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Expansion of the Southern Variant of the Fire and Fuels Extension for the Forest Vegetation Simulator

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Expansion of the Southern Variant of the Fire and Fuels Extension for the Forest Vegetation Simulator

Final Report

S. M. Zedaker, S. A. Rebain, P. J. Radtke

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Introduction and Background

This project specifically addressed AFP 2006-3, Task 3, by providing guidance for maintaining effective fire and non-fire fuels treatments, with the aim of supporting long-term fuels management.

The overall goals of the project were to parameterize, expand, and improve the Southern Variant of the Fire and Fuels Extension (FFE) to the Forest Vegetation Simulator (FVS) with the best data currently available, to identify data weaknesses and gaps that may require additional research to reduce the uncertainty of Southern FFE model predictions, and to determine a validation framework for the Southern FFE. A wide variety of fire and fuels data and expertise is necessary to parameterize a local/regional FFE. Some of the model inputs are derived research data, but many inputs must be acquired as educated estimates from local experts. This lack of validated data quality means that the model outputs contain a substantial amount of uncertainty. Forest land managers must justify their actions and management to an increasingly skeptical public, often in courts of law. Knowledge of model uncertainty is essential for defending the validity of model outputs and the forest/park management plans that they influence.

The specific project objectives were:

a. To parameterize, expand, and improve the Southern-FFE for FVS with the best data currently available.
b. To identify data weaknesses and gaps that may require additional research to reduce the uncertainty of Southern-FFE model predictions.
c. To determine a validation framework for the Southern-FFE.

As such, this report assesses the capabilities of existing software and decision-support tools for evaluating vegetation/fire treatment life span and/or maintenance requirements by documenting the quality of data, and data gaps, in the most common tool used by federal managers to project forest conditions on the basis of fire and fuel treatments.

Without a well calibrated/parameterized model, none of the specific objectives of Task 3 can be realized. This report summarizes the discussion at a workshop held to better parameterize the Southern FFE, evaluates the quality of the data in the model, and provides suggestions for a rigorous validation of the model. Since scientific and legal challenges to forest plans are common and the bases for management are often projections (simulations) of future conditions, it is essential that the quality of model inputs be understood and assured.

Objective a):

A workshop was held at the Courtyard Marriott Atlanta Airport North, Atlanta, Georgia, on May 22, 2007. The workshop generated the data and ideas for the improvement of the Southern FFE. The attendees were:

Stephanie Rebain, USFS-Washington Office-Forest Management Service Center
Chad Keyser, USFS-Washington Office-Forest Management Service Center
Shep Zedaker, Fire Researcher, Virginia Tech
Phil Radtke, Biometrician, Virginia Tech
Tara Keyser, Research Forester, USFS-Southern Research Station-Bent Creek
Dave Haywood, Research Forester, USFS-Southern Research Station-Louisiana

Ken Outcalt, Research Fire Ecologist, USFS-Southern Research Station-Athens, GA
Tom Waldrop, Research Fire Ecologist, USFS-Southern Research Station-Clemson University
Eugene Brooks, Forest Silviculturist, National Forest System, Alabama

Based on workshop feedback, the following changes to Southern-FFE are planned:

Fuel Model Logic – Joe Scott is working on new fuel model selection logic for all variants that includes the 40 new Scott and Burgan fuel models. Once this is programmed into FFE, we can see if this works better for the whole southern region.

Dead Surface Fuel Loads – The current initial dead surface fuel values are as follows, in dry tons/acre:

	Size Class (in)							
Species	**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
Pines	.13	.92	1.31	.92	.31	0	1.1	6
Hardwoods	.08	.46	1.2	1.57	1.25	.70	6.8	4

FIA down woody data for the South has been requested. When the data are received, it will be analyzed and new initial dead surface fuel defaults will be determined based on forest type, size class, or other variables.

Live Surface Fuel Loads – The current live surface fuel values are as follows, in dry tons/acre:

Forest Type	**Herbs**	**Shrubs**
Pines	0.10	0.25
Hardwoods	0.01	0.03
Redcedar species	1.0	5.0
Oak-Savannah	0.02	0.13

These will be adjusted for most EUC (Ecological Unit Codes) in the southern variant. Specifically, where the EUC indicates galberry/palmetto sites of the coastal plain, the tons/acre values in Brown and Smith (eds. 2000), Table 43, page 63 will be used:

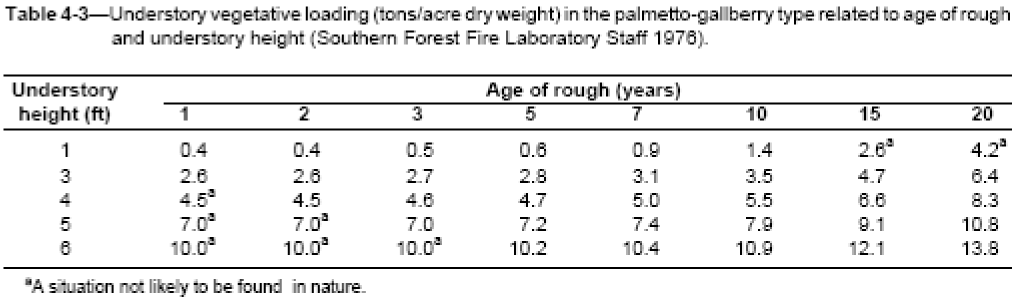


Table 4-3—Understory vegetative loading (tons/acre dry weight) in the palmetto-gallberry type related to age of rough and understory height (Southern Forest Fire Laboratory Staff 1976).

Understory height (ft)	Age of rough (years)							
	1	2	3	5	7	10	15	20
1	0.4	0.4	0.5	0.6	0.9	1.4	2.6[a]	4.2[a]
3	2.6	2.6	2.7	2.8	3.1	3.5	4.7	6.4
4	4.5[a]	4.5	4.6	4.7	5.0	5.5	6.6	8.3
5	7.0[a]	7.0[a]	7.0	7.2	7.4	7.9	9.1	10.8
6	10.0[a]	10.0[a]	10.0[a]	10.2	10.4	10.9	12.1	13.8

[a] A situation not likely to be found in nature.

In order to do this, the understory height values in the table will be correlated with site index accordingly:

50-Year Site Index	Assumed Understory Height (ft)
< 50	1
50 - 65	2
65 – 80	3
80 – 95	4
95 - 110	5
>= 110	6

Also, the age of the rough will correspond to the time since disturbance (fire or management). Because when data comes into FVS, no disturbance history is known, it will be assumed that it has been 10 years since disturbance. All of the biomass/dry tons/acre values will be split 100%/0% between the shrub and herb categories (i.e., it will all go into the shrub category).

For piedmont and mountain pyric shrub types (mountain-laurel and rhododendron), the associated EUC codes will be determined, and for these types, the live fuel loading will also be taken from Table 4-3, but will be set to 40% of the values in the table.

For EUC codes that are not part of the coastal plain, piedmont, or mountain pyric shrub types, the live surface fuel values will not be modified.

Surface Fuel Decay Rates – The following are the current decay rates used in the SN-FFE:

Size Class (inches)	**Annual Loss Rate**	**Proportion of Loss Becoming Duff**
< 0.25	0.11	0.02
0.25 – 1		
1 – 3	0.09	
3 – 6	0.07	
6 – 12		
> 12		
Litter	0.65	
Duff	0.002	0.0

These will be left as is for hardwoods, but will change to the following for conifers based on a decay study done by Philip Radtke:

Size Class (inches)	**Annual Loss Rate**	**Proportion of Loss Becoming Duff**
< 0.25	0.11	0.02
0.25 – 1		
1 – 3	0.11	
3 – 6	0.11	
6 – 12		
> 12		
Litter	0.65	
Duff	0.002	0.0

Snag Fall Rates – The snag fall rates will be adjusted for loblolly pine, longleaf pine, sand pine, and scrub oak as follows, based on data from Philip Radtke and Kenneth Outcault:

> *From Ken's unpublished data for longleaf pine (Ocala NF, 3-year rx burning regime) - 4% fall during the first year and 11% fall each year from then on.*

From Ken's published paper for sand pine and scrub oak (Outcalt 2003) - (after fire) - oaks fall faster than the pines, pines would be all down in 11 years, with about 9% falling each year. On average, 13% of the oaks fall each year.

From Phil's data for loblolly pine - all down by 20 years with variable rates over time (with bigger annual fall percentages right after death that then taper off).

Snag Height Loss Rates – Currently, snag height loss is not modeled in SN-FFE. This will not be changed.

Objective b):

A rigorous post-workshop evaluation was used to develop a list of sub-models, equations, tabular values, and parameters necessary to the Southern FFE model that were rated for data quality. A five-level rating system was used to estimate data quality:

5 – from multiple refereed literature sources,
4 – from a single refereed literature source,
3 – from gray (non-refereed) literature source(s),
2 – confirmed/estimated/contributed from/by multi-experts, and
1 –confirmed/estimated/contributed by a single expert.

Results:

The FFE includes three major sub-models that interact with the FVS (Reinhardt and Crookston, 2003):

1. A snag model for tracking and simulating decay and fall of standing dead trees.
2. A fuel model that simulates the accumulation and decomposition of surface fuel, tracks canopy fuels, and selects current fire behavior fuel models as inputs to the third sub-model.

3. A fire model that simulates fire intensity, fire effects on trees, snags, and surface fuels, as well as other ecosystem attributes.

During the workshop, there was a substantial amount of discussion on fire effects, but no data sources were offered by the participants to modify the fire model. Only the first two sub-models were addressed with concrete data sources. Workshop participants did not provide data to assess the impacts of fires, or rather simulated fires, on trees, snags or fuels.

Snag Sub-Model Assessment:

The majority of the snag model logic in FFE is based on unpublished data from Marcot, USFS, Portland OR, 1995 (Reinhardt and Crookston, 2003). Specific snag fall and decay parameters for the Southern variant were developed at the SN-FFE development workshop held in Springfield, Missouri, in 2002.

Three variables are used to modify the Snag Sub-model:

1. A multiplier to modify snag fall rates;
2. A multiplier to modify the snag condition from “hard” to “soft;”
3. The maximum number of years that snags will remain standing.

Tree species were categorized into three classes based on estimated snag fall and decay rate at the SN-FFE development workshop. Snag fall and decay rates were then assigned to these three classes. In some cases, the dynamics of pines and eastern redcedar were modified from their respective snag classes (FFE addendum, 2008).

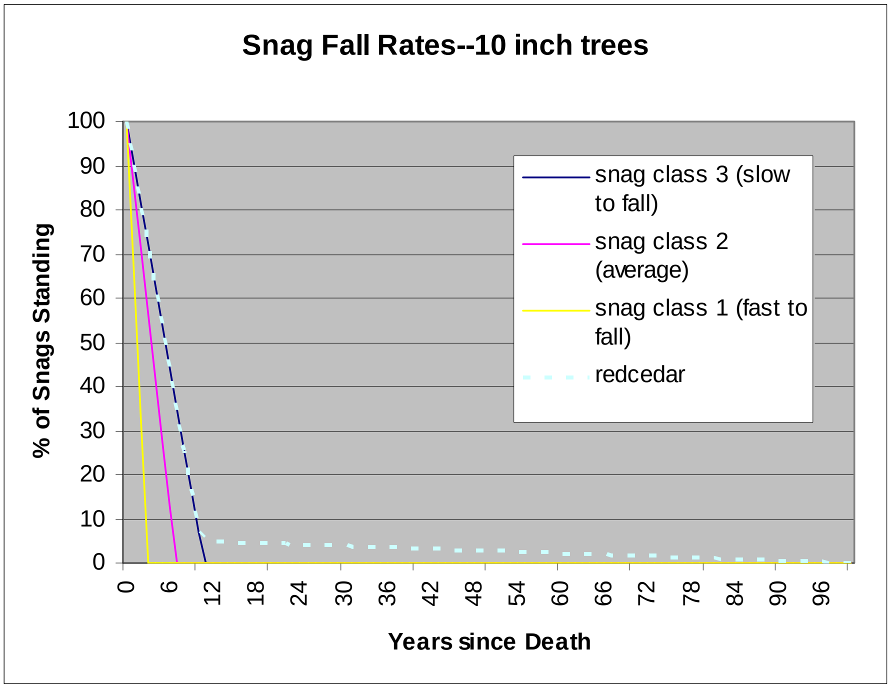


Figure 4.15.1. Snag fall rates for 10-inch trees.

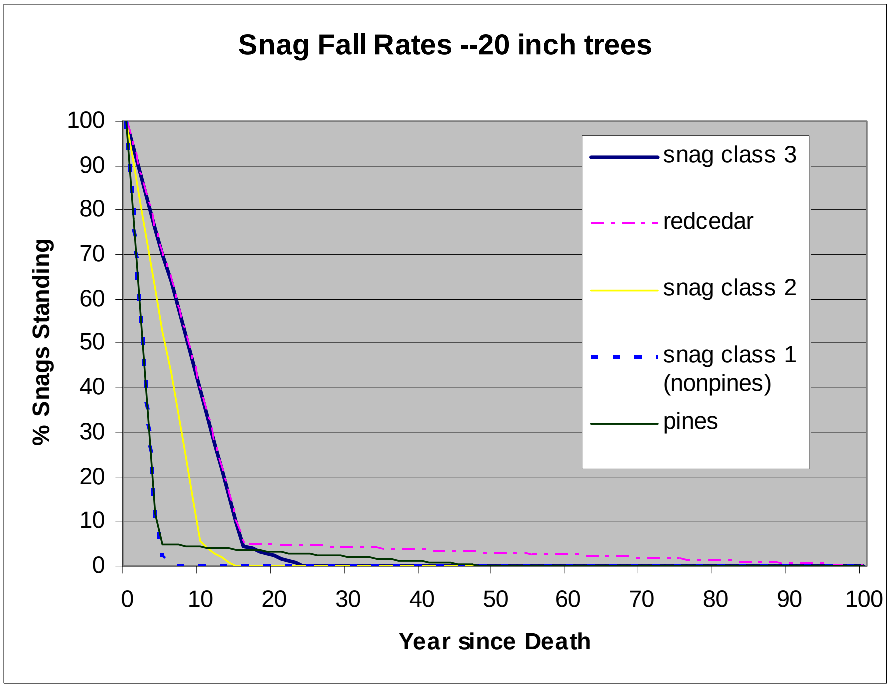


Figure 4.15.2. Snag fall rates for 20-inch trees.

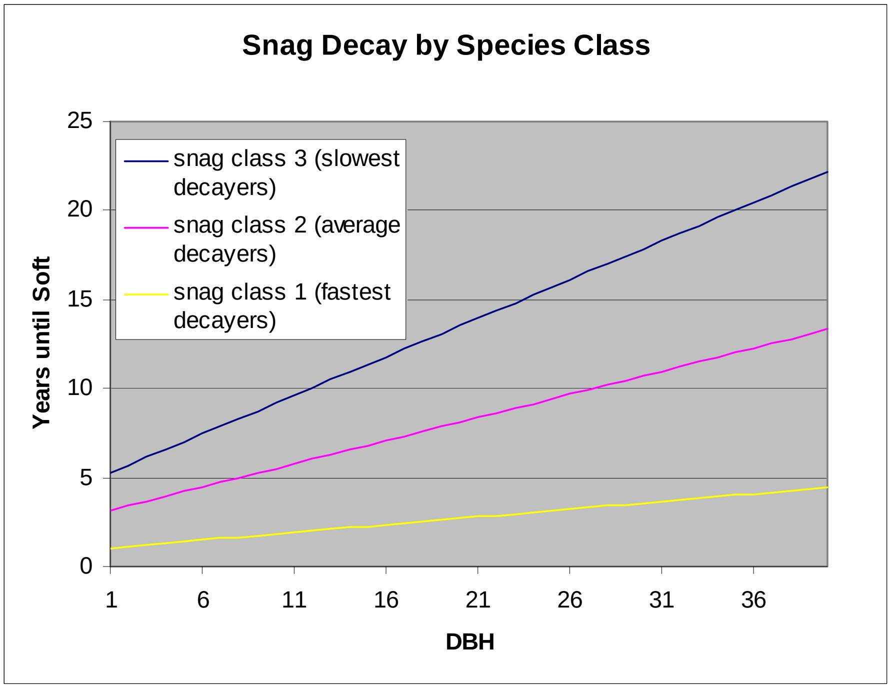


Figure 4.15.3. The number of years until soft for various diameter snags.

The basis for the species categorization and associated snag fall and decay rates is level 2 in terms of data quality, since they were developed at the SN-FFE workshop, with multiple experts involved in the decision process.

Overall, the data quality of the SN-FFE Snag Sub-model would have to be rated as relatively low. There are no published, refereed sources of the model logic (equation form(s)), and only the educated judgment of several researchers/forest managers to quantify the parameters.

Fuels Sub-model Assessment:

The Fuels Sub-model is divided into several categories, each of which has several separate variables that are modeled (FFE addendum, 2008):

1. Live and dead trees:
    a. Boles
    b. Crowns

2. Live Understory:
    a. Shrubs
    b. Herbs
3. Dead surface fuels:
    a. Litter
    b. Duff
    c. >0.25 in diam. (1-hr time lag fuel)
    d. 0.25-1 in (10-hr fuel)
    e. 1-3 in (100 hr fuel)
    f. 3-6 in (part of the 1,000 hr fuels (to 8 in))
    g. 6-12 in
    h. >12 in

For each of these variables/sub-variables, there are both input and output functions that increase and decrease the pool (fuel loading) of these variables in the FFE. For example, live trees grow and die (at death they become snags) within FVS. When snags fall, they become surface fuel. Live and dead tree bole mass is computed using the estimated volume and the Wood Handbook (USDA Forest Products Laboratory, 1999) tabular values for wood density. However, Jones and Zedaker (2008) have documented at least 20% differences in the density of many tree species in southern forests, depending on the location and management intensity of the forests. The source/origin and sampling procedures for the data in the Wood Handbook is very poorly documented and may represent far fewer samples/individual tree boles than are contained in data sets from many other researchers.

Tree crowns are grown and recede (die from the ground up, fall off, and contribute as inputs to the surface fuels pools). Estimates of tree crown material were taken largely from two sources, Smith (1985), a grey-literature source for branch material, and Jenkins et al. (2003), a refereed source for leaf biomass. There are many, many other sources of crown biomass for tree species in the southeast. Crown branch wood is distributed into size classes (for input into surface fuels) by equations stemming from several sources (Snell and Little, 1983; Loomis and Blank, 1981; Loomis and Roussopoulos, 1987; and Loomis et al 1966). However, only one of these sources is from southeastern forests, and this is also the only one that is refereed literature: Loomis et al. (1966). Leaf life-span, or leaf fall rates, were derived from Hardin et al. (2001). Crown mortality, or more specifically, crown fall rates, are determined by crown fall classes, with individual species assigned to one of six classes:

Table 4.15.7. Years until all snag crown material of certain sizes has fallen by crown fall class

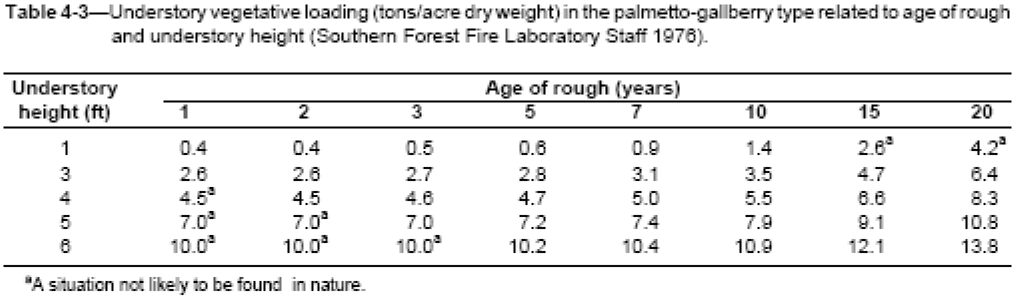
Crown fall class	Snag Crown Material Time to 100% Fallen (years)					
	Foliage	**<0.25”**	**0.25–1”**	**1-3”**	**3-6”**	**6-12”**
1	1 (RC is 3)	5	5	10	25	25
2	1	3	3	6	12	12
3	1	2	2	5	10	10
4	1	1	1	4	8	8
5	1	1	1	3	6	6
6	1	1	1	2	4	4

These data were derived from the opinions of several local experts at the SN-FFE development workshop held in 2002.

Much of the workshop discussion concerned the live understory vegetation: shrubs and herbs. Southeastern U.S. forests have at least two distinctly different pyric shrub understories that are unique in their fire behavior and in their development. The first, Coastal Plain forests, have understories described by many fuel models as “southern rough.” The growth of these understories can be very fast, particularly on wet sites, far outgaining conventional Fuel Model 7 live and dead fuel loads. Palmetto, gallberry, yapon understories in southern pine stands can develop live fuel loads exceeding 10 tons/ac and litter loads exceeding 20 tons (Wade et al., 2000, Table 4.2 & 4.3). The current SN-FFE Fuel Sub-model uses **(**in dry tons/acre):

Forest Type	**Herbs**	**Shrubs**
Pines	0.10	0.25
Hardwoods	0.01	0.03
Redcedar species	1.0	5.0
Oak-Savannah	0.02	0.13

The live fuel loads in pine and cedar forests for the SN-FFE come from Mincemoyer (National Vegetation Classification System, reference database for the fuels loadings for the continental U.S. and Alaska, on file at the Missoula Fire Lab). The data for hardwoods and oak-savannahs come from Nelson and Graney (1976), a grey literature conference proceedings source. A new data source was discovered which more accurately depicts the development of "southern rough" (from Brown and Smith, eds. 2000):



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Understory height (ft)	Age of rough (years)							
	1	2	3	5	7	10	15	20
1	0.4	0.4	0.5	0.6	0.9	1.4	2.6[a]	4.2[a]
3	2.6	2.6	2.7	2.8	3.1	3.5	4.7	6.4
4	4.5[a]	4.5	4.6	4.7	5.0	5.5	6.6	8.3
5	7.0[a]	7.0[a]	7.0	7.2	7.4	7.9	9.1	10.8
6	10.0[a]	10.0[a]	10.0[a]	10.2	10.4	10.9	12.1	13.8

[a] A situation not likely to be found in nature.

These data will be used in the updated Fuel Sub-model; however, they are still derived from a single non-refereed source.

The second pyric shrub understory is evergreen mountain laurel and rhododendron complexes typical in the mountain oak and oak-pine stands. The mountain laurel complex is also common in many piedmont stands. Like the coastal plain stands, the development of this understory far exceeds standard fuel model loading values, but these stands grow much slower. Tom Waldrop, a workshop participant ands USFS SRS scientist, has over 1,000 fuel loading plots in the SE, many of which would include these understory types, and these data might be available for incorporation into the SN-FFE.

Initial dead surface fuels are mainly from unpublished data provided by Gregg Vickers. Litter and duff values are from Mincemoyer (National Vegetation Classification System, reference database for the fuels loadings for the continental U.S. and Alaska, on file at the Missoula Fire Lab), with the exception of hardwood litter, which was derived from a single un-refereed proceedings paper (Spetich et al. 1997).

Table 4.15.9. Forest type is used to assign default coarse woody debris (tons/acre) by size class.

	Size Class (in)							
Species	**< 0.25**	**0.25 – 1**	**1 – 3**	**3 – 6**	**6 – 12**	**> 12**	**Litter**	**Duff**
Pines	.13	.92	1.31	.92	.31	0	1.1	6
Hardwoods	.08	.46	1.2	1.57	1.25	.70	6.8	4

There are also many, many potential sources, both refereed and non-refereed literature, for dead fuel loads. However, possibly the best source of dead fuels data is now the USFS Forest Inventory and Analysis (FIA) data. Since 2001, the USFS Forest Inventory and Analysis unit has been taking fuels data during their regular re-inventory of some FIA plots. These data would fit well as an average starting value, depending on the location and age since disturbance of the sites modeled.

Losses from the dead surface fuel pools come from estimates of decay rates. Default wood decay rates were based on Abbott and Crossly (1982) and Barber and VanLear (1984), two refereed sources. Litter decay rates also come from refereed sources: Sharpe et al. (1980) and Witkamp (1966). Additional decay rate data was provided by Philip Radtke.

In summary, for the Fuels Sub-model:

Live Tree Boles and Crown data quality = 3
Live Understory data quality = 3
Dead Surface Fuel initial conditions = 2
Dead Surface Fuel Decay = 2

Overall, the data quality of the Fuels Sub-model is intermediate but could probably be improved with the incorporation of known new sources, including the FIA data. The FIA data would be judged to be “multiple refereed-5,” since the data collection protocols have received multiple critical reviews and there is a system in place for data quality assurance.

Objective c):

Discussions between the project PI’s and with some of the participants indicated that before any formal validation of the Southern FFE occurs, a sensitivity analysis needs to be performed on different model components to see how much they affect things. If the goal of the validation is to reduce uncertainty in FFE simulations, at this point, it is unknown which model variable(s) and inputs affect the uncertainty of model outputs the most. In addition, it is unknown what types of output uncertainty are of greatest concern to forest managers, researchers, and other FFE shareholders. For instance, is it most important that across simulations, the snag estimates are correct, or is it most important to have the right stand structure (species and sizes)?

Any validation project for SN-FFE should concentrate on what part of the model is most variable or has the biggest impact. This may be the fire behavior and fire effects that are predicted for any simulated fires. Southern variant users often want to simulate repeat prescribed burn scenarios where they are burning every 5 or 10 years. Because burns are simulated so frequently, there is compounding error. For instance, if the burns individually are a little too intense, and overpredict mortality, the stand at the end of the simulation can be very different than what would occur in real life. There are really two aspects to simulating fires: first, getting the fire behavior right, and then, given the correct fire behavior, getting the fire effects right. The two most important modelled fire effects on the vegetation and fuels are mortality and fuel consumption. The mortality predicted during repeat burns can be especially important because it affects future stand composition directly, as well as affects how much sprouting will automatically occur in the model.

So the initial validation strategy should involve these two components – validation of the fire behavior algorithms and the resultant mortality it causes and fuel consumption predictions using data from observed prescribed burns in the South. This would entail a multi-year project to inventory current stand and fuel conditions, burn these stands, and compare the actual conditions to what is predicted by FVS-FFE.

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