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# Research Applications of the Forest Vegetation Simulator: Documentation and Citation

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## **Purpose**

The Forest Vegetation Simulator (FVS) is a modeling platform developed to project the growth and development of forest stands, particularly with respect to the application of silvicultural treatments. Although predominantly used as a management tool, FVS has also been used in research, leading to publication of findings in various formats including peer-reviewed journals. Proper assessment and vetting of results and inferences derived from modeled stand projections requires researchers to document the model and its application with sufficient detail to permit a comprehensive review, which may include repetition of the modeling exercise by a reviewer. To this end, we describe in this document the essential information that researchers should report when communicating the outcomes of their FVS-based modeling research.

## **FVS Structure and Flexibility**

FVS has evolved from a relatively focused growth and yield model, Prognosis, to a more complex suite of base models supplemented by several tools and features developed to address ecological processes (e.g. regeneration, fire, and disease) and management practices (e.g. harvest, site preparation, fuels reduction). Forest types from across the United States are addressed by geographic variants of FVS. Keyword files provide users great flexibility in defining variables and controlling simulation operations. Although the base models, data requirements, and reporting features for all variants are similarly structured, the additional support modules and options often differ among variants. Given this great flexibility and the different options available to users of different FVS variants, it is necessary for researchers to be explicit in describing their assumptions and modeling approaches when reporting on FVS-based simulations.

# A Documentation Approach

FVS modeling decisions can be generally categorized according to their relevance to the fundamental elements of the modeling process: variant selection, input data, simulation control, and output summarization.

Figure 1 represents one conceptual outline of potential decision points in an FVS modeling exercise. While not all FVS applications will incorporate all of these decision points, this outline provides many examples of decisions commonly made and potentially worthy of reporting.

**Figure 1**—An outline of potential decision points and options affecting an FVS simulation exercise that potentially warrant discrete reporting in the presentation or publication of FVS applications.

## 1. Variant Selection

- Which variant (and model type if applicable) was used?
- What is the revision date of the variant (obtained from the main FVS output file)?

## 2. Input Data

### Stand Input Data

- What was the source of the data, if known (stand examination or inventory plots)?
- What was the inventory year?
- What location was specified (region, national forest, and possibly district)?
- If elevation, slope, and aspect were included, what were the values?
- If habitat type, plant association, ecoregion, or PV code and reference were included, which codes were specified?
- If site quality (site index and site species) was included, what was specified?
  - Was a conversion necessary to use the curve required by FVS?
- If stockability (or number of nonstockable plots) was included, what value was specified?
- If maximum basal area or maximum stand density index was included, what was the value?
- If surface fuel information or photo series was included, what was specified?
- If a fuel model was included, what was specified?

### Tree Input Data

- Do recorded tree diameters represent actual diameters or diameter classes?
- Were tree heights included in the input data?
- Was diameter growth or height growth included? If so:
  - Was the value measured directly (e.g., diameter increment core) or calculated based on a previous diameter or height measurement?
  - If the growth measurement period was not the default length, what period length (years) was specified?
- Was crown ratio included?
- Was there a need to use substitutes for species unrecognized by FVS?
- Were any damage/severity codes included?
- Were small trees excluded from the inventory, and if so what was the threshold size?

## 3. Simulation Control

### Calibration

- Did FVS automatically apply any diameter growth or height growth scale factors based on input growth data (check the Calibration Statistics table in the main FVS output file)? If so:
  - Which species were affected?

- Which model (large tree diameter growth or small tree height growth) was affected?
  - What were the initial scale factors?
- Was automatic calibration turned off using the NOCALIB keyword?
- Was calibration of the height-diameter calculation turned off by using the NOHTDREG keyword?
- Were any calibration factors applied using the READCORx keywords? If so:
  - Which species were affected?
  - Which model (large tree diameter growth, large tree height growth, or small tree height growth) was affected?
  - What were the scale factors?
- Were random errors in the diameter increment model changed by using the DGSTDEV keyword?

#### Modifiers

- Were mortality modifier keywords used?
- Were growth modifier keywords used?
- Were any crown modifier keywords used?
- Were any site index values changed? If so:
  - Was the change species-specific or for the whole stand?
- Was maximum basal area or maximum stand density index changed? If so:
  - Was the change species-specific or for the whole stand?
- Was tripling turned off?
- Was random number seeding used?

#### Timing

- What were the start and end years for the simulation?
- What was the cycle length used?
- Were there any cycles that differed in length from the common cycle length used?

#### Management

- Which keywords were used and what parameter values were specified?
- When were they scheduled (year or condition)?
- Were harvests simulated? If so:
  - Was YARDLOSS used to leave material in the stand?
  - Were merchantability standards or volume equations changed?

#### Regeneration

- If applicable to your variant, was the full establishment model on?
- Was any planting or user-specified natural regeneration included? If so:
  - What was scheduled, and when?
- Was sprouting adjusted or turned off?

#### Extensions

- Were any fires or fuel treatments done? If so:
  - What was done and when?
  - For fires, what weather conditions, fuel moistures, and fuel models were specified?
- Were any insect or disease extensions used? If so:
  - What was simulated?
- Was the climate extension used? If so:
  - Which GCM/RCP scenario was used?
  - Were any growth or mortality modifiers used?
- Was the ECON extension used? If so:
  - What was the discount rate?
  - Was the Pretend keyword used?

- What were the fixed/variable costs and harvest revenue (unit price by species)

#### 4. Output Summarization

- Were output values summarized either within the FVS interface or with another tool? If so:
  - How were the summarizations done?
  - Were values weighted in any way?
- Were values calculated within FVS using the COMPUTE keyword? If so:
  - What was the mathematical logic used to compute the values.

## Reporting Rationale

### Variant Selection

Two of the most important items to report for an FVS exercise are the variant and the version of the variant used. Selecting the variant appropriate to the geographic or ecological context of the project is fundamental to ensuring that the forest types of interest are appropriately modeled. Issues to consider include species representation as well as the geographic scope of the underlying data that were used to build various growth and mortality functions. Further, the version (or release date) should also be reported as FVS is not a static modeling system. Different variants have undergone different modifications over time. For example, the Pacific Northwest Coast (PN) variant has incorporated several major revisions, including the incorporation of a new small tree growth model in 2013 and adoption of alternative mortality functions in 2015. Both of these modifications had substantial impact on modeling outcomes and comparisons among modeling exercises.

The variant, version and release date of the FVS model used in a simulation can be found in the header of the main output text file.

### Site Information

Site information is critical in establishing the relative productive capacity for the stands being simulated. The capacity of a site to support growth and productivity is accounted for in the algorithms determining individual tree growth as well as the behavior of density-dependent mortality functions. Several specifications of site are possible with site index and maximum stocking (maximum stand density index or maximum basal area) being very important modeling parameters. The user has the option to input site index and maximum stand density index or maximum basal area values directly, or in some variants the respective defaults are established by user specification of a habitat type or plant association. It is important to report when values other than the defaults are used for these parameters.

### Tree Data Inputs

Each observation in the input tree data represents a tree (or trees) of a given species and size. Minimum data requirements are species and diameter at breast height. Additional details related to size or condition can also be included and may substantially influence modeling outcomes. For example, inclusion of tree heights and crown ratio can influence estimates of crown base height, which in turn can influence modeled fire behavior.

Critical to the outcome of the exercise is the inclusion of tree attributes that the model may use to calibrate growth and mortality processes. For example, inclusion of periodic radial increment data for some or all of the observations can be used by the model to automatically generate diameter growth calibration factors to proportionately modify estimates generated by the default growth algorithms. It is important to document any calibration, whether automatic or through FVS keywords.

Trees are alive by default, so tree history/status (live or dead) is important if dead trees are included in the input data. The designation as ‘recent mortality’ is important because trees with this designation will affect automatic calibration.

It is important to specify whether the source tree data were sampled using variable radius plots, fixed area plots, or some combination of the two to reflect the various plot expansion factors to be applied to observations in the tree list.

## **Simulation Prescription & Control**

FVS can be employed in a myriad of ways to model stand growth and development, with and without management intervention. An obvious need in reporting research applications of the model is to communicate the various steps taken that determine how the model operated on the input tree data. Here we briefly focus on a few of the major considerations.

### Regeneration Modeling

Modeling realistic regeneration to predict outcomes of management activities and disturbances is fundamental for stand dynamic modeling. The foundational models of FVS originally focused on growth and development of existing trees. The process of regeneration has been added to the FVS platform to varying degrees in the individual variants (Dixon 2002). Some FVS-variants (Central Idaho; Eastern Montana; Inland Empire; Kootenai, Kaniksu, and Tally Lake; Southeast Alaska and Coastal British Columbia) use a full establishment regeneration model, which models regeneration densities. Within these variants, the user has the ability to turn on or off ingrowth, sprouting, and automatic tallies. The remaining variants use a partial establishment model. The partial establishment model requires the user to enter regeneration values. Sprouting tree species in either establishment model automatically regenerate from stump and root sprouts. The user has the ability to turn on and off the sprouting option and apply multipliers. In both establishment models it is important to report if and when regeneration was entered because this could impact model outputs.

### Management Actions and Control

Management actions within the FVS modeling framework are driven by keywords and event monitoring activities. There are hundreds of keywords for FVS (Van Dyck and Smith-Mateja 2015). Keywords are used to invoke management activities, describe sampling schemes and modify rates of growth, mortality, snag fall, etc. Since FVS has the ability to simulate a variety of management activities it is important to document which were used. For example, the YARDLOSS keyword allows the user to designate a portion of a harvest to be left in the woods. This would have impacts on fuel loads and dead trees left in the stand. Therefore, if a user invokes a keyword, documentation of the changes from the default is important for the reader to know for a fair assessment of the predictions.

It is important to recognize two distinct ways in which management interventions are commonly modeled in FVS – cycle defined events and conditionally defined events. Both approaches occur in relation to the cyclical time steps (5 or 10 years by default, depending on variant) modeled by FVS. Using cycle defined events, prescriptions may be written which impose a specific action or series of actions at predetermined time steps in the simulation; for example, a pre-commercial thinning at 20 years followed by a commercial thin at 40 years, regardless of the specific stand conditions modeled at those times. In contrast, conditionally prescribed events are executed at a cycle dependent on conditions meeting predetermined criteria. Logic based rules (typically if-then constructs) are defined by the user and implemented via the event monitor functionality of FVS (Dixon 2002). Documentation of these event monitors will enable research reviewers to assess the logic controlling the implementation of specific management activities at certain times throughout the stand projections.

## Output Tree Lists

FVS produces output tree lists that allow the user to monitor key tree components that are being used for projecting stand development. In contrast to the various summary table options that describe stand attributes, output tree lists are primary FVS data outputs that feed into data summaries and can be employed externally in other user-defined processes or models. Specific documentation of output tree lists is generally unnecessary unless the user manipulates output tree lists for purposes that might affect either the FVS simulation behavior or the FVS summaries.

## Extensions

Extensions have evolved as means for FVS to address important issues (e.g. pests or disease, fire behavior) to forest management and to incorporate data sources and models developed external to FVS. Each extension will have its own data requirements and standard FVS tree lists may or may not be sufficient to run the extension. Documentation for specific extensions is available from the FVS website and should be consulted to determine which attributes require specific documentation when reporting FVS results based on the extension.

For illustrative purposes we consider one Extension here – the Fire and Fuels Extension because of its importance in linking FVS to contemporary issues related to fire and forest carbon stocks.

### Fire and Fuels Extension (FFE)

For each simulation that includes fire or potential fire, FFE-FVS users should specify the moisture content of all dead woody fuel (1, 10, 100, 1000-hr), moisture content of live vegetation, wind speed, and ambient air temperature or choose from FFE-FVS predefined fuel moisture conditions. Historical percentile weather data downloaded from tools such as FireFamilyPlus (Bradshaw and McCormick 2000), should specify the name and location of the remote automated weather stations (RAWS) and how many years of data the station has recorded. Users should indicate the fuel model used for fire behavior projection where they may specify one of 53 standard fuel models or allow FVS to select the fuel model(s) using the original FFE fuel model selection logic or the new fuel model selection logic (Rebain 2010). Users should specify modifications made to the calculation of canopy base height and canopy bulk density. Where carbon estimations are of interest, it is important to report the basis for calculation of aboveground live material as either the Jenkins equation (Jenkins and others 2003) or the tree volume equation option (Rebain 2010).

## Data Summaries and Visualizations

Most of the summary tables and SVS graphical representations produced by FVS communicate stand conditions at a given cycle in a simulation. They typically do not require explicit reporting or documentation because they are generally canned outputs, uninfluenced by the modeler. Nonetheless, information contained in some of the tables is critical to report. A particular example is the Calibration Summary Statistics table as it provides the proportionality coefficients imposed by the model to adjust (calibrate) the default parameterization to reflect the data specific growth attributes. After variant and site information, calibration parameters are some one of the most important information to share with reviewers.

## Recommendations

Effective reporting of the methods used and choices made in structuring FVS simulations for purposes of research or any other important management applications is needed in order to allow assessment of the exercise by reviewers or potential users of the results.

We recommend authors consider including the following when reporting FVS applications.

- 1) The model variant and its revision date must be reported (obtained from the main FVS output file).
- 2) A summary of the input data used in FVS projections must be reported.
- 3) Approaches used to adjust and calibrate the model to the project being modeled must be reported.
- 4) In general, anything affecting the outcome of a stand projection over time must be reported whether affecting base growth and mortality modeling or a simulated management or disturbance.
- 5) We highly recommend including a listing of management keywords and event monitoring information, preferably as key files, and their parameterization as appendices or supplemental material where allowed by the reporting outlet. Regardless, such documentation should be made available to interested parties upon request when results from FVS modeling exercises are made available to the public or other audiences as a product of the U.S. Forest Service.

Further, we encourage all authors to communicate that FVS modeling outputs represent possible or likely outcomes, and therefore must be viewed with some uncertainty.

## References

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