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Forest Vegetation Simulator

Model Validation Protocols

Validation Subcommittee
FVS Steering Team

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INTRODUCTION

The Forest Vegetation Simulator (FVS) is the USDA Forest Service's nationally supported growth and yield modeling system that is used to forecast stand development with and without management or other disturbance events. Geographically-based variants of FVS have been calibrated to most forest types in the United States and can be downloaded from the USDA Forest Service, Forest Management Service Center (FMSC) website (www.fs.fed.us/fmsc). Each FVS variant is a self-calibrating distance independent, individual tree growth model that has the capability of including silvicultural, fire, and insect and disease impacts on forest stands.

FVS is maintained by the FMSC-FVS staff, located in Ft. Collins, CO, which is a detached unit of the US Forest Service Washington Office. In March, 2008, the FVS staff held the first FVS steering team meeting and established a steering team charter. In short, the purpose of the steering team is to help review and prioritize the program of work of the FVS staff and ensure best available science is used in the development of FVS. As part of the steering team, subcommittees were established to help provide protocols and oversight for high priority programs, such as the validation of existing FVS variants. Specifically the steering team called for a validation subcommittee to:

1) Establish protocols for variant testing and validation;
2) Develop partnerships to perform validation; and
3) Suggest/facilitate possible funding sources.

This document outlines the protocols to be followed and suggested deliverables when performing FVS model validation efforts funded, in part, by the USDA Forest Service, FMSC. Specifically this document will provide: (*i*) definitions of terminology relevant to validation; (*ii*) a detailed description of the minimal and ideal dataset to be used in the validation effort; (*iii*) descriptions of model evaluation methods; and (*iv*) a description of the deliverables expected as a product from the validation effort.

TERMINOLOGY

Terminology definitions were obtained from (1) Dixon 2002, (2) Dodge 2003, (3) Fairweather and Ramm 1996, (4) Leary, R. 1988 (5) Mitro 2001, (6) Saltelli and others 2008, (7) Schlesinger 1980, and (8) Walther and Moore 2005. Definition sources are identified via superscripts referencing the citation numbering above.

Model Testing Terminology

Accuracy - the overall average error between estimated and observed values. [2]
Bias - the average deviation of repeated estimates from the true value. It is also called systematic error. [8]
Bakuzis Matrix - a graphical matrix identifying relationships of stand attributes in even-aged stands. Of the original 64 cells of the matrix, 11 have relationship cells have shown enough consistency to have been named.[4]

Calibration - the process of fitting mathematical equations to data that represent the system of interest and evaluating "goodness of fit". Calibration is part of model building.[3]
Model Evaluation - the process of testing model through verification and validation procedures. This term is often used when describing model validation as a whole, see figure below. [5]

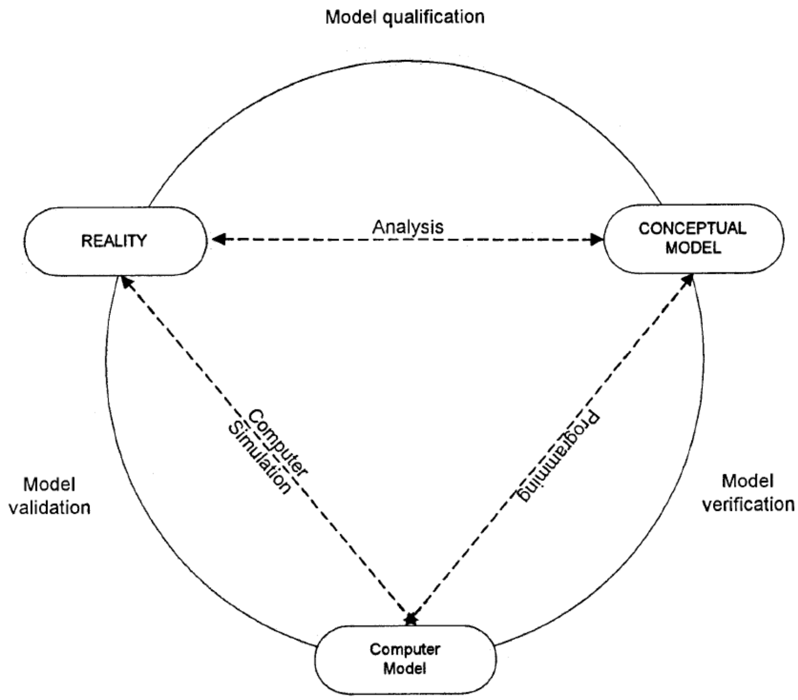

Figure 1 The validation of simulation models (Schlesinger 1980)

Precision - the variability of model results regardless of whether or not the data are dispersed around the true mean. [2]
Prediction Error (Residual) - the difference between observed and predicted values.[3]
Sensitivity Analysis - the process of identifying how model inputs affect model outputs, often in graphical form.[6]
Validation - the process of testing a model by comparing projections to "real world" observations through the use of subjective or objective methods. [3]
Verification - the process of checking that a computer model is carrying out its instructions correctly; this does not address whether the model is doing a good job of mimicking the real world. [3]

FVS Terminology

Base Model - all portions of FVS that are not part of an extension, e.g. diameter growth, height growth, mortality and volume routines. [1]
Extension - an additional part of the FVS system that enhances the capabilities of the base model to either simulate forest dynamics other than tree growth and mortality, such as insect and pathogen modeling, or adds additional analysis capabilities. [1]

FVS - the Forest Vegetation Simulator growth model used to predict forest stand dynamics throughout the United States. [1]
FVS Version number / Revision Date - references the date of the last major and/or minor changes have been made to the variant. The Revision Date (RV) is documented on the first line of the FVS Main Output file (*.out) or in the executables DOS prompt window. [1]
Variant - a version of FVS where growth, mortality, and volume equations are developed for a specific geographic area.[1]

DATASET DESCRIPTION

Ideally, FVS models would be evaluated using an independent dataset, consisting of long-term permanent sample plots maintained by a Continuous Forest Inventory (CFI) entity such as individual State Land Departments, the Bureau of Indian Affairs, or the Forest Inventory and Analysis branch of the USFS. Furthermore, the dataset should be as ecologically similar to those used to construct the model, or as a suitable proxy for testing expected results in the geographic region or ecosystem where FVS is being evaluated.

At a minimum, this independent dataset should represent the expected range of species compositions and have relatively large variations in age, stand density and stocking, tree size (qmd), growing conditions, and site index. For consistency, efforts should be taken to ensure the measurements quantify the exact same attributes, using the same or comparable methods, and are in the same unit of measurement used to construct the model. For example, if site index is a significant predictor of diameter growth, then the test dataset should also contain estimates of site index when attempting to validate the diameter growth model. It should be built from two successive measurement dates for the same permanent sample plot, on a cycle length corresponding to those used for model development (5- or 10-yr cycles).

VERIFICATION

Model verification is intended to ensure that a model performs per its instructions. In its most basic form, verification includes confirmation that the basic calculations the model carried out are, indeed, correct. Basic verification (e.g. is the model applying the correct volume equations, is the model implementing silvicultural treatments as instructed, does the model correctly calculate trees per acre, etc. [see Fairweather and Ramm 1996]) of the model occurs routinely by FVS users. Any concerns regarding these types of verification issues are usually brought to the attention of FVS staff members by FVS users via the FVS helpdesk. However, assuring that FVS is modeling basic stand dynamics correctly will be required as a deliverable. For example, an unmanaged stand's trees per acre (TPA) should decrease and quadratic mean diameter (QMD) should increase. The process by which this level of model verification should be performed is quite simple and outlined, in brief, as follows:

1) Conduct a bare ground planting for each of the major forest types in the FVS variant being validated;
2) Grow the planted stand through time (up through 100 years) without simulating management actions;
3) Confirm graphically that, through time, even-aged stand development as modeled by FVS complies with very basic stand dynamics concepts including that:

a. Stand basal area (BA; ft^2/acre) increases through time;
b. Stand density (TPA) decreases through time;
c. Stand QMD increases through time;
d. Dominant site height (ft) through time in is accordance with an assigned site index (SI) value for the species; and
e. All values of aforementioned stand metrics (a-c) are within reasonable limits for each forest type being assessed.
   i. If unfamiliar with what is reasonable given a specific forest type, contact a professional (e.g. district silviculturist) and confirm/verify the model outcomes are within reasonable limits.

SENSITIVITY ANALYSIS

Prior to performing a full validation analysis, it is important to understand what variables affect growth and how strong those affects are in a growth and yield model, this can be done through sensitivity analysis. Sensitivity analysis looks at how sensitive the dependant variable is to changes in the model parameters. Specifically when looking at a growth and yield model like FVS, sensitivity analysis compares the change in the predicted variable like diameter growth to changes in the input site, stand, and tree level variables.

For example, this can be extremely insightful when dissecting the diameter growth equations typically found in the FVS variants. The independent variables typically fall into three categories:

- tree level variables (i.e. DBH, height, and crown ratio) - which describe the trees present condition and vigor
- stand variables (i.e. basal area and basal area in trees larger) - which describe competition affects, and
- site variables (i.e. habitat type and site index) – which quantify the productivity of the site.

In most variants, site is also represented by location variables such as National Forest and topography (slope, aspect and elevation). In combination these site variables are surrogates for direct productivity variables related to soils and climate that are not recorded in the typical inventory.

The use of sensitivity analysis identifies the magnitude (importance) of the contribution of predictor variables in specific growth routines, tests how the model performs under valid extreme parameters, and checks to make sure the model is behaving properly or biologically makes sense. The process of the sensitivity analysis will clarify what predictor variables are imperative to have included in the validation data set.

VALIDATION

There are many statistical tools for model validation, but the primary tool for most modeling applications is graphical prediction error (residual) analysis. Different types of plots of the prediction error from a model provide information on the adequacy of different aspects of the model. Numerical methods for model validation, such as the r^2 statistic, are also useful, but usually to a lesser degree than graphical methods. Graphical methods have an advantage over numerical methods for model validation because they readily illustrate a broad range of complex aspects of the relationship between the model and the data. Numerical methods for model validation tend to be narrowly focused on a particular aspect of the relationship between the model and the data and often try to compress that information into a single descriptive number or test result.

Common graphical methods include figures that show *i*) the distribution of cumulative errors with regard to sign; *ii*) predicted vs. observed values; *iii*) prediction error (residuals) versus tree and stand attributes; and *iv*) projection error over time.

Common numerical methods include the estimation of bias and root mean square error across species and size classes. Bias and root mean square error are calculated as:

$$\text{Bias} = \frac{\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)}{n} \tag{1}$$

$$\text{Root mean square error} = \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)^2}{n}} \tag{2}$$

where y_i is the response variable of interest, $\hat{y}_i$ is the expected value of y_i , and n is the number of observations used in the calculations.

Another statistical method includes the use of equivalence test for model validation (Robinson and Froese 2004, Robinson et al. 2005). Generally speaking, these methods are derived from bioequivalence testing often used to compare efficacy of drugs. These can easily be extended to FVS model validation where the comparison of two populations (the independent observations and the model predictions) using a test statistic (e.g. mean difference between associated pairs) is the focus. These methods place the burden of proof with the model (i.e., does the model show that it can make accurate predictions?) and explore the reverse of the traditional null hypothesis (i.e., the model and the data are no different, or are there differences). In simple terms, equivalence test for model validation hypothesize that the populations being compared are different and use the data to prove otherwise.

DELIVERABLES

Deliverables will depend on the quality and extent of the data used to evaluate the model. A minimum set of deliverables is identified below. Evaluators will work with the FVS staff when modifying or enhancing the deliverable list.

Dataset Description

Provide an electronic copy of the validation dataset (if allowed by cooperators) as well as summary information regarding dataset used in model evaluation.

Verification

Provide results of bareground planting simulations for forest types and construct a Bakuzis Matrix. If odd results occur, contact the FVS staff prior to performing the sensitivity analysis and validation.

Sensitivity Analysis

Provide a description and ranking of independent variable effects on diameter growth projections.

Validation

Provide graphical and statistical analyses that describe the bias, precision, and accuracy of FVS. At a minimum, the large-tree diameter growth model will be validated. Validation of other component models (e.g., mortality, height growth, etc.) is highly encouraged when requisite data is available.

LITERATURE CITED

Dixon, Gary W. comp. 2002 (revised frequently). Essential FVS: A user's guide to the Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Management Service Center.

Dodge, Y. 2003. The Oxford Dictionary of Statistical Terms. The International Statistical Institute, Oxford University Press.

Fairweather, Stephen E.; Carl W. Ramm. 1996. A Guide to the Basic Evaluation of Forest Growth Models. Unpublished Report. Mason, Bruce & Girard, Inc. Portland, OR.

Leary R. 1997. Testing models of unthinned red pine plantation dynamics using a modified Bakuzis matrix of stand properties. Ecological Modelling, 98:35-46.

Mitro, M. 2001. Ecological model testing: verification, validation, or neither? Bulletin Of The Ecological Society Of America, 82:235-236.

Robinson, Andrew P., Remko A. Duursma, and John D. Marshall. 2005 A regression-based equivalence test for model validation: shifting the burden of proof. Tree Physiology, 25: 903-13.

Robinson, A.P., and R.E. Froese. 2004. Model validation using equivalence tests. Ecological Modelling, 176: 349–358.

Saltelli, A., Ratto, M., Andres, T., Campolongo, F., Cariboni, J., Gatelli, D. Saisana, M., and Tarantola, S., 2008, Global Sensitivity Analysis. The Primer, John Wiley & Sons.

Schlesinger, S. 1980. Terminology for Model Credibility. Simulation, 34: 101-105.

Walther, B., and J. Moore. 2005. The concepts of bias, precision and accuracy, and their use in testing the performance of species richness estimators, with a literature review of estimator performance. Ecography, 28(6):815-829.