over time: density, height, decay status, and time since death. Trees can become snags through stand management, fires, or natural death. The number of snags per acre is reduced through fall down or management. The remaining snags will experience some breakage or height loss. The annual rate of this loss depends on species and will affect the calculated snag volume. The branch and stem material lost from the snags through fall down or height loss is transferred to the fuel pools. Finally, as the snags decay, hard snags will become soft. The parameters driving each of these processes are under keyword control.

Keywords are available to allow users to remove snags of given ages and decay states (for example, do a salvage cut), and to create snags either as part of a regular harvest (for example, trees that are killed as a result of the harvest but are left standing) or as an entry that is designed to create "wildlife" trees. A keyword allows users to add snags to the stand inventory at the start of the simulation. These snags are considered to be in addition to the dead trees in the treelist.

Output is available that gives the density, height, volume, decay class, and time of death for all snags in the model. These values are grouped into one to six classes based on stem diameter at the time of death. Class boundaries and output frequency are under user control.

Fuel Dynamics Model

In the FEME, fuels are defined as organic material on the ground. This includes woody material of any size, litter, duff, and live herbs and shrubs. The woody fuels are stored in six different size classes, based on piece diameter: 0 to 0.25 inch, 0.25 to 1 inch, 1 to 3 inches, 3 to 6 inches, 6 to 12 inches, and greater than 12 inches. Input to the litter and woody fuel pools comes from snags (breakage and falling), litter fall, canopy breakage (from tree growth, scorching, or other causes), and residue from harvest. As the fuels in the fuel pools decay, the material either enters the duff pools, or is oxidized to the air. Decay rates are based on the size and type of fuel and are modeled using a simple exponential decay process. Fuels that have come from soft snags decay faster than those from hard snags, and litter and small fuels decay faster than larger fuels. Besides the transfer of material to the duff pool as part of the decay process, there is no transfer of material between size classes. Decay rates and the proportion of the decayed material that is transferred to the duff pools are all under user control.

The live herbs and shrubs are not modeled explicitly. The biomass in these classes depends on the dominant species in the stand. It is a constant, using the assumption that the herbs grow back within 1 year of fire and their volume will compensate for the slower regrowth of the shrubs. At this time, herbs and shrubs only affect the amount of smoke produced by the fire.

Because the fuel model receives input from the canopy of live trees, there is a separate submodel that uses tree information (species, diameter, relative position in the stand, and so forth) from FVS to determine the amount of foliage and branch material in the canopy of each tree. The amount of canopy breakage and litter fall entering the fuel pools can then be calculated for both live trees and snags.

Fuel levels in the model can be reduced using various fuel burning options such as, pile bums or jackpot burns, as well as prescribed burns. Additions to the fuel pool at the time of harvest are also under keyword control. The fuel model output reports the amount of fuel in litter, duff, small and large fuel classes, and includes summary information on small and large snags, and small and large live trees.

Burn Model

The burn submodel consists of two parts: calculations of fire intensity and calculation of fire effects. Fire intensity, using flame height, is directly based on a routine in the existing FIRESUM model (Keane and others 1989) that is based on the FIREMOD model (Albini 1976b). Inputs to the fire intensity calculations include moisture, windspeed and the characteristics of small fuels. The characteristics of small fuels are calculated from equations derived from the standard static fuel models (Albini 1976a) and use the small and large fuel loads from the fuel dynamics model.

The model calculates various fire effects, many of which are based on algorithms in FOFEM (Reinhardt and others 1997). The effects include: tree mortality, fuel consumption, smoke production, growth reduction of scorched trees, and fuel creation (from fire-killed canopies). Tree mortality in the model is primarily based on flame height and scorch height, and varies by species and diameter. Additional mortality can be caused by crown fires. Fuel consumption is based on moisture and fuel class and directly affects the amount of smoke produced.

Users must select the year and stand in which fires occur. A keyword controls the type of fire (for example, prescribed fire, wildfire, throttle back, or mass ignition). Each type determines the default windspeed or flame length that is used for the fire. Additional keywords allow users to change the conditions at the time of a burn: moisture levels, windspeed, temperature, flame length or flame length multiplier, and percent of stand experiencing crowning.

At the time of a fire the model reports, if requested, the burn conditions (moisture, windspeed, flame length, and so forth), tree mortality by species and size class, fuel consumption, smoke production and percent of the stand that experienced crowning. Users may also request output that gives an indication of the risk of stands to different types of fire. This table contains the potential flame length for prescribed burns and wildfire. Finally, if the fire model is run as part of the PPE, landscape-level reports can be produced that show the amount of the landscape in different fuel load classes, by fuel pool, and the percentage of the landscape that would experience flame lengths of different categories for prescribed burns and wildfire.

Results

Two scenarios were simulated using stand data from the Nez Perce National Forest. The scenarios demonstrate the model's ability to produce different effects from occasional stand-replacing fires and from frequent underburns. In the first scenario, 60 percent of the landscape experienced two severe wildfires, the first 50 years after the start of the simulation and the second 100 years later. In the second scenario, underburns occurred every 20 years in the entire landscape.

Results from one of the stands that experienced the fires in the first scenario are presented here as an example. While the numeric values of the results vary between stands, the general dynamics are similar, especially the effect of the fires. Differences between stands arise primarily due to different initial size and species compositions. The fires occurred under "very-dry" conditions with 90° F temperatures and a midflame windspeed of 2 mph. Flame lengths ranged from 2.3 to 11.0 ft, and for the stand pictured here were 2.3 and 4.2 ft for the first and second fire, respectively.

Standard FVS stand dynamics have not been pictured here. The fire kills trees from all size classes and of all species, but mortality is higher on the smaller trees. The stands regenerate after the fires, and thus are about 100 years old at the time of the second fire.

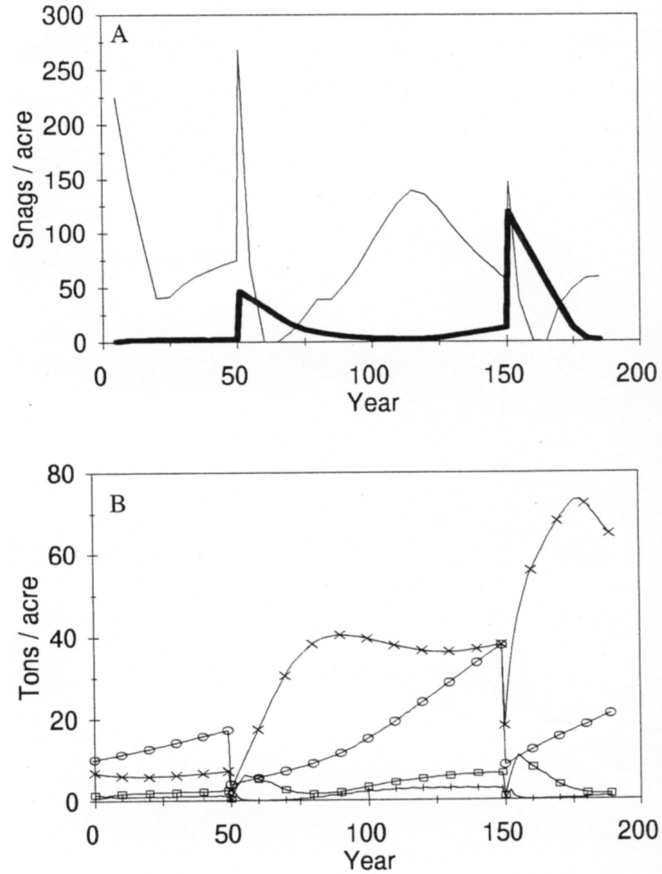

Figure 2—Example indicators from one simulation of the FEME. Severe wildfires occurred in year 50 and year 150. (A) Density of snags less than 12 inches diameter at the time of death (thin line) and greater than 12 inches diameter (thick line). (B) Fuel pools. Pools are: litter (|), duff (O), fuels less than 3 inches diameter (0), and fuels greater than 3 inches diameter (X).

In this scenario, the stand initially contains a large number of small dead trees (fig. 2a). These slowly fall and break apart. New snags are created through tree mortality. Immediately after the fire, the number of snags, both large and small, increases dramatically with the input of the firekilled trees. The fall rate of small, fire-killed snags is higher than for trees killed by other causes, and thus the pool of small snags decreases rapidly. The increase of small snags between fires is from natural mortality of the regenerating trees. At the time of the second fire, bigger trees are present, so the pool of large snags increases by a larger amount than after the first fire.

The debris pools show the opposite pattern. While all pools increase slightly in the first 50 years of the simulation, they all show a dramatic drop at each fire due to fuel consumption (fig. 2b). Seventy-seven percent of the duff pool was consumed in each fire and 64 percent (first fire) or 52 percent (second fire) of the large fuels was consumed. Fuel pools, especially the large downed woody debris, increase after the fire due to input from the falling and breaking snags. Duff pools show the most noticeable increase a number of years after the fire. As material decomposes in all other fuel pools, a portion enters the duffpool. Material enters at a faster rate than the rate of decay of the duff layer. Litter pools remain relatively constant throughout the simulation period with the exception of their consumption during a fire.

The simulations were done using the PPE version of the model. Thus, the model produced output that showed the percent of the landscape that was in different fuel loading classes, for certain fuel pools. Fuel loading classes are defined as 0 to 10 tons per acre, 10 to 20 tons per acre, 20 to 30 tons per acre, and greater than 30 tons per acre. Figure 3 shows the results of the landscape-level simulation on the small fuel loading (fuels less than 3 inches). Initially, the entire landscape contains less than 10 tons per acre of small fuels. As the landscape ages, the amount of small fuel increases. The first fire occurs in year 50 and its impacts are easily seen as the increase in the area containing small fuels. The second fire is also noticeable because in year 150, 60 percent of the landscape, the amount of area burned, contains less than 10 tons per acre of small fuels.

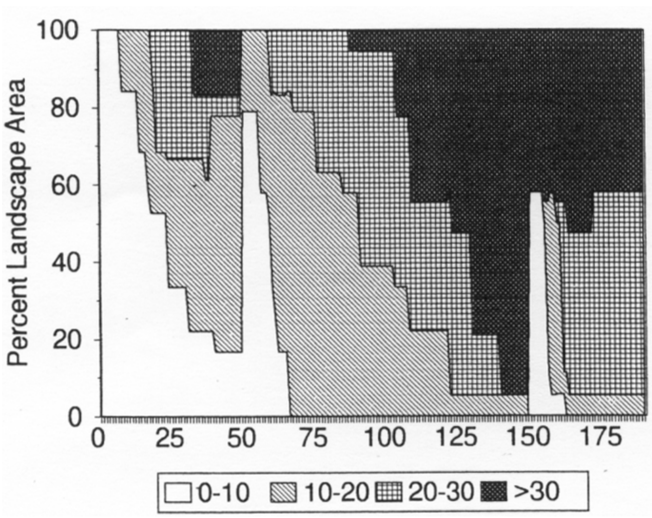

Figure 3—Landscape-level fuel loading of small fuels (0 to 3 inches diameter) in the scenario with two stand-replacing fires in 60 percent of the landscape. The y-axis shows the percentage of the landscape in each of four loading categories, measured in tons per acre.

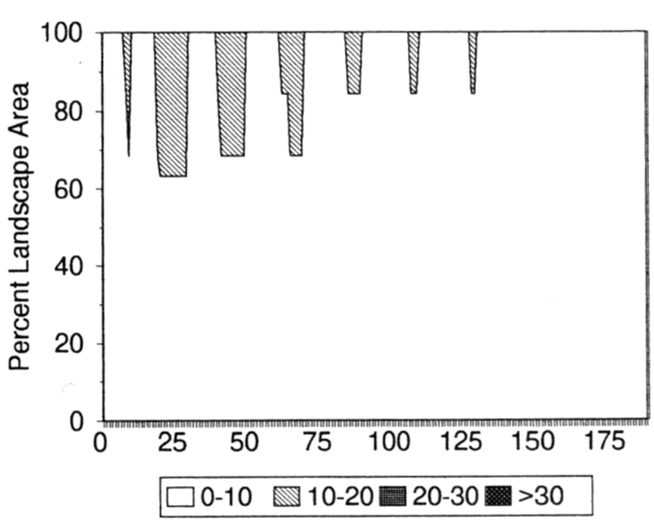

Figure 4—Landscape-level fuel loading of small fuels (0 to 3 inches diameter) in the scenario with frequent underbums. The y-axis shows the percentage of the landscape in each of four loading categories, measure in tons per acre.

This result contrasts with the same landscape-level indicator in the second scenario. In this scenario, repeated underburns prevent the small fuels from accumulating in the landscape (fig. 4).

Summary

The FEME is a flexible model that allows users to simulate snag and fuel dynamics with or without fires; predict changes in fuel levels due to management, fire, or natural aging; calculate a fire severity indicator for the stand or landscape; and predict the effects of fire on various indicators, including stand structure and composition. The fire model cannot, however: predict when a fire will occur, calculate the probability of a fire, or simulate the spread of fire between stands. The model is still in a state of testing and calibration, especially the fuel dynamics components. Additional refinements to the model will allow users to use the Event Monitor (Crookston 1990) to schedule fires based on live tree, snag or fuel conditions. In addition, the snag submodel will be integrated as a component of the base model FVS that will be available to users outside of the fire model.

Acknowledgments

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