Through a Glass, Darkly—Comparing VDDT and FVS

Donald C.E. Robinson and Sarah J. Beukema

Authors

Donald C. Robinson and **Sarah J. Beukema** are senior systems ecologists, ESSA Technologies Ltd, 600-2695 Granville Street, Vancouver, BC, V6H 3H4, Canada, drobinson@essa.com and sbeukema@essa.com.

Abstract

Land managers commonly use FVS and VDDT as planning aids. Although complementary, the models differ in their approach to projection, spatial and temporal resolution, simulation units and required input. When both are used, comparison of the model projections helps to identify differences in the assumptions of the two models and hopefully will result in more consistent results across models.

We used the transition probability matrix as the basis for comparing the two models, using side-by-side simulations with FVS and VDDT to project 250 mixed conifer stands. We designed and carried out a simulation experiment with managed and unmanaged scenarios, to explore the consequences of different approaches to filtering FVS outputs by removing censored and rare observations, as well as smoothing out side-effects such as jitter which result from creating categories from continuous data.

Our analysis includes verification of the Preside system, comparison of matrix behavior, as well as the behavior of VDDT with FVS runs imported into VDDT. Three useful conclusions are that: (1) including rare transitions from FVS is important to getting reasonable temporal dynamics; (2) initialization and censoring issues can be ignored; and (3) smoothing and jitter can also be ignored.

One surprising conclusion is that very different assumptions about regeneration cause VDDT and FVS results to be profoundly different for species, size and canopy structure. One nagging question is "how can we tell which model is right?" Field observations would help, and iterative model revision of both FVS and VDDT models is also helpful to a point. Our best advice is to use each model to challenge and improve the assumptions of the other, using each model to illuminate the "blind spots" of the other.

Keywords: Forest Vegetation Simulator, Vegetation Dynamics Display Tool, FVS, VDDT, scale, simulation.

Introduction

Land managers use simulation tools to help them analyze and understand how different management scenarios or disturbance regimes will affect future landscape conditions. Two commonly used tools are the Forest Vegetation Simulator (FVS; Stage 1973, Crookston and Dixon 2005) and the Vegetation Dynamics Development Tool (VDDT[1]; ESSA Technologies Ltd. 2007). The foundations of FVS lie in four decades of empirical growth and yield modeling and forest management, while the roots of VDDT are found in the lineage of probabilistic ecosystem succession models. Although both may be used to simulate the same landscape and vegetation, the models differ in their approaches to projecting vegetation change, in the spatial and temporal resolution of projections and in the fundamental simulation units, processes and required input data.

The decision to use FVS or VDDT can depend upon circumstances such as data availability, disturbance dynamics, forest management strategies, the presence of non-forested conditions, and the scale and type of issues that are being addressed. When there is an opportunity to use both models to project the same landscape, it raises the possibility of comparing the projections. Such comparisons can draw attention to differences in the projections, which can result in a more thorough understanding of the two modeling systems. Going deeper, they also create the opportunity to compare specific common parameters; to consider the reasons for any difference and to decide whether there are

[1] VDDT simulations can also be carried out using the Path Landscape model (http://pathmodel.com), in which the VDDT state transition model is embedded.

compelling reasons to transfer a parameter estimate made by one model, for use in the other. If good reasons exist for modifying previously-accepted VDDT parameters based on FVS, then this could be termed “calibrating” VDDT with FVS.

At the finest resolution, FVS projects the change in density, diameter- and height-growth of a collection of individual trees (the stand) and simulates the development of a non-spatial inventory over time, and often with management activities. When needed, attributes of the whole stand (e.g., percent canopy cover, quadratic mean diameter, basal area) can be easily derived from the finer scale attributes of individual trees. FVS simulations frequently use a 5- or 10-year timestep. In its most basic use, VDDT uses state-transition probabilities to simulate temporal changes in vegetation classes on an annual timestep. These probabilities are often developed in collaborative workshops at which ecologists synthesize published literature and their experience with a particular landscape or ecosystem, to define the vegetation classes found on the landscape, and the transitions between the classes. VDDT models can range from very simple models with a few classes, to very complex models with dozens of vegetation states, along with the disturbance and succession probabilities that control how vegetation classes change. The fundamental unit of resolution of VDDT is a physical abstraction called the pixel[2]. Pixels can represent almost any vegetation state (e.g., “open single-story ponderosa pine dominant” or “mature tall-grass prairie”), but do not explicitly represent an element or cell of any particular size or location in a spatial landscape map. Rather, each pixel represents an instance of one of the possible vegetation states defined for the landscape. Frequently, VDDT users use 1,000 pixels, but the actual number is arbitrary and is chosen to provide enough detail for the management questions under study. Over time, pixels change between different vegetation states in response to succession or disturbance using user-defined deterministic or probabilistic rules.

VDDT models usually define vegetation classes and transition probabilities based on a mixture of literature and expert judgment. Because of this subjective element, some land managers believe that VDDT models could be put on a stronger footing by incorporating parameters estimated from FVS simulations, thus providing more defensible land use decisions. In this way, the empirical basis of FVS might serve as an additional source of guidance for VDDT.

The key step in bridging the two models is to translate FVS results so that the two models have a common basis. This is achieved by post-processing FVS landscape simulations to create vegetation classes that are identical to those used by VDDT, then computing transition probabilities based on the class changes that take place during the FVS stand simulation. A software program called Preside (Moeur and Vandendriesche 2009)[3] has been created for this translation step, using the FVSSTAND keyword and the FVSStand (Vandendriesche 1997) post-processer. Tabular results from FVSStand are processed by Preside to create a classification of stand structure over time, classes that are user-defined and compatible with the class definitions used to create VDDT models for the same landscape. Once the classification step is complete, Preside creates a matrix of the occurrence and frequency of transitions between different states, similar to the transition matrix created by VDDT.

Transitions defined through FVS are the result of its internal dynamics combined with post-simulation classification, while those found in VDDT are defined by a model developer. In the case of VDDT, the model developer defines all possible transitions in advance, while transition pathways and probabilities predicted by FVS are derived from the detailed growth, mortality and regeneration of individual trees in stands simulated over time.

However they were created, the results of the VDDT and FVS simulations use a common set of vegetation classes, and the transitions between those classes should be comparable. That said, the differences between the two models—the continuously varying world of FVS and the

[2] Pixel is technically a misnomer and is unrelated to “picture elements” or remotely sensed data or Geographic Information Systems. This label for VDDT simulation units was coined many years ago and has come into common parlance.

[3] Available at: http://www.fs.fed.us/fmsc/ftp/fvs/software/pre_post/Preside_z.exe.

Table 1—High level summary of the simulation scenarios

Management Scenario	VDDT	FVS
Unmanaged	Succession + Natural Disturbance	Unmanaged
Managed	Succession + Natural Disturbance +	Restoration management
Data Simplification Scenarios		
All	Use all observed transitions	
Sub	Use a subset, removing transitions that occur fewer than 5 times	
Base	Include all timesteps	
Drop Zero (DZ)	Remove transitions in the first timestep	

class- and transition-based world of VDDT—are not simple to overcome. While class models are usually much simpler in structure, both models have subtle assumptions that can produce large effects, and the introduction of class boundaries to FVS simulations can create significant artifacts. As this paper shows, removing these artifacts is not trivial, and can introduce changes to the "signal" of FVS-based transition parameters.

Materials and Methods

As key factors in this study, we created simple managed and unmanaged scenarios in both FVS and VDDT and went on to analyze those simulations in different ways. Facing the challenges of comparing two models with markedly different approaches, we tested a variety of approaches for presenting the data from each model in ways that fostered comparisons. As there are inherent issues with trying to classify a continuous landscape, we performed extra analyses using the unmanaged FVS scenario to explore the sensitivity of our classification boundaries.

Scenario Design

To compare the landscapes predicted by the native-VDDT and FVS outputs converted to VDDT transitions, we made 300 year simulations of Unmanaged and Managed scenarios (see table 1) using both VDDT and FVS. Other scenarios were explored as well, as described below.

Management scenarios—
Two FVS scenarios were compared with matching VDDT simulations. After the results of the FVS simulations were processed with FVSStand, some analyses used a custom Excel spreadsheet to implement different smoothing methods (described below), which were then exported and formatted to conform to the Preside input file format. VDDT outputs were similarly treated, so that both modeling systems were processed identically as much as possible. Preside was configured to use the classification rules shown in table 2, and the information about the state of each stand at each timestep was used to create VDDT-like transition probability matrices. These matrices contained between 42 and 58 different state classes, depending on the scenario and model.

Data simplification scenarios—
One of the outputs of the Preside model is an estimate of the annual probability of changing from one vegetation class to another, based on FVS outputs. It is an attempt to classify FVS in the language of VDDT. Using options in Preside, we examined two different approaches to calculating the probability of different transitions. The first approach we used—*All*—accepts all observed transitions; even those that are not observed very frequently. This allows greater successional complexity to be captured, but rare transition parameter estimates may not be very precise. The second approach we examined—*Sub*—removed transitions that were observed fewer than 5 times: less than 1 percent of the total number of transitions. The implicit hypothesis underlying this approach is that more frequent transitions are more important to the overall successional pattern and that less frequent transitions can be ignored.

As a second part of this exercise we explored the impact of removing a model initialization artifact from the FVS results. The first approach—*Base*—includes the initial timestep in Preside's calculation of classes and transitions. The second treatment—*Drop Zero*—accounts for the fact that two kinds of initialization artifacts can incorrectly influence the estimation of transition probabilities. The first is caused by the internal calibration of FVS growth and mortality to local site conditions during model initialization.

Table 2—Stand classification variables defined for the Preside program

Variable Name	Variable Type	Class	Definition
DOMTYPE	Categorical	Classification of the dominant tree species for the landscape.	
		PP	early seral—LAOC, PICO, PIPO or TEIX leading
		DW	late seral—DF, WF or any other species leading
QMD	Continuous	Quadratic mean diameter (cm) of the >80th percentile largest-diameter trees	
		Y	<5cm—young seedling/sapling
		P	5-10cm—pole
		S	10-15cm—small tree
		M	15-20cm—medium tree
		L	20-30cm—large tree
		G	>30cm—giant tree
CANCOV	Continuous	Canopy cover (percent)	
		n	<10 percent—non-stocked
		o	10-40 percent—open canopy
		m	40-70 percent—medium canopy
		c	70 percent—closed canopy
		—	Unclassifiable
STORY	Categorical	Number of canopy layers	
		1	one story or poorly defined
		2	two story
		—	Unclassifiable

This adjustment is reported in the first simulation timestep, and can create “pseudo-transitions” that are unrelated to natural succession. The second artifact is caused by the fact that the first transition observation lacks any information about how long the stand was in its initial vegetation state prior to the transition.

Smoothing scenarios—
Classifying a landscape made up of continuous variables (such as height or QMD) into discrete variables carries the risk that the classification can change in more than one direction, especially if any variable is near a classification boundary. In this case a stand can move back and forth between two classes, creating jitter. We developed and tested two different ways to smooth the classification of FVS stand output to see if any would reduce the jitter or impact the landscape-level results. Detailed descriptions of the these methods and their results are in found in Appendix 2.

Program Configuration

FVS—
We used 500 FVS inventories (two inventories of 250 stands taken at different times) taken from mixed conifer dry site stands from the East Cascades of Washington, USA, compiled and prepared as part of the IMAP study (Miles Hemstrom, pers. comm.). These stands are principally made up of Douglas-fir and ponderosa pine. The 500 FVS inventories were projected using 10 year timesteps for 200 years using the East Cascades FVS variant (model date: 04/07/09). Ingrowth in open stands was simulated by using the Repute Event Monitor keyword package (Vandendriesche, 2009). The FVS main output file and the supplementary detailed output file created by the FVSStand keyword were then post-processed using the FVSSTAND Alone program, creating a set of input files for Preside.

After an initial analysis of the inventory, the FVS East Cascades variant was calibrated by adjusting small and large tree growth increments and maximum SDI and basal area (see Appendix 1 for details). In the unmanaged scenario, FVS was calibrated and run with the Repute-based regeneration information described above. For the managed scenario we implemented a simple management system with a restoration focus in which stands are thinned from below whenever they exceed 65 percent of the maximum SDI, removing smaller stems until the SDI is reduced to 50 percent of the maximum SDI, preferentially retaining ponderosa pine. These limits were selected based on Cochrane and others (1994), who recommend that stands be managed between 50 percent and 75 percent of full stocking. With these two thresholds, stands are re-entered every 20 to 40 years. Over time, this system creates open forests of large, older ponderosa pine, using smaller trees for low or moderate amounts of timber. Like the unmanaged scenario, management simulations were run with the calibrated model using 10 year timesteps for 200 years.

VDDT—

VDDT diagrams were defined for the landscape and included numerous pathways representing succession, natural disturbances from bark beetles, mistletoe, wild fire and management (J. Merzenich, *pers. comm*.). For the unmanaged simulation, all management pathways were disabled. Since base FVS mortality rates include mortality from background disturbance, we kept most disturbance pathways active to make the FVS and VDDT simulations more comparable. The only disturbance type that was excluded from the unmanaged simulations was stand-replacing fire, since this level of disturbance is not consistent with the FVS assumptions.

Simulations of 1000 pixels were initialized by assigning pixels evenly over most of the VDDT vegetation classes. We then simulated VDDT for 300 annual timesteps; saving information about the transitions that occurred in each timestep and printing the detailed landscape state class output every 10 timesteps to emulate the temporal resolution of FVS. We then formatted the output so that it could be provided to Preside in the same way as FVS. Finally, we ran Preside using the output generated by VDDT, allowing Preside to independently calculate the transition probabilities, in order to verify the Preside algorithms.

The VDDT management scenario was based on the same model diagram and initial conditions as the unmanaged scenario, activating some of the management pathways and simulating these pathways using a file of input multipliers which defined multipliers for a private lands scenario. In order to keep the managed scenario as similar as possible to its FVS management counterpart, we excluded the simulation of prescribed fire. As with the unmanaged VDDT runs, we ran the model for 300 years, saving transition information in all years, and state information every 10 years.

Preside—

Preside takes classification rules provided by the user and applies those criteria to the output of FVS landscape projections, classifying stand structure in a way that is compatible with VDDT. When processing is complete, FVS stand structure is classified at each timestep with user-defined rules corresponding to VDDT vegetation states, along with the probability of changing from one vegetation state to another. Preside organizes these transition probabilities into a matrix that can be compared with a matrix of transition probabilities created by VDDT for the same landscape[4] Following a comparison step, VDDT transition probabilities can be adjusted to be more FVS-like, if desired.

To faithfully recreate the VDDT classification for the mixed dry landscape, we configured Preside to classify each stand and timestep using the classification variables and breakpoints shown in table 2. Preside labelled each stand's state at each timestep, constructing a label from the concatenation of the four variables:

DOMTYPE + QMD + CANCOV + STORY

Using this coding, the label **PPGo2** indicates a pine-leading (PP) stand of giant (G) diameter class, with an open canopy (o) having two (2) stories.

The first step taken by Preside is the classification of each stand, so we began by verifying its classification algorithm. To do this, we exported results from the FVS simulation of the unmanaged landscape scenario simulation to a database using the FVS Database Extension (Forest

[4] Although stochastic transitions are commonly found in VDDT models, VDDT can also be parameterized for other modes of state change, including combinations of deterministic and stochastic rules.

Vegetation Simulator Staff 2003). We then classified those results using our own SQL queries and compared our stand classification with the classification created by Preside. Using the same stratification and breakpoints used by Preside, our checks agreed with the Preside classification. After further checks we also concluded that Preside's calculation of class-transitions were correct.

Consistency of VDDT and VDDT—Preside—VDDT Transitions

As in internal consistency check of our arithmetic and of the methodology for processing transitions with Preside, we compared the distribution of vegetation classes created directly from VDDT against VDDT output that had been processed through Preside and then simulated by VDDT. We expected that after allowing for stochastic variation, a comparison of the results these simulations would show them to be identical, and that this would verify the mathematical steps upon which the translation of FVS results are based.

We began this check by performing an Unmanaged VDDT simulation lasting 300 years, printing the landscape state every 10 years to match the output interval from FVS. This decadal output was then processed into a format that could be read by Preside, which then independently recalculated the transition probabilities using the same algorithms employed for processing FVS output. These probabilities were provided as input to a new VDDT simulation, treating all transitions as purely probabilistic. The results of the two VDDT simulations were independently simulated five times and then compared.

Transforming the Time Scale

Preside (Version 2010.06) uses decadal FVS output, conceptually creating an initial square matrix $\boldsymbol{M}$ of 10-year transition probabilities. Each diagonal element of this matrix represents the probability of remaining in vegetation class $\boldsymbol{i}$ after 10 years, and each off-diagonal element represents the probability of changing from vegetation class $\boldsymbol{i}$ to class $\boldsymbol{j}$ in the decade. Zero values are allowed, but each row must sum to 1.0. Preside converts these values to annual transition probabilities through the separate transformations for the diagonal terms of the matrix (Eqn. 1: probability of remaining in the same vegetation state) and for the off-diagonal elements (Eqn. 2), in which $\boldsymbol{M'}$ is the resulting square matrix of 1-year transition probabilities:

$$M'_{i,j \mid i=j} = e^{\ln(\lambda)\, M_{i,j}/10} \qquad \text{[Eqn 1]}$$

$$M'_{i,j \mid i \# j} = 1 - e^{\ln(1-M_{i,j})/10} \qquad \text{[Eqn 2]}$$

In cases where a diagonal entry is absent from the matrix (i.e., in which all pixels in vegetation class $\boldsymbol{i}$ change class in a single timestep), we found that row totals calculated by Preside do not always sum to 1.0, a necessary condition for accounting for all transitions over the landscape. However, the impact of this problem is small since VDDT does not actively make use of the probability of remaining in a vegetation class, and uses only the probability of changing state. Hence any imbalance in the transition calculations will be offset by the implicit value of the diagonal, which will result in an implicit row total of 1.0.

However, the annualized probabilities of $\boldsymbol{M'}$ computed using Eqn. 1 and 2 do not account for transitions to intermediate classes at the 1-year time scale, which in the case of high transition probabilities (i.e., fast transitions) can lead to different vegetation classes from those calculated at the 10-year timestep. It is therefore possible that when simulated at a faster timestep, the Preside time-scaling method will incorrectly simplify transitions that lead to different pathways.

As an alternative method, we used a classical matrix analysis approach to change from the decadal to annual time scale, to compare the matrices produced by FVS and VDDT. Beginning with the matrix $\boldsymbol{M}$ produced by Preside, we transformed to the annual probability matrix $\boldsymbol{M'}$ by transforming $\boldsymbol{M}$ to diagonal form (Eqn. 3), where $\boldsymbol{V}$ and $\boldsymbol{\lambda}$ are the matrix of eigenvectors and array of eigenvalues of $\boldsymbol{M}$, respectively.

$$M = V^{-1}\, D(\lambda)\, V \qquad \text{[Eqn. 3]}$$

Eqn. 4 then rescales the eigenvalues of the diagonal matrix $\boldsymbol{D}$ from a decadal to an annual interval leaving the eigenvectors unchanged.

$$M' = V^{-1}\, D(e^{\ln(\lambda)/10})\, V \qquad \text{[Eqn. 4]}$$

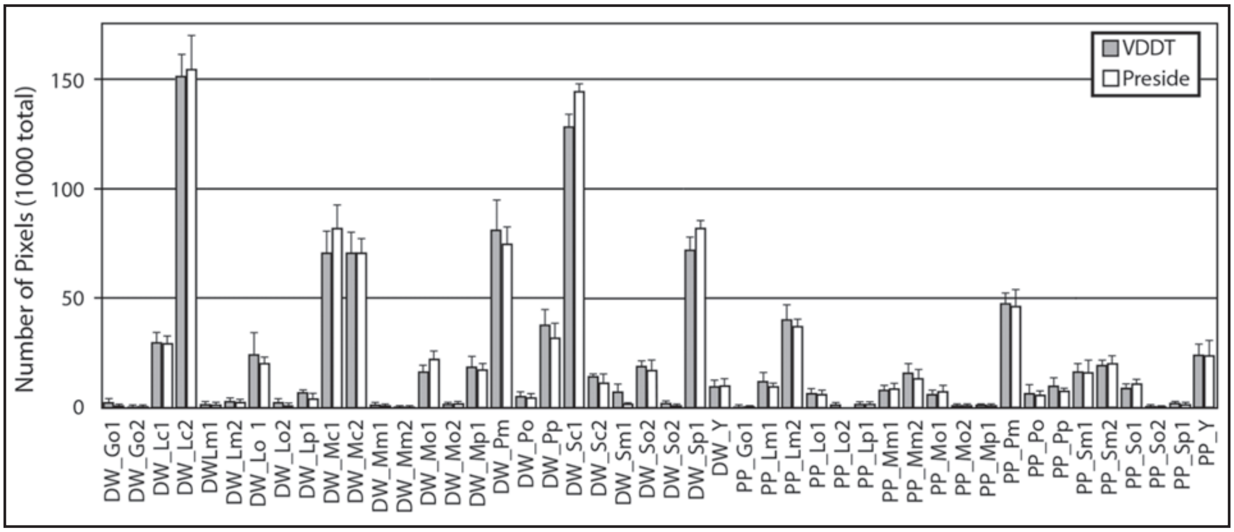

Figure 1—Comparison of the number of pixels in each state class after 300 years for the original VDDT simulation and for the VDDT simulation using transitions and probabilities exported and recalculated by Preside. Error bars are from 5 Monte Carlo simulations.

This method avoids the separate equations used by Preside, scales correctly between any two time intervals, and produces row sums of 1.0 for all possible timesteps.

Matrix Analyses

The properties of the transition matrices were used to compare VDDT and FVS simulations over the scenarios and treatments described above. Each row and column of the transition probability matrix represents a unique vegetation class (e.g., PPGo1). Depending on the scenario, there were 42 rows and columns in the FVS matrix and up to 58 rows and columns for the VDDT simulations. In the case of the VDDT simulations, the extra 16 vegetation states represent post-disturbance classes which are impossible to distinguish from other vegetation classes in FVS.

Matrix properties were characterized in two ways. First we found the dominant eigenvector, which is the theoretical equilibrium composition of the landscape. Secondly, we explored the behavior of the matrix system over time through simulation. One method of analyzing the temporal behavior was to run the matrix in VDDT. The other method we used was to characterize temporal dynamics through Monte Carlo simulation of the matrix directly (i.e., not in VDDT) through the calculation of the approach to the theoretical stable equilibrium, using the time to reach 99.9 percent of the equilibrium as a consistent measure of system dynamics. This is an arbitrary condition that will never be seen in physical landscapes. However, it provides a standardized way of comparing the behavior of different transition matrices.[5]

Results

Verification of Preside Calculations

A comparison of the results from the simulation of the unmanaged scenario in VDDT and a previous run of VDDT exported and processed through Preside shows that both runs are very similar (fig. 1). In both runs the most frequent 10 classes are identical and represent about 75 percent of the total area. Only two of the classes differ by more than 1 percent of the total landscape area. This result confirms that Preside transforms results in a consistent way, and that the transition probabilities are comparable between the two models, other things being equal. Indirectly, these results also show that for this landscape, the differences of the two

[5] Supplemental information about the simulation methodology and detailed results are available at: http://essa.com/wp-content/uploads/RobinsonBeukema2012Supplement.pdf.

Table 3—Summary of vegetation class transitions present in Unmanaged FVS and VDDT models. The two simulation systems have few vegetation states in common

	Observed Transitions		
Vegetation Class	**FVS only**	**VDDT only**	**FVS and VDDT**
Regular	127	145	43
Post Disturbance	0	115	0
Total	127	260	43

methods of transforming from decadal to annual timestep are not large in this landscape.

Presence and Absence of Transitions

The transition matrices from the Unmanaged VDDT and FVS simulations were analyzed using a simple count of the presence or absence of different transitions (table 3). Remarkably, FVS predicts many fewer total transitions than VDDT and only one quarter can be matched with a transition in the Unmanaged VDDT landscape. A further 115 transitions are found only in the post-disturbance classes that are unique to VDDT. Considering all transitions, there is about a two-to-one disparity. From this simplified aggregation we conclude that VDDT shows a much wider range of behavior, in spite of the fact that we might expect FVS to account more explicitly for growth, mortality and regeneration in multi-species stands. As described in more detail below, we find that much of the complex behavior of VDDT can be traced to detailed transitions driven by disturbance agents in VDDT.

FVS Transitions Caused by Calibration and Regeneration

Study of the transitions that are absent from VDDT but present in FVS shows that a number of them occur when a continuous classifier (QMD or CANCOV) switches to a smaller class. Of the 11,000 timesteps in the projection, such events take place in about 7 percent of timesteps: 226 times for QMD and 505 times for CANCOV. We found that these changes are primarily caused by regeneration in the FVS model. For QMD this happens when a pulse of regeneration grows large enough to be classified among the largest 20 percent of trees. The diameter threshold then drops to include the numerous smaller trees and the indicator declines markedly.

We examined sixteen stands that showed the most extreme decline in CANCOV or QMD. Of these sixteen cases, ten undergo the transition in the first model timestep, indicating a marked change from the inventory condition to the first projected state. Examples of results showing this behavior are shown in figure 2, which shows vegetation class over time for 10 stands. In this example, nine of the stands undergo a transition between timestep 0 and timestep 1. Our analysis shows that the first kind of declining transition is a simulation artifact produced by the initial FVS self-calibration adjustment and expressed as large tree mortality. Fortunately, transitions occurring this way can be screened out using the *Drop Zero* method, as described below.

The second kind of declining transition typically happens later in the simulation, as regeneration begins to reach a size where it can be in the top 20 percent of trees, contributing noticeably to canopy cover. It can then trigger a change in the dominant overstory layer, as the stand moves from larger older trees to include smaller younger trees. This kind of transition is not inherently unreasonable, but underscores the role of regeneration in stand dynamics and in measures related to stand maturity, and signals the need for further consideration of how the indicator is intended to be used. If QMD or CANCOV alone do not adequately capture the qualities of a mature stand and the stand truly remains in a mature state, then novel attributes (perhaps combinations of existing attributes or heuristic rules) may be called for. Alternatively, these transitions caused by regeneration also underscore the need to better consider the role of small trees when defining states and state transitions in VDDT.

Jittery Transitions

Besides declining transitions, there are frequent cases of back-and-forth switching between two classes (see two lower horizontal boxes in fig. 2), occasionally accompanied by a change in dominant cover type (PP or DW in our study landscape). We examined nine stands with jitter effects, and

	Model Timestep																		
Stand ID	0	1				5					10					15			
1238228-1	U	T	T	T	T	L	L	L	L	L	L	L	L	L	L	L	L	M	M
1238240-2	E	F	F	J	J	J	L	L	M	M	M	M	M	M	P	P	P	P	P
1252252-2	A	B	B	C	C	C	C	E	F	G	G	G	F	J	J	K	K	K	M
1278224-1	H	C	C	E	J	J	L	L	L	L	M	M	M	M	M	R	R	R	R
1284300-1	F	C	C	E	F	F	F	F	F	F	J	J	J	J	J	J	J	J	J
2201208-1	H	S	C	C	E	F	F	F	F	F	F	F	J	J	J	J	J	J	J
2207204-1	D	C	C	C	C	E	E	G	E	F	J	J	J	J	K	M	M	M	M
2213210-1	F	F	F	F	F	F	F	F	F	E	F	F	F	F	F	F	F	J	J
2277230-1	N	F	F	F	J	J	J	J	J	J	J	J	J	J	J	J	J	J	J
2278314-2	F	C	C	F	F	F	F	J	J	J	L	L	L	L	L	L	L	L	N

Figure 2—Vegetation classes are shown for 10 stands from the unmanaged FVS landscape simulation. Each class is represented by a single letter and state changes are shaded for clarity. The heavy box at left highlights the large number of transitions that take place between timestep zero (inventory) and one. The three horizontal boxes show examples of rapid state change (upper box) and classification jitter (two lower boxes).

found that jitter is also closely associated with regeneration, generally taking place when QMD or CANCOV are close to a transition threshold. In these cases the regeneration contribution, while small, is sufficient to push the indicator over the class boundary. In the examples we studied, significant regeneration mortality can occur in the following cycle, causing the classifier value to drop and return back across the threshold a second time. If there is another round of regeneration, the classification can change yet one more time. Jitter ends when there is no regeneration for two cycles, allowing the stand to grow substantially beyond the boundary condition.

A classification change due to small back and forth movement across a boundary has a large impact on the average residency time, expressed as the annual probability of changing from Class X to Class Y. A stand that alternates between two classes each 10-year timestep will have numerous predicted residence times of 10 years. If the classification was more flexible or the stand was farther from a boundary, it might have residence times of 20 or 40 years. For example, consider a stand with nearly 70 percent canopy cover for four cycles: 69.5, 70.1, 69.6 and 70.3 percent. In this example, the stand would be classified as: X-Y-X-Y. If the values were all slightly less (e.g., ranging from 68–69 percent), they would all remain in class X, resulting in a longer residence time with no transitions, and if they were slightly higher, they would all be in class Y.

This kind of classification problem is not new. A nearly identical case is addressed by Stage (1997) in the context of stand structure classification, transition probability and declining transitions. Stage's suggested approach to the problem is to move the boundary by one-sixth of the class width whenever a retrogressive (declining) transition is predicted, thus avoiding the transition. This might be reasonable for individual cases, but it often only moves the boundary problem to another value or causes it to emerge in another stand, and does not remove it entirely. Other ad hoc solutions that involve visualization of a stand's state space and its proximity to a border may be suitable for single stands, but are not feasible for the automatic classification of thousands of stands over dozens of timesteps. Ideally, what are needed are algorithms that solve the logical problem of the classification boundary and which can be implemented programmatically. In Appendix 2 we present different approaches to smoothing and further analyze the consequence of these smoothing methods on measures of the equilibrium behavior of the system. Generally, our smoothing methods resulted in landscapes that were quite

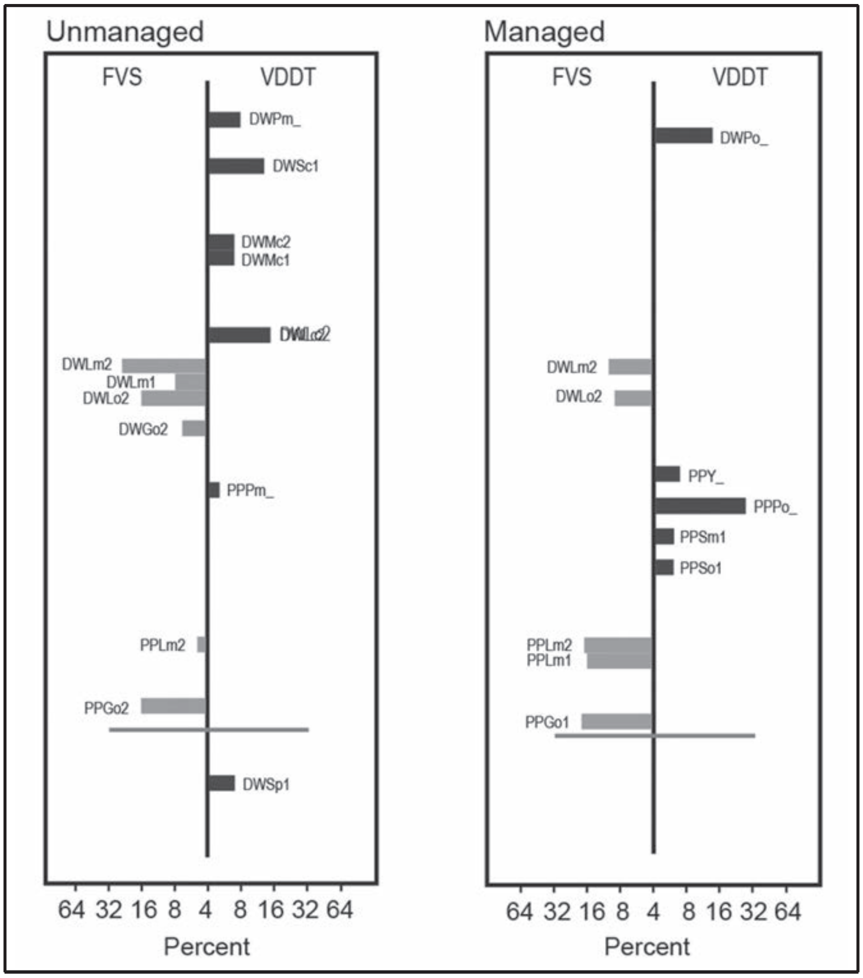

Figure 3—Left and right panels compare the composition of Unmanaged (left) and Managed (right) landscapes near equilibrium. In each panel the FVS-derived landscape composition is shown on the left (light grey bars) and the VDDT-derived composition is shown in on the right (dark grey bars). The horizontal grey line separates vegetation classes common to both models at the top, from those found in VDDT only, at the bottom. ***Key to bar labels:*** the first two letters are the dominant species; letters (Y,P,S) are small trees and (M,L,G) are medium, large or giant trees; the fourth letter represents open, medium or closed canopy, and the final number is the number of strata. Labelling details are in table 2. Vegetation classes <4 percent are not shown.

different from both FVS and VDDT landscapes; leading us to conclude that smoothing is not a panacea that will easily reconcile model differences.

Comparison of Native and FVS–Derived VDDT

Extending the analysis described earlier, we compared a Base Unmanaged VDDT simulation with an FVS simulation processed through Preside into matrix form and then simulated in VDDT. The results are notably different, but consistent with the results presented in table 3. Since VDDT defines a set of up to 16 post-disturbance classes that are not possible to define within FVS, some differences are to be expected. The key differences are unrelated to those novel classes, however, and the most common classes, accounting for 70 percent of the landscape in each model, are completely different. As shown in the left panel of fig. 3, FVS generally predicts a less complex landscape that consists primarily of “Large” or “Giant” multiple story stands. In contrast, VDDT predicts stands in which sapling and medium size trees are more common.

When the Managed FVS and VDDT transition matrices are compared, the same types of differences can be seen, with FVS predicting more big trees and VDDT predicting smaller trees (fig. 3, right panel). Both VDDT and FVS predict open to medium canopies, however.

The goal of the management regime was to preferentially retain open forests of large, older ponderosa pine. This was successful, and PP-dominated vegetation classes are more common in the managed landscape than in the unmanaged landscapes for both models. The FVS landscape contains more than 3 times as much ponderosa pine in the managed run compared to the unmanaged case, and represents just over half of the landscape, with the majority of the vegetation classes in large open or moderately open

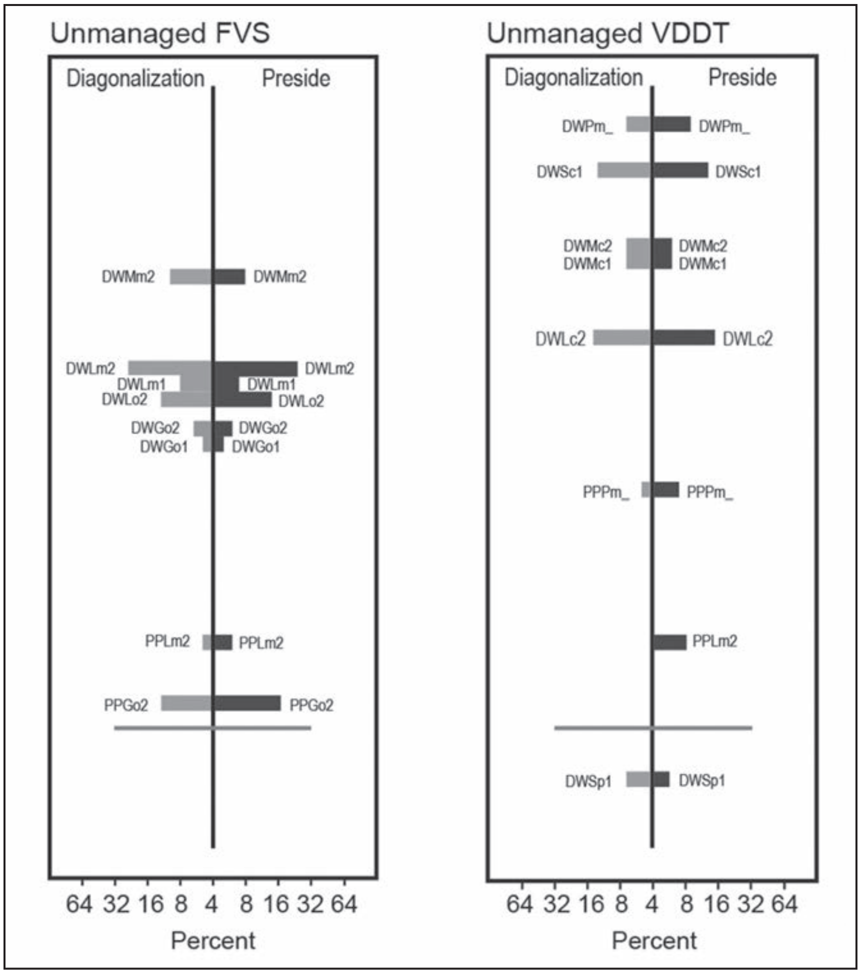

Figure 4—Decade-annual transformation differences are shown for Unmanaged FVS (left panel) and VDDT (right panel) simulations. Within each panel, horizontal bars show the landscape composition near equilibrium as calculated through matrix diagonalization on the left (light grey bars) and by Preside on the right (dark grey bars). The horizontal grey line separates vegetation classes common to both models at the top, from those found in VDDT only, at the bottom. Bar labels are defined in the preceding figure and vegetation classes <4 percent are not shown.

stands. The managed VDDT landscape also shows significantly more ponderosa pine stands. However, the managed VDDT stands are generally much younger than in either the unmanaged VDDT run or the managed FVS run.

Changes in Temporal Scale

Two methods—Preside and matrix diagonalization—exist for scaling from the decadal to annual timestep. The outcomes of these two methods are compared in figure 4, using example transition matrices for Unmanaged FVS and VDDT landscapes. The symmetry of the two examples indicates that the long-term behavior is very similar for both methods, usually with maximum differences of a few percent in vegetation categories. In the VDDT example in figure 4, there is a small excess in PP vegetation classes predicted using the Preside method, compared to the diagonalization method. In transition matrices with faster transitions or more transitions (i.e., in which the transition matrix was less sparse) the differences between the two calculation methods would probably be more significant.

Comparative Matrix Analysis of FVS and VDDT

The important results from the analysis of the equilibrium of some of the treatment matrices are summarized in table 4; with more complete results found in Appendix 2 and in supplementary material.[5] Since they show the distribution of vegetation states very near equilibrium, these results are not identical (and sometimes not even very similar) to those

[5] Supplemental information about the simulation methodology and detailed results are available at: http://essa.com/wp-content/uploads/RobinsonBeukema2012Supplement.pdf.

Table 4—The percent of the landscape in different state classes near equilibrium for Unmanaged and Managed VDDT and FVS simulations. The FVS simulations were analyzed with transitions using all years (FVS-Base), and ignoring the transition between years 0 and 1 (FVS- DZ). Within those treatments each matrix contained either all transitions (All), or the most frequent transitions (Sub) as described in the Materials section. Vegetation classes <4 percent are excluded. The transition classes shown in the two bottom rows are post-disturbance classes that have no analogue in FVS. The bottom row shows the sum within each column, and indicates the importance of rare vegetation classes in VDDT simulations

	Unmanaged						Managed					
	VDDT		FVS-Base		FVS-DZ		VDDT		FVS-Base		FVS-DZ	
	Sub	*All*	*Sub*	*All*	*Sub*	*All*	*Sub*	*All*	*Sub*	*All*	*Sub*	*All*
DWSn_							6	6				
DWPm_	7	7										
DWPo_							13	13				
DWSc1	15	15			8		4	4				
DMMo2												
DWMc2	9	9										
DWMc1	9	8										
DWLc2	19	19										
DWLc1	4	4										
DWLm2										6		5
DWLo2										6		8
DWGo2			38		39					6		6
DWGo1			30		31							
PPSn_							9	9				
PPPo_							28	28				
PPSm2							4	4				
PPSm1			9				6	6				
PPSo1							6	6				
PPMm2							5	5				
PPMo1									5			
PPLm2										13		13
PPLm1										11		11
PPGo2			23	93	18	93			76	35	80	36
PPGo1				7	4	7			19	9	20	9
DWPp1		4										
DWSp1	10	10										
Total	73	76	100	100	100	100	81	81	100	86	100	88

shown in figure 1 or figure 3 or figure 4, all of which show the distribution of vegetation classes farther from equilibrium.

The Base and Drop Zero treatments in table 4 are very nearly identical for both the managed and unmanaged FVS scenarios, regardless of whether all transitions (All) or a subset of transitions (Sub) are used. Data Simplification treatments that include rare transitions take at least a century or more to approach equilibrium (table 5).

A set of simplified complementary views of the equilibrium results is found in table 6, which regroups the data of table 4 into three groups of two strata each. Viewed through the perspective of these coarser strata, the overall disparity between the VDDT and FVS simulations is striking. When using the All-transitions treatment, VDDT is primarily small to medium Douglas-fir with medium to closed canopy at equilibrium, while FVS is primarily large, open ponderosa pine. When rare transitions are excluded,

Table 5—The median number of years required to reach near-equilibrium for the Unmanaged and Managed VDDT and FVS simulations. The FVS simulations were analyzed using All timesteps (Base) and excluding the first timestep (Drop Zero). These treatments were further divided to use all observed transitions (All) and to exclude rare transitions (Sub)

		Unmanaged		Managed	
		VDDT	FVS	VDDT	FVS
Base	Sub	223	38	142	138
	All	209	208	140	368
Drop Zero	Sub		165		156
	All		209		342

the species mix is more similar, but not the size or degree of canopy closure. Dropping the first transition makes little difference to the results.

Comparing simulations made using all transition probabilities and those with fewer transitions gives a fairly consistent result for timing and complexity: simpler stochastic matrices generally reach a near-equilibrium state two to three times faster than their more complex counterparts, and also tend to reach a simpler end-state with a small number of final vegetation classes. That said, the near-equilibrium (climax vegetation) end states can be remarkably different: PP in some cases and a mix of DW and PP in others. As a result of this, the attempt to simplify transitions only adds to our woes and makes it seem unlikely that FVS and VDDT simulations can be easily reconciled.

Summary and Recommendations

Although we have not been able to develop ways to easily bridge FVS and VDDT, we have learned some useful lessons. We have independently confirmed that Preside's methodology for calculating transitions and their probabilities is correct, and that identical results are obtained in VDDT when using VDDT-defined pathways and probabilities directly, and when VDDT results are output as FVS-like results which are then imported back into VDDT using Preside-calculated pathways and probabilities. This gives us confidence that if the issues caused by classification boundaries and model behavior can be resolved, accurate FVS-generated information can be provided to VDDT. Although we found that the algorithm for converting FVS decadal transition probabilities into annual VDDT probabilities is not correct, the consequences of this error are small when the transition matrix is sparse and probabilities are small. Correcting this error is conceptually straightforward.

Even after taking care to calibrate FVS and to make the FVS and VDDT simulations as similar as possible, we found two notable sources of discordance. First, the FVS simulation contains complex regeneration rules which have a significant influence on the types of transitions that emerge from the model. And for its part, VDDT also contains assumptions about regeneration that are implicit in the user-defined pathways (e.g., when moving from a

Table 6—Simplified near-equilibrium states for Unmanaged and Managed VDDT and FVS simulations, showing the percentage in different groupings by dominant species, QMD class and Cover class. Some columns do not add to 100 percent due to rounding

		Unmanaged						Managed					
		VDDT		FVS				VDDT		FVS			
		Base		Base		DZ		Base		Base		DZ	
		Sub	All	Sub	All	Sub	All	Sub	All	Sub	All	Sub	All
Species	PP	2	3	32	100	23	100	66	63	100	71	100	72
	DW	88	88	68		78		29	29		24		23
QMD	P,S,M	63	64	9		9		95	92	5	1	2	
	L,G	27	27	91	100	92	100			95	94	98	95
Cover	n,p,o,_	23	24	91	100	100	100	68	68	100	61	100	64
	m,c	67	67	9		1		24	24		34		31

single-story to a multistory stand), but which are nonetheless obscure. These different regeneration assumptions work themselves out in different ways and result in different stand structures that cannot easily be reconciled. Improvements could possibly be made in the VDDT regeneration arena by more careful and explicit attention to regeneration and its temporal and structural consequences, which might require additional detail in the state models. FVS would benefit from a thorough review of the Repute model which was used to drive regeneration in the FVS simulation. Secondly, VDDT contains explicit rules about low levels of natural disturbances (insects, pathogens and low-level fire) which cumulatively keep the landscape from reaching an old giant forest state. FVS has a set of assumptions about the role of natural disturbance which are embedded in its mortality model, but these rules generally have less impact on the size or structure of the forest.

Because of the underlying differences in the biological processes that are included, classifying FVS outputs into discrete VDDT-like vegetation states will always present difficulties. Simple approaches such as smoothing or moving a class boundary such as QMD, simply transfers the classification problem to another type of stand structure. Because of the way they are defined, the algorithms which define QMD and Cover remain sensitive to the appearance of any new regeneration, and the jitter issue therefore remains unresolved as long as standard definitions and categorical variables are used to stratify stand structure. There are other intrinsic difficulties for comparing the two models since in this landscape at least, VDDT contains a number of vegetation states that are undefined and therefore never observable in FVS. In the Managed case using all transitions, about 20 percent of the VDDT landscape is in vegetation classes that are out-of-scope for FVS.

Given the initial jump in stand vegetation class often produced by FVS self-calibration, combined with the censoring that takes place between the initial inventory condition and the end of the first timestep, the Drop Zero treatment should produce more reliable results than the control Base treatment. It is therefore surprising to note that the dynamics of these two treatments are very similar (table 6). Regardless, removal of the first transition is recommended to reduce initialization artifacts.

Finally, we explored a further layer of data treatments through scenarios which either retained or removed rare transitions. We discovered that the removal of the less frequent transitions results in stochastic matrices with overly simplistic pathways, along with the side effect that the landscape dynamics are sped up, often dramatically, in their approach to equilibrium. This speed seems unreasonable in forests marked by century-scale life spans, and suggests that rare transitions should always be retained.

We also examined smoothing methods that might result in less jittery FVS transition dynamics which we hoped would be more transferrable to VDDT. This exploration was neither simple nor uniformly successful. The methods we tested often resulted in system dynamics that were quite different from the comparatively similar Base and Drop Zero treatments described above. We were unable to find similarities between any smoothed scenario and the VDDT landscape dynamics that were consistent across the unmanaged and managed landscapes. A Preside option that allowed the calculation smoothed classes would provide a way to examine the benefit of reducing jumpy transitions, leaving it up to the modeler to decide whether this created better agreement between the two models.

Because of the differences in intent and design, no one model can capture all aspects of stand or landscape dynamics. Our findings show that FVS can be used to capture changes due to stand processes: tree growth, mortality, and regeneration and the associated changes in size and structure, and that these transitions can be transferred to VDDT. Modelers should consider these transitions as candidate versions of reality, just as VDDT transitions are different candidate versions of reality. Given the many possible differences between the two models, it might be helpful to develop automated methods of comparing large matrices which highlight transition probabilities that differ between the two models. Tools that allowed modelers to quickly simulate stable states might also provide insight into model differences that would highlight, for example, the role of regeneration and disturbance in creating and maintaining different pathways. When doing a landscape level analysis using VDDT however, including FVS transitions by themselves are not sufficient, and it remains necessary to add the important effects of landscape level disturbances such as beetles and fire. In this way, one is using the strengths in both models to create the best possible VDDT model.

Given the challenge of reconciling the two model paradigms, we have proposed and examined some possible approaches to aide in model comparison. Using the common framework of the transition matrix, its dynamics and stable states are a useful way of comparing two complex models, producing compact summaries—two vectors—which allow the quick identification of similarities and differences. Identifying these contrasts is the first step toward understanding the underlying mechanisms which create different projections. Although it is possible to compare the two transition matrices directly, landscape dynamics are based on the aggregate behavior of the entire system, making it misleading to consider the automated insertion of specific transitions from one model into another without careful examination of the consequences.

Acknowledgments

We express our great appreciation to the numerous people who provided ideas and guidance for this project. In alphabetical order, they are: Miles Hemstrom, Jim Merzenich, Melinda Moeur, Don Vandendriesche and Reuben Weisz. Don Vandendriesche also provided support through the FVS calibration exercise. Funding for this project was supplemented by Joint Venture Agreement PNW 08-JV-11261976-362, between the USDA Forest Service Pacific Northwest Research Station and ESSA Technologies, and by internal research funding provided by ESSA Technologies.

References

Crookston, N.L.; Dixon, G.E. 2005. The Forest Vegetation Simulator: a review of its structure, content, and applications. Computers and Electronics in Agriculture. 49: 60–80.

ESSA Technologies Ltd. 2007. Vegetation Dynamics Development Tool User Guide, Version 6.0. Prepared by ESSA Technologies Ltd., Vancouver, BC. 196 p.

Forest Vegetation Simulator Staff. 2003. Users guide to the Database Extension of the Forest Vegetation Simulator Version 2.0. Fort Collins, CO. U.S. Department of Agriculture, Forest Service, Forest Management Service Center. (July 2009 revision). 60 p.

Moeur, M.; Vandendriesche, D.A. 2009. Calibration of state and transition models with FVS. In: T. Jain, R.T. Graham and J. Sandquist, tech. eds. 2010. Integrated management of carbon sequestration and biomass utilization opportunities in a changing climate: Proceedings of the 2009 National Silviculture Workshop; 2009 June 15–18; Boise, ID. Proceedings RMRS-P-61. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 275–287.

Stage, A.R. 1973. Prognosis model for stand development. Res. Pap. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 36 p.

Stage, A.R. 1997. Using FVS to provide structural class attributes to a forest succession model (CRBSUM). In: R. Teck, M. Moeur and J. Adams (comps.). Proceedings: Forest Vegetation Simulator Conference; February 3–7; 1997. Fort Collins, CO. Gen. Tech. Rep. INT-GTR-373. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 139—147 p.

Vandendriesche, D. 1997. FVSSTAND Alone: generate dynamic yield reports from the Forest Vegetation Simulator. In: R. Teck, M. Moeur, and J. Adams (comps.). Proceedings: Forest Vegetation Simulator Conference; February 3–7; 1997. Fort Collins, CO. Gen. Tech. Rep. INT-GTR-373. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 168–177.

Vandendriesche, D.A. 2009. Repute–regeneration imputation extractor. http://www.fs.fed.us/fmsc/ftp/fvs/software/pre_post/repute_z.exe. (6 August 2009).

Van Dyck, M.G.; Smith-Mateja, E.E. (compilers) 2000. Keyword reference guide for the Forest Vegetation Simulator. Revision: March 2012. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Management Service Center. 119 p.

Appendix 1: Calibration of FVS

This Appendix contains the details of the parameters that were changed or added to calibrate FVS for these simulations.

As described in the body of the paper, site quality was constrained to a maximum SDI of 380 and maximum basal area of 164 ft^2 ac^{-1}. As part of the FVS calibration process, the large tree diameter increment model and small tree height increment model were also adjusted (table 7 and 8) to globally reflect pooled diameter and height calibration data from the full set of stands. Mortality was also adjusted using the TreeSzCp keyword (Van Dyck and Smith-Mateja, 2000) to reduce survival of larger trees.

Additional keywords were needed to implement the restoration management scenario (fig. 5). These keywords instruct FVS to thin the stand to 50 percent of SDI when the stand is more than 65 percent of maximum SDI, and to preferentially retain larger ponderosa pine.

Table 7—Parameters of the ReadCord and ReadCorH keywords used to adjust baseline diameter and height growth. Empty fields have coefficients of 1.0

Species	Diameter	Height
WP		
WL	0.799	
DF	1.056	2.730
SF		
RC		
GF	0.575	
LP	0.861	0.461
ES		
AF	0.637	
PP	0.824	
OT		

Table 8—Parameters of the TreeSzCp keyword used to adjust survival and dimension constraints for larger trees

Species	DB (in)	Mortality ($10y^{-1}$)	Height (ft)
WP	28	0.374	120
WL	26	0.118	120
DF	32	0.103	125
SF	12	0.129	70
RC	26	0.159	95
GF	22	0.291	120
LP	18	0.259	95
ES	16	0.223	100
AF	12	0.243	70
PP	34	0.135	120
OT	10	0.464	70

```
SpecPref                                WP      10
SpecPref                                WL      10
SpecPref                                DF      10
SpecPref                                SF      10
SpecPref                                RC      10
SpecPref                                GF      10
SpecPref                                LP      10
SpecPref                                ES      10
SpecPref                                AF      10
If                      0               OT      10
BSDI  GT  (BSDIMAX*0.65)
Then
ThinSDI
Endif                   0  Parms ( (BSDIMAX8.500, 1, 0, 0, 999,1)
```

Figure 5—FVS keywords used to implement a simple Restoration Management regime that retains large ponderosa pine.

Appendix 2: Impacts of Smoothing

As described in earlier sections, the use of boundaries to classify FVS stands into VDDT classes can create cases of jitter: rapid sequences of change between different classes. We experimented with two different methods for smoothing jittery transitions. The first method—*Running Smooth*—uses an evenly weighted running smoother (*t–1, t, t+1*) to average the CANCOV and QMD variables that are

Table 9—The near-equilibrium states of the Unmanaged and Managed FVS simulations, expressed as a percentage of the landscape in each vegetation class using the two smoothing methods. FVS Base results are provided from table 4 for comparison. "All" and "Sub" indicate analyses that include all transition probabilities or exclude rare transitions, as described in table 1. Minor vegetation classes (<4 percent) have been excluded. No Managed Conditional smoothing simulations were carried out

	Base		Running		Conditional	
	All	Sub	All	Sub	All	Sub
Unmanaged						
DWSm2				5		
DWMm2				14		
DWMo2						
DWLm2				34		
DWLm1				11		
DWLo2				13		
DWGo2	38					
DWGo1	30					
PPSm1	9			100	16	
PPMo1						
PPLm2				6		
PPLm1						
PPLo2						
PPGo2	23	93			84	93
PPGo1		7				7
Total percent	100	100	100	83	100	100
Managed						
DWSm2						
DWMm2			4	5		
DWMo2						
DWLm2		6	17	15		
DWLm1			8	7		
DWLo2		6	12	10		
DWGo2		6				
DWGo1						
PPSm1						
PPMo1	5					
PPLm2		13	20	20		
PPLm1		11	16	16		
PPLo2			6	5		
PPGo2	76	35				
PPGo1	19	9				
Total percent	100	86	83	78	–	–

used to assign vegetation classes to the output of each FVS timestep. The second method—*Conditional Smooth*—uses a simple rule which is applied at each timestep *t*. The rule is: if a stand's change in QMD or CANCOV in timestep *t* causes it to be assigned to a class that differs from the one to which it was assigned in timestep *t-1*, or would be assigned in the timestep *t+1*, then the classification boundary must be exceeded by at least 1/6 of the class width for the new classification to be accepted. Thus, patterns such as A-B-A would likely become A-A-A, but patterns of A-B-B would likely stay A-B-B. We examined the impact of the application of these two kinds of smoothing methods to the behavior of the resulting transition matrices.

The results of applying these smoothing methods are shown in table 9 (the distribution of vegetation states near equilibrium), table 10 (a measure of the time required to approach equilibrium) and table 11 (a condensed comparison of the vegetation states). The Base FVS scenario is included with each table to facilitate comparison with a non-smoothed simulation. The general conclusion from these simulations and comparisons is that the smoothing methods have significant effects upon the behavior of the transition matrices, but that they are as different from the Base FVS simulation as they are from any of the VDDT-based simulations.

Table 10—The median number of years required to reach near-equilibrium for the Unmanaged and Managed FVS simulations for different smoothing methods. FVS simulations were analyzed using all timesteps (Base), subdividing those results to use all observed transitions (All) and to exclude rare transitions (Sub)

		Unmanaged	Managed
Base	Sub	38	138
	All	208	368
Running	Sub	155	183
	All	247	178
Conditional	Sub	223	–
	All	211	–

Table 11—Simplified near-equilibrium states for Unmanaged and Managed FVS simulations for different smoothing methods, using all transitions (All) and excluding rare transitions (Sub). FVS Base results are provided from table 4 for comparison. Vegetation classes are grouped as in table 4, showing the percent-age in different groupings by dominant species, QMD class and Cover class. Some columns do not add to 100 percent due to rounding; those marked with '–' were not simulated

		Unmanaged FVS						Managed FVS					
		Base		Running		Conditional		Base		Running		Conditional	
		Sub	All	Sub	All	Sub	All	Sub	All	Sub	All	Sub	All
Species	PP	32	100	100	10	36	100	100	71	51	51	–	–
	DW	68			86	64			24	47	45	–	–
QMD	P,S,M	9		100	22	4		5	1	7	12	–	–
	L,G	91	100		74	96	100	95	94	91	84	–	–
Cover	n,p,o,_	91	100		21	96	100	100	61	30	26	–	–
	m,c	9		100	75	4			34	68	70	–	–