Use of the Forest Vegetation Simulator to Quantify Disturbance Activities in State and Transition Models

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Authors

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Abstract

The Forest Vegetation Simulator (FVS) has been used to provide rates of natural growth transitions under endemic conditions for use in State and Transition Models (STMs). This process has previously been presented. This paper expands on that work by citing the methods used to capture resultant vegetation states following disturbance activities; be it of natural causes or human induced. Forest Inventory and Analysis (FIA) plots were stratified by representative Potential Natural Vegetation Types (PNVTs) of the southwestern United States. Structural states within the Vegetation Dynamics Development Tool (VDDT) (i.e. STM used for forest planning) were defined based on dominant tree size, canopy cover density, and vertical story layering. A standard set of silvicultural and fire prescriptions were evaluated using FVS projections. Outputs such as post treatment vegetation states, harvest volumes, and snag generation were captured and linked to transitions in VDDT. A case study involving the ponderosa pine/bunchgrass forest ecosystem will be presented to demonstrate features of the modeling approach.

Introduction

State-and-transition models (STM) have the ability to integrate multiple interactions between ecological processes and land management strategies and as such are increasingly being used to guide land management decision making. However, owing to their complexity, some state characteristics and transition probabilities are largely constructed from expert opinion because of a lack of empirical data or lack of tools to test STM performance against empirical data. Recently, the Forest Vegetation Simulator (FVS) (Dixon 2002) has been used to provide rates of natural growth transitions under endemic mortality conditions for use in Vegetation Dynamics Development Tool (VDDT) (ESSA 2006) models (Henderson 2008, Moeur and Vandendriesche 2010, Weisz et al. 2010, Shlisky and Vandendriesche 2012). In our previous work in analyzing landscapes for forest plan revision, we divided the southwestern United States into terrestrial ecosystems that range from dry grasslands-shrublands, to semi-arid woodlands, to moist forestlands. Each ecosystem is representative of a Potential Natural Vegetation Type (PNVT) (Schussman and Smith 2006). Each PNVT, which is depicted within separate VDDT models, was then further broken into vegetation states. A vegetation state is a composite of cover type (preeminent species composition) and stand structure (dominant tree size, canopy cover density, and vertical canopy layering). The vegetation states developed for the ponderosa pine/bunchgrass (PPG) ecosystem are illustrated in table 1.

Vegetation states can transition to other states in the absence of disturbance due to natural processes. Tree establishment, growth, and mortality comprise the main components for natural succession. For example, the straight green lines connecting model states in figure 1 represent deterministic pathways (i.e., natural transitions in the absence of disturbance).

Change in vegetation states can also result from management activities, insect and disease outbreaks, and wildfire occurrence. The blue lines in figure 1 represent the myriad of stochastic pathways (i.e., probabilistic transitions due to disturbance events). State-and-transition models (STMs) such as VDDT can be used to evaluate natural succession and disturbances effects that result in vegetation change on the landscape (He 2008). The objective of this

Table 1—Stratification of figure 1 ponderosa pine/bunchgrass PNVT vegetation states A through N, according to key attributes of dominant tree size, canopy cover, and canopy layering

	Tree diameter					
GFB	0-5 in.	5-10 in.	10-20 in.	20+ in.	Canopy[a] cover	Canopy layering
A or N[b]	B	C	D	E	Open	Single
	F	G	H	I	Closed	Single
			J[c]	K[c]	Open	Multi
			L	M	Closed	Multi

[a] Except for States A and N, "Open" states have 10 to 30 percent canopy cover and "Closed" states have greater than 30 percent canopy cover. States A and N have less than 10 percent canopy cover.

[b] States A and N are grass, forbs, brush, and shrub states (GFB). State A is the characteristic state which existed in reference conditions. State N is the uncharacteristic state resulting when stand-replacing fires occur in closed canopy states. (Smith 2006)

[c] The *desired condition* is an open multi-layered (> 5 age classes) state with average diameter varying by site productivity with State J occurring on low productive sites and State K occurring on high productivity sites. (Triepke et al. 2011)

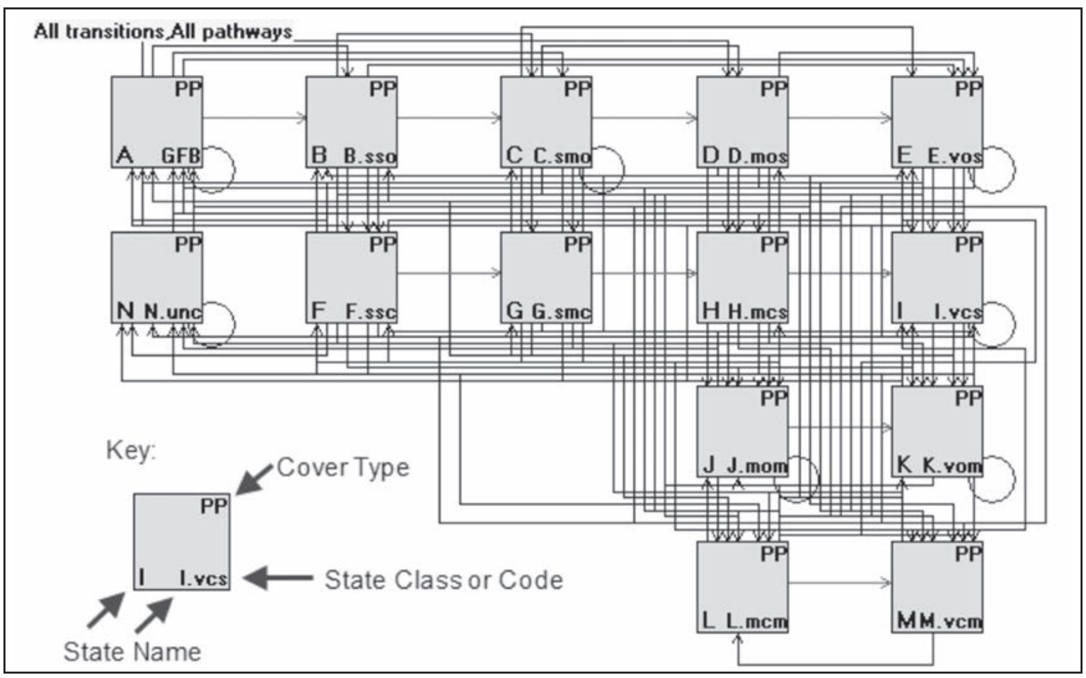

Figure 1—Conceptual pathways diagram for the ponderosa pine/bunchgrass PNVT. Boxes represent model states and arrows represent transitions due to natural growth and other natural and anthropogenic transitions such as management activities, fires, and insects and disease. In the key to the conceptual diagram we see the Cover Type (Ponderosa Pine = PP), State Name (1) and the State Class or Code (VCS = Very-large, Closed, Single story).

paper is to illustrate the expanded use of FVS for estimating outcomes from disturbance agents within the context of national forest land management planning. The general process that we used for FVS analysis is described in the sidebar. The red line between step 4 and 5 demarks the break between our initial effort to capture natural growth succession and our subsequent work to quantify resultant vegetation states due to disturbance activities. The later steps will be elaborated in the following sections.

Sidebar

The conceptual method for estimating transition rates and destination states for STMs involved using inventory data, FVS model runs, and post processing software. The analysis process culminated with formal evaluation and adjustment of model results where needed. The steps utilized were:

Step 1. Assemble inventory data for FVS projections. Regional strategic inventories such as FIA provide an excellent data source to represent vegetation stratification schemes. Classification attributes can be used to filter plot sets for finer resolution. In the absence of adequate sample, FVS can be used to grow plots into model states.

Step 2. Adjust FVS parameters to the current inventory trends (Vandendriesche 2010). The default model context for FVS is to forecast stand development to full site occupancy. If endemic or epidemic conditions are to be portrayed, the FVS model needs to be adjusted toward those ends.

Step 3. Develop natural growth projections to estimate parameters for deterministic pathways without disturbance. The goal here is to capture ecological processes that represent stand development over at least one life cycle.

Step 4. Process successional progressions through the Preside program (Vandendriesche 2009). Vegetation classification attributes are compiled into a report from which mean residence times within states and transition probabilities between states are computed.

Step 5. Develop management activity projections to estimate parameters for stochastic pathways. Construction of a treatment matrix is beneficial in assigning silvicultural prescriptions and fire activities to each model state.

Step 6. Process probabilistic transitions through the Preside program. Resident and resultant vegetation states for pre and post treatment/activity are captured. Average stand conditions and reporting attributes are summarized.

Step 7. Review model results and make adjustments in relation to conceptual expectations. When necessary, account for knowledge obtained from ancillary literature and professional judgment.

Methods

Coarse and Fine Filter Plot Datasets

During our initial phase for forest planning, "coarse filter" field data plots consisted of all Forest Inventory and Analysis (FIA) plots meeting habitat type (USDA FS 1997) specifications for each PNVT[1]. Table 2 provides a listing of the habitat types associated with the PPG PNVT. For our current work, we began by using the coarse-filter plot set. However, during the process, and under the scrutiny of silviculturists and fire ecologists, questions arose as to whether the coarse filter plots were homogeneous enough to evaluate the effects of management activities in the VDDT models. Some of the arguments against using coarse filter plots exclusively were that they contained:

- plots that were designated with incorrect habitat types,
- plots that represented inclusions or ecotones, within or between PNVTs, and
- plots that included non-stockable areas (i.e., rock outcrops, perennial water).

These contentions indicted that coarse filtered plots would add unrealistic effects to our results because they didn't represent the type of vegetation that typically would be affected by our treatment activities. Classifying forestland with respect to its capacity for timber production has been a requirement of the National Forest Management Act and subsequent implementation regulations since the early 1980's (Youtz 2006). Determining timber suitability is a stepwise process that separates National Forest System lands into various classification categories. (Refer to figure 2.) Separating our data set into proxies of land generally not suitable and land generally suitable for timber production or harvest is analogous to applying finer resolution to the coarse filter data set.

We therefore created fine filters to remove the non-representative plots from the coarse filtered data set using rules determined by our silvicultural and fire ecology specialists. As an example, by using the PNVT—habitat type crosswalk

[1] The terms "habitat type" and "plant association" are synonymous in the southwestern region. A PNVT is composed of several habitat types.

Table 2—Habitat type codes associated to the ponderosa pine/bunchgrass PNVT

Habitat type code	Common name
011092	Ponderosa pine/Arizona fescue/blue gramma
011093	Ponderosa pine/Arizona fescue/Gambel oak
011330	Ponderosa pine/mountain muhly
011340	Ponderosa pine/screwleaf muhly
011341	Ponderosa pine/screwleaf muhly/Gambel oak
011350	Ponderosa pine/Indian ricegrass
011380	Ponderosa pine/black sagebrush
011390	Ponderosa pine/screwleaf muhly-Arizona fescue
011391	Ponderosa pine/screwleaf muhly-Arizona fescue/blue gramma
011392	Ponderosa pine/screwleaf muhly-Arizona fescue/Gambel Oak
011400	Ponderosa pine/kinnikinnik
011470	Ponderosa pine/Arizona walnut

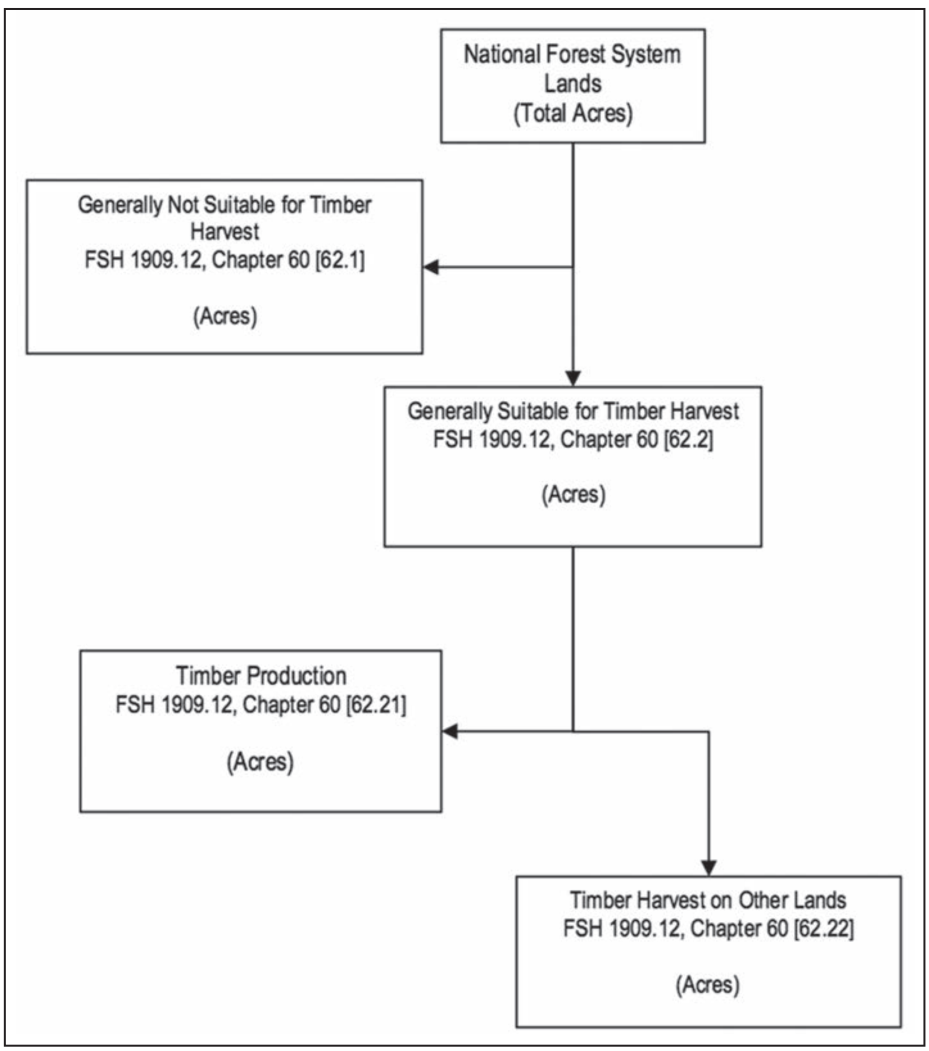

Figure 2—Timber suitability screening process.

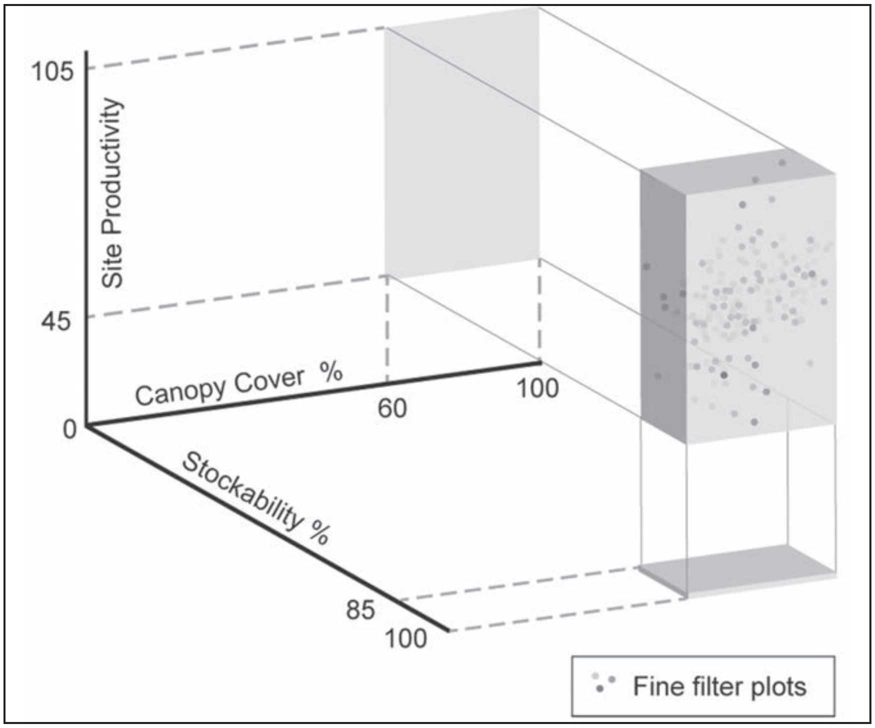

Figure 3—Use of expert opinion rules to define fine filter plots sets.

as defined for coarse filter plots, we identified 477 FIA plots associated with the ponderosa pine/bunchgrass forest ecosystem. The following fine filters were applied:

1. Must have 60 at least percent canopy cover in ponderosa pine trees
2. No canopy cover restrictions on:
    a. junipers
    b. pinyons
    c. bristecone/limber pine
    d. aspen
3. Must have less than 5 percent canopy cover for all other tree species except:
    a. Must have 0 percent canopy cover for corkbark fir, Engelmann spruce, blue spruce
    b. Must have 0 percent canopy cover narrowleaf cottonwood, other hardwoods
    c. Must have less than 2 percent canopy cover Chihuahua pine, other softwoods
4. Stockability: 85 percent or greater
5. Site Productivity: Ponderosa Pine Site Index within the range of 45 to 105.

This resulted in a subset of 283 plots meeting the fine filter criteria (approximately 60 percent of coarse file plot set). These were used in FVS projections to evaluate the effects of management activities. Figure 3 characterizes the winnowing of fine filtered plots from the coarse filtered data set.

Supplementing Plot Sample Sizes With Synthetic Datasets

When processing FIA plots to compute transition probabilities for STMs, on occasion there were either too few plots (i.e. less than 10) or no plots at all to represent particular model states. In these cases, confidence in the results from FVS simulations was relatively low. Having a small sample within a vegetation state increased the likelihood that a borderline plot (i.e. plots at the edge of the shaded box in fig. 3) would have undue effects on the resultant transition probabilities. For example, if one plot (of three) responded to treatment by transitioning to an unlikely vegetation state, the relative impact would suggest that 33 percent of representative acres within the state would transition to this suspect destination state. With a larger sample size, the

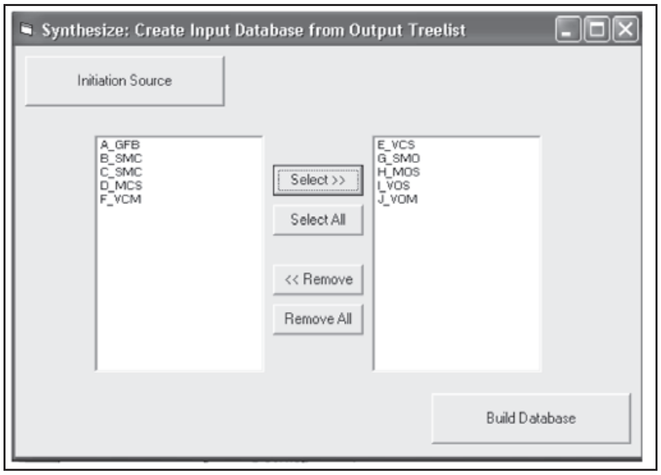

Figure 4—The Synthesize post processing program can be used to select deficient vegetation states to increase sample representation.

transition probabilities would be buffered against unlikely end states. Occasionally, this problem was encountered with coarse filtered plot sets; however, it was more likely to occur with the reduced subset of fine filtered plots.

We set the minimum sample size for a vegetation state to greater than or equal to 10 plots. If this criterion was not met, we created synthetic plots and added those to the original inventory sample. Having 30 or more representative plots in a vegetation state is desirable. An FVS post processing program (named Synthesize[2]) was developed to create modeled plot sets. The process involves first using FVS to grow existing inventory plots into vegetation states with a deficiency of existing plot data. Next, the Synthesize program reads the output tree list files created by FVS and extracts the plot and tree information of specified vegetation states (fig. 4). This extracted information is then converted into input plot and tree records in database files. These databases are used as the plot data input source for deficient vegetation states. With respect to the PPG PNVT, there were no vegetation states that lacked an adequate inventory sample. There was a need to augment the inventory sample with synthetic plots in other PNVTs in the southwestern region.

Validation of Disturbance Transitions

Two types of disturbance were considered during this phase of modeling analysis: human induced and naturally caused. Silvicultural treatments in the form of tree removal were the primary source of human intervention. Depending on the ignition source and outcome, fire can be considered either or both types of disturbance activity. Planned fires (i.e. prescribed) served as a secondary source of human induced disturbance. Unplanned fires (i.e. wildfires) for our purposes were considered the primary natural disturbance agent. Inferences regarding insects, disease, wind, and other sources of natural disturbances outside of pervasive impacts were not modeled independently due to time constraints.

The Forest Vegetation Simulator and Fire and Fuels Extension (FVS-FFE; Rebain 2010) were used to simulate the effects of using tree cutting, and planned and unplanned fires as restoration tools for the various PNVTs of the Southwest. A standard set of management activities were applied to each model state. Species composition and structure (i.e. vegetation state) were compared pre and post treatment. The resultant conditions were then used to assign the transition pathways for each disturbance type in VDDT.

Land managers should consider a full "toolbox" of treatment methods in order to work toward achieving desired conditions. However, in an effort to reduce the modeling workload, eight silvicultural prescriptions and three burning intensities were evaluated (table 3).

Silvicultural prescriptions—
Cutting parameters were adjusted in the FVS model runs to fit each PNVT and the intent of the particular treatment method. Knowledge of species silvics and ecological objectives were considered and adjusted for each PNVT as appropriate. Residual target basal areas (BAs) were assigned according to cutting prescriptions as shown in table 4 for PPG.

Tree species cut/leave preferences were set within the FVS model to fit the native species mix and emphasized

[2] Synthesize, Version 2011.01, programmed by D. Vandendriesche while working with USDA Forest Service, Forest Management Service Center, Forest Vegetation Simulator Staff, Fort Collins, CO. Inquiries should be directed to the developer.

Table 3—Standard treatments used to evaluate the effects of management activities within each VDDT Model State

Management activity	Code
Natural endemic growth in the absence of disturbance[a]	A
Free thin, all sizes to target basal area	B
Thin-from-below to target basal area	C
Thin under a 16" diameter cap to target basal area	D
Group selection with matrix thin to target basal area	E
Shelterwood seed cut to target basal area	F
Clearcut with non-regeneration objective legacy trees	G
Clearcut/coppice for hardwood regeneration	H
Prescribed fire, low intensity burning conditions	J
Prescribed fire, moderate intensity burning conditions	K
Prescribed fire, high intensity burning conditions conditions	L
Thin under a 9 inch diameter cap	M

[a] Specifying a "No Treatment" activity implies by default a management decision.

Table 4—Prescribed residual basal area targets by cutting method for the ponderosa pine/bunchgrass PNVT

Cutting method	PPG
B = Free Thin All Sizes to Target BA	50 BA
C = Thin From Below to Target BA	70 BA
D = Thin Under 16" Diam. Cap to Target BA	60 BA
E = Group Selection, with Matrix Thin to Target BA	60 BA
F = Shelterwood Seed Cut to Target BA	30 BA
G = Clearcut with Non-regen. obj. Legacy Trees	na
H = Clearcut /Coppice with Non-regen. Legacy Trees	na
M = Thin Under 9" Diam. Cap for MSO Recovery	na

restoring each PNVT to reference conditions.[3] Where certain tree species, such as aspen and oaks, were desired to retain they were either favored in the species preference settings or as a percentage of the total target residual BA. Trees with recorded dwarf mistletoe infection were selected for removal in silvicultural treatments aimed at improving overall stand vigor and health.

Cutting treatments were to be followed by a cool prescribed burn as part of the same restoration entry. These follow-up burns were not modeled in FVS-FFE. The thought being that these surface fires would treat the understory ground/shrub level and not have an impact on the resultant vegetation state. Prescribed fire treatments were modeled in FVS-FFE as the sole method of thinning trees in areas where tree cutting is not possible.

Fire modeling parameters—

Fire behavior is a combination of fuels, weather, and topography. The FVS-FFE model accepts fuel and weather parameters that mimic environmental conditions at the time of an ignition. The resulting fire behavior, such as type of fire (surface, passive, or crown fire), flame length, and torching and crowning index are then estimated by FVS-FFE. These fire behavior parameters were applied to our model states and FVS-FFE then estimated mortality and survival of the vegetation by species and size. One fire disturbance was applied at the beginning of the growth cycle with each fire modeled at low, moderate, and high conditions of weather and fuel moisture.

Environmental conditions used to simulate the low, moderate, and high fire conditions are based on historic weather data from the Alpine, Arizona, Remote Automated Weather Station (RAWS). The Alpine RAWS has the most complete and accurate data of all the weather stations on the Apache-Sitgreaves National Forests, and was used for FVS-FFE modeling of the ponderosa pine/bunchgrass PNVT.

Weather data were sorted using FireFamilyPlus[4] (v4.1) to produce a Percentile Weather Report. This percentile report was used to determine the 15th, 75th, and 90th percentile weather for the past twenty years (1990–2009). Weather data used were from the period of April 1 through October 15 each year, representing a typical fire season. The 15th percentile represents natural fire season conditions for a low intensity fire; the 75th is moderate conditions; and, the 90th is high intensity fire conditions (table 5).

[3] The concept of 'desired conditions' and 'forest restoration' strategies for the ponderosa pine and dry mixed conifer PNVTs of the southwestern region is documented in Triepke et al. 2011.

[4] USDA Forest Service, Rocky Mountain Research Station, Missoula, MT. Software and User's Guide available online at: http://www.firemodels.org/index.php/firefamilyplus-software/firefamilyplus-downloads.

Table 5—Percentile Weather Report derived from FireFamilyPlus program

Station: 020401: ALPINE, AZ Variable: ERC Model: 7G2PE2
Data Years: 1990–2009 Date Range: April 1–October 15 Wind Directions: S, SW, W

Percentile, Probabilities and Mid-Points			
Variable/Component Range	**Low**	**Moderate**	**High**
Percentile Range	0-15	16-89	90-97
Climatological Probability	15	75	7
Mid-Point ERC	15-15	48-48	90-90
Number Observations	61	82	61
Calculated Spread Component	4	10	16
Calculated ERC	16	49	91
Percent Area Burned	60	70	80

Fuel Moistures/Weather			
Variable	**Low**	**Moderate**	**High**
1 Hour Fuel Moisture	11.17	4.46	2.42
10 Hour Fuel Moisture	15.39	6.15	2.81
100 Hour Fuel Moisture	19.11	10.39	4.36
1000 Hour Fuel Moisture	21.81	13.95	6.06
Herbaceous Fuel Moisture	108.83	60.23	39.72
Woody Fuel Moisture	166.06	105.34	60.00
Duff Moisture	125	50	15
Temperature	60	75	90
20’ Windspeed	10	15	20

3772 Weather Records Used, 2200 Days.

These percentile environmental conditions were used to represent both natural fire conditions, such as wildfires that may be managed to move vegetative conditions toward desired conditions, as well as burning treatments that may be used for management ignited prescribed fires. These environmental conditions approximate conditions under which a natural fire may burn. They represent a good starting point for development of a management burning prescription.

Winds are recorded at the RAWS each day at 1:00 p.m. and while they capture wind speed and direction at the average hottest time of the day, this does not represent wind gusts adequately. Consequently, the wind speeds generated from analysis of the historical weather were considered too low to reflect wind gusts effecting fire behavior, so 10, 15, and 20 mph winds were substituted for low, moderate and high wind speeds at 20’ above the main vegetation canopy (where RAWS wind speeds are measured). Based on analysis of the weather data and professional judgment, 60, 75, and 90 degrees were used respectively for air temperature. Duff moisture is also not produced by the percentile weather report. These were derived using FVS-FFE defaults for duff moisture under moist (125 percent duff moisture), dry (50 percent), and very dry (15 percent) conditions (Rebain, 2010). These conditions were used across all vegetation types to provide consistency.

Treatment Matrix

A group of silviculturists and fire ecologists was assembled from throughout the southwestern region for the purpose of providing input to the forest plan revision effort. Recall that this group influenced the decision regarding the base datasets used for modeling management activities. This same group collaboratively developed a standard set of prescriptions (eight silvicultural treatments, three burning activities) that were used to address the management alternatives put forth by planning teams on the various National Forests. For each PNVT, a “0–1 Treatment Matrix” was created that designated in which model states FVS would be used

Table 6—The "0–1 Treatment Matrix" for the ponderosa pine/bunchgrass PNVT. Model state "H" is discussed in more detail in the text

		VDDT model states													
RX	**Management activities**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**
B	Free thin all sizes to target Basal Area (BA)	0	0	1	1	1	1	1	1	1	1	1	1	1	0
C	Thin-from-below to target BA	0	0	1	1	1	1	1	1	1	1	1	1	1	0
D	Thin under 16-inch diameter cap to target BA	0	0	0	1	1	0	0	1	1	1	1	1	1	0
E	Group selection with matrix thin to target BA	0	0	0	1	1	0	0	1	1	1	1	1	1	0
F	Shelterwood seed cut to target BA	0	0	0	1	1	0	0	1	1	1	1	1	1	0
G	Clearcut with non-regeneration objective legacy trees	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H	Clearcut/Coppice for hardwood regeneration	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I	Artificially plant seedlings (modeled in VDDT alone)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J	RX fire in low intensity burning conditions	0	1	1	1	1	1	1	1	1	1	1	1	1	0
K	RX fire in moderate intensity burning conditions	0	1	1	1	1	1	1	1	1	1	1	1	1	0
L	RX fire in high intensity burning conditions	0	1	1	1	1	1	1	1	1	1	1	1	1	0
M	Thin under 9-inch diameter cap to target BA	0	0	0	0	0	0	0	0	0	0	0	0	0	0

to determine the effects of management activities. The 0–1 Treatment Matrix for the PPG PNVT is shown in table 6.

A "1" in a cell indicated that we used FVS to simulate the effects of that treatment in that model state given this was an option to be considered in the analysis of management alternatives. A "0" in the treatment matrix meant that this type of treatment was either not likely to be used in the landscape analysis process for forest planning, or that it could be readily evaluated with professional judgment. FVS was not used for these cells. A national forest could decide independently whether or not to use specific cells within the "0–1 Treatment Matrix". Adjusting the transition probabilities within VDDT for particular vegetation states allows "turning on" or "turning off" movement between model states.

"Transition probability multipliers" are values within VDDT that increase or decrease the average probability for one or more transition types. This feature simplified sensitivity testing of the probabilities and allowed exploring "what if" scenarios (for example, "what if fires were twice as frequent?"). To perform this type of sensitivity testing without multipliers, we would have needed to edit the probability of each fire transition in each model state individually. Alternatively, we specified a transition multiplier of "2" for fire transitions, and the VDDT software automatically doubled the values of all fire probabilities.

Here is an example of the computational process for determining the transition probabilities following a disturbance activity. Within the PPG PNVT, there were 40 FIA plots that represented vegetation state H (i.e. medium tree size class, closed canopy, single storied). According to table 6, silvicultural prescriptions B-F and fire intensities J-L would apply to vegetation state H. The FVS model was run eight times to represent these disturbance activities. Table 7 summarizes the destination state (post treatment) for each management activity. Dividing the total number of FIA plots (40) into the FIA plot counts by prescription (across rows in table 7) produces the proportion of plots that stayed within the original vegetation state and those that transitioned to alternant states (table 8). These transition probabilities are then used in the VDDT model.

Summary Reports by State Class

Several FVS post-processing steps were bundled together to produce aggregate summaries for each vegetation state. Table 9 provides vegetation characteristics of State H. These attributes were computed for each model state by growing the representative FIA plots forward, in the absence of disturbance, for 150 years and summarizing the results.

Table 7—Destination states of 40 plots initially residing in vegetation state H as the result of FVS simulations of management activities

		Destination states								
RX	Management activities	A	C	D	E	G	H	J	L	Total
B	Free thin all sizes to target Basal Area (BA)		4	34	2					40
C	Thin-from-below to target BA			26	2	1	10		1	40
D	Thin under 16-inch diameter cap to target BA			36	2	1			1	40
E	Group selection with matrix thin to target BA			36	3				1	40
F	Shelterwood seed cut to target BA	5	2	32	1					40
J	RX fire in low intensity burning conditions			11			25		4	40
K	RX fire in moderate intensity burning conditions			13			23	1	3	40
L	RX fire in high intensity burning conditions	16		20			1	3		40

Table 8—Transition probabilities based on the proportions of FIA plots remaining and moving to alternant states as a result of management activities in vegetation state H

	Destination states								
RX	A	C	D	E	G	H	J	L	Total
B		.10	.85	.05					1.00
C			.65	.05	.025	.25		.025	1.00
D			.9	.05	.025		.025		1.00
E			.9	.075			.025		1.00
F	.125	.05	.8	.025					1.00
J			.275			.625		.1	1.00
K			.325			.575	.025	.075	1.00
L	.4	.5				.025	.075		1.00

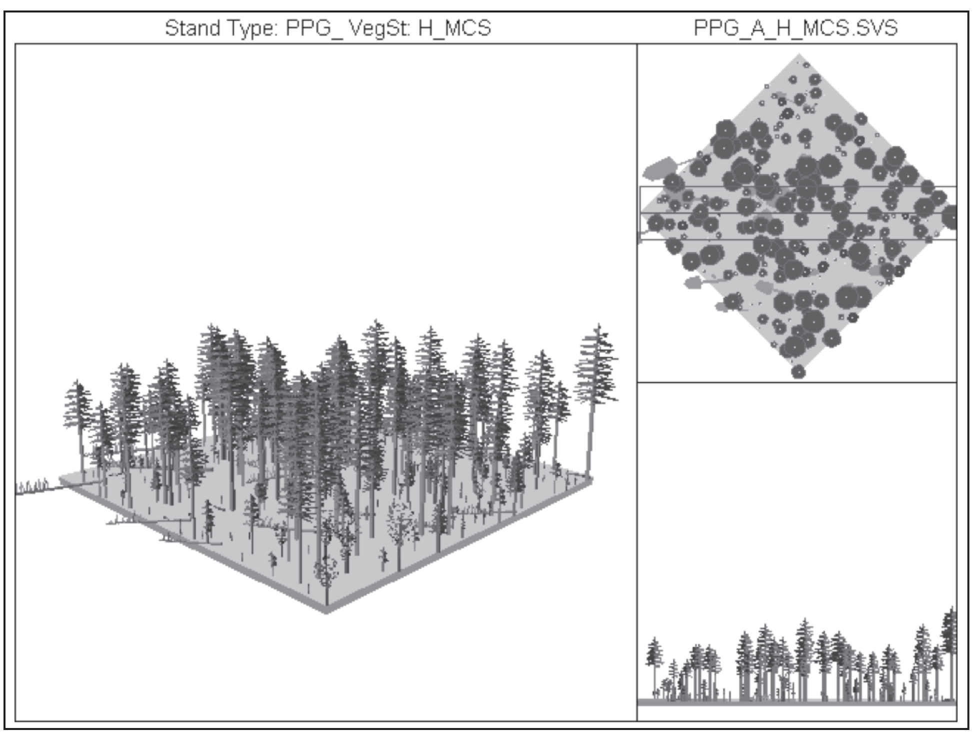

Figure 5—Stand Visualization System images of vegetation state H, the Medium Size, Closed Density, Single Story state.

Table 9—Composite characteristics of ponderosa pine/bunchgrass PNVT, vegetation state H

Vegetation characteristics	Value for State H
Vegetation structure variable examples	
Dominance type	PIPO
Canopy layers	1
Stand age in the overstory	139
Total plot activity count	1424
Proportion of stockable acres	.99
Stand-stock variable examples	
Seedlings per acre less than an inch in diameter	53.2
Trees per acre greater than an inch in diameter	249.7
Basal area per acre greater than an inch in diameter	151.6
Canopy cover percent	47.2
Annual growth: cubic feet/acre >5 inches in diameter	42.4
Annual mortality: cubic feet/acre >5 inches in diameter	20.3
Wildlife habitat variable examples	
Standing snags 8 to 12 inches in diameter	8.23
Standing snags 12 to 18 inches in diameter	6.24
Standing snags >18 inches in diameter	2.04
Pestilence disturbance examples	
Dwarf mistletoe awareness indicator (plot count)	278
Mountain pine beetle hazard	3
Wildfire risk examples	
Crown bulk density	.07
Crown bulk height	19.33
Crowning index	30.14
Torching index	32.54
Fuel load in the duff layer	4.16
Biomass and carbon examples	
Tree biomass in dry weight of live and dead boles and crown	64.5
Total stand carbon above and below ground	55.5

Figure 5 provides graphical depictions of vegetation state H using the Stand Visualization System (McGaughey 1997), which can be obtained directly from FVS output.

Timber volume calculations—

In addition to evaluating the effects of disturbance activities on post treatment states and determining average stand conditions by model state, FVS simulations also were used to quantify timber volumes required by the National Forest Management Act of 1976 (NFMA). For each combination of standard silvicultural treatment, model state, and PNVT, a variety of per acre wood volume statistics were produced in a cut-volume spreadsheet. Table 10 illustrates the harvest volumes for silvicultural prescription B in State H. When these per acre values are multiplied by the acres treated outputs from VDDT, total timber volume removal can be estimated.

Species composition—

A topic of interest was estimating the changes in species composition resulting from alternative treatment options. Relative to other management treatments, silvicultural prescription D “Thin under a 16” diameter cap to target basal area” (table 3) is controversial. Refer to Triepke et al. 2011 for a more in-depth discussion of the impasse; specifically, on page 4, Diameter Cap discussion. Each PNVT has a set of desired conditions as developed by Southwestern Regional resource specialists to guide management practices as specified in forest plan revisions. For example, the ponderosa pine/bunchgrass forest ecosystem includes

Table 10—Example of a summary of wood volume removed per acre for silvicultural prescription B in vegetation state H

Type of wood volumes per acre (cubic feet, board feet, and tons)	Net value
Softwoods	
5-9” DBH Cubic Feet (CF) for allowable sale quantity (ASQ)	153.91
> 9” DBH (CF) for ASQ	534.30
Total CF of ASQ contribution on suitable lands (excludes aspen)	688.21
0-5” DBH (tons of biomass) not ASQ	10.63
5-9” DBH (tons of biomass) not ASQ	2.22
> 9” DBH (tons of biomass) not ASQ	8.23
> 9” DBH (board feet) not ASQ	2,384.87
Nonindustrial Species > 5” diameter (PJ, etc.) (CF) not ASQ	8.14
Nonindustrial Species > 0” diameter (Tons of Biomass) not ASQ	.15
Hardwoods	
Aspen > 5” DBH (industrial CF), optional ASQ addition	8.53
Aspen > 0” DBH (tons of biomass) not ASQ	.12

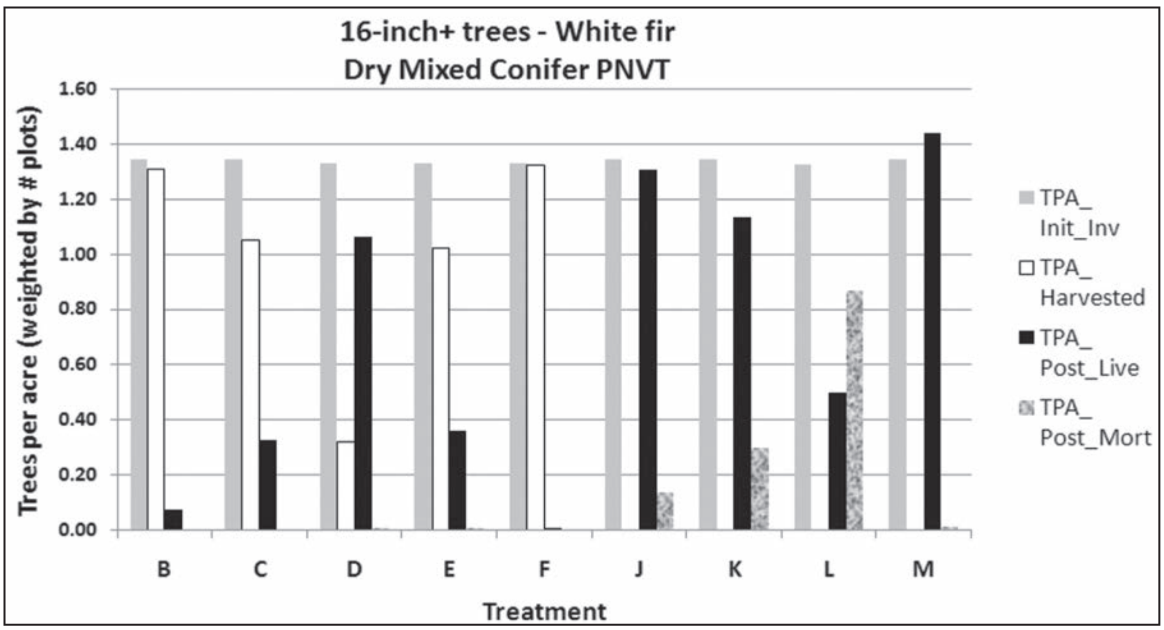

Figure 6—Tree frequency of white fir following alternative management activities in the Mixed Conifer Dry PNVT.

characteristics such as open canopy, uneven-aged structure, desired species composition, etc. In the mixed conifer dry PNVT, the goal for species composition is to mimic reference conditions under frequent, low-intensity fire regimes (i.e. open uneven-aged forests). White fir is susceptible to fire and is shade tolerant (favored by infrequent fire and closed canopy conditions). Historically, white fir was absent or rare in this forest type but over time has increased in abundance due to fire suppression and high canopy densities. FVS predicted that prescriptions B, C, E, F, and L left less white fir than did the 16-inch diameter cap prescription. Figure 6 summarizes post treatment white fir densities for the mixed conifer dry PNVT.

Discussion

Using one model’s output (FVS) as input to another model (VDDT) poses a valid question: Are the estimation error associated with the first model being passed on and perhaps compounded within the second model. Truly, inferences associated from the second model can only be as good, at the base level, as the information/parameters derived from the first model. To address this potential dilemma, we crafted the FVS model runs to forecast in accordance with observed trends from permanent plot inventory data (FIA) as based on contemporary climate. Our previously published paper (Vandendriesche 2010) stresses the importance of knowing the modeling context and making the proper adjustments in the FVS model to achieve viable estimations that are empirically based.

Based on variation in the availability of measurement data and scientific information, we recognized the importance of striking a balance between the FVS predictions, expert opinion, and research literature. This truism came into play regarding the data sets used to populate the FVS model. Based on feedback from resource specialists, criteria for fine filter rules were developed to apply against the coarse filtered, habitat type based PNVT plot sets. Additionally, when professional judgment indicated that we didn't have a sufficient number of plots in a vegetation state, we generated synthetic plots. In addition to the methods discussed above, further adjustments were made during the process based on lessons learned.

Vegetation Responses Drawn from the Literature—
Our initial intent was to quantify all STM transitions based on the results of FVS simulations using FIA plots. However, although endemic insect and disease activity (such as dwarf mistletoe) was included in our FVS projections, the probability of major insect and disease outbreaks was taken from the literature including Lynch et al. (2010) and Smith (2006). As mentioned, we did not model these effects with FVS because of time limitations in the land management planning process as implemented by the Southwestern Region. Beginning in the last quarter of 2005, each National Forest and Grassland was programmed to work through forest plan revision within a three year time period (fig. 7). This requirement focused efforts to meet required benchmarks in the planning process. Overall modeling analysis needed to be tapered to achieve the specified time goals.

Professional Judgment: Fire Effects—
Interdisciplinary teams on each national forest needed to review the results of our modeling work to differentiate acres belonging to the characteristic versus uncharacteristic "grass, forbs, brush, shrub" states (A versus N, respectively). Our mid-scale vegetation mapping products (Triepke 2005, Weisz et al. 2010) did not delineate between these two vegetation states. Consequently, when tabulating the results of fire burning under high intensity conditions (Rx L, table 3), all FVS plots destined for the "grass, forbs, brush, shrub" stage were initially assigned to state A. Following the interdisciplinary review, plots were reallocated between states A and N based on local terrestrial ecological unit data, historical fire data, and professional judgment.

As an example, FVS results of a prescribed fire burning under high intensity conditions in state H resulted in 40 percent of the plots transitioning to state A. However, a review of historical fire data and fire effects data on the Apache-Sitgreaves National Forest suggested that 27 percent the plots would go to state A and 13 percent of the plots would go to state N. It should be expected that each national forest and PNVT has a unique division of plots between states A and N resulting from fires burning under high intensity conditions in closed canopy states.

We decided that the effects of unplanned ignitions would be the same as the effects of planned ignitions. Essentially, we assumed that unplanned nonlethal ignitions would have the same destination states as Rx J; unplanned mixed severity ignitions would have the same destination states as Rx K; and, unplanned stand replacing ignitions would have the same destination states as Rx L. This was based on an interdisciplinary review of the results of the FVS-FFE modeling process.

Professional Judgment: Group Selection—
At the start of our FVS modeling process, we made two simplifying assumptions. The first assumption was that a 14-box model with states classified on the basis of cover type, dominant trees size, percent canopy cover, and storiedness (single story versus multi-story) was sufficient to represent most forest conditions and management activities (table 1). The second assumption was that for modeling

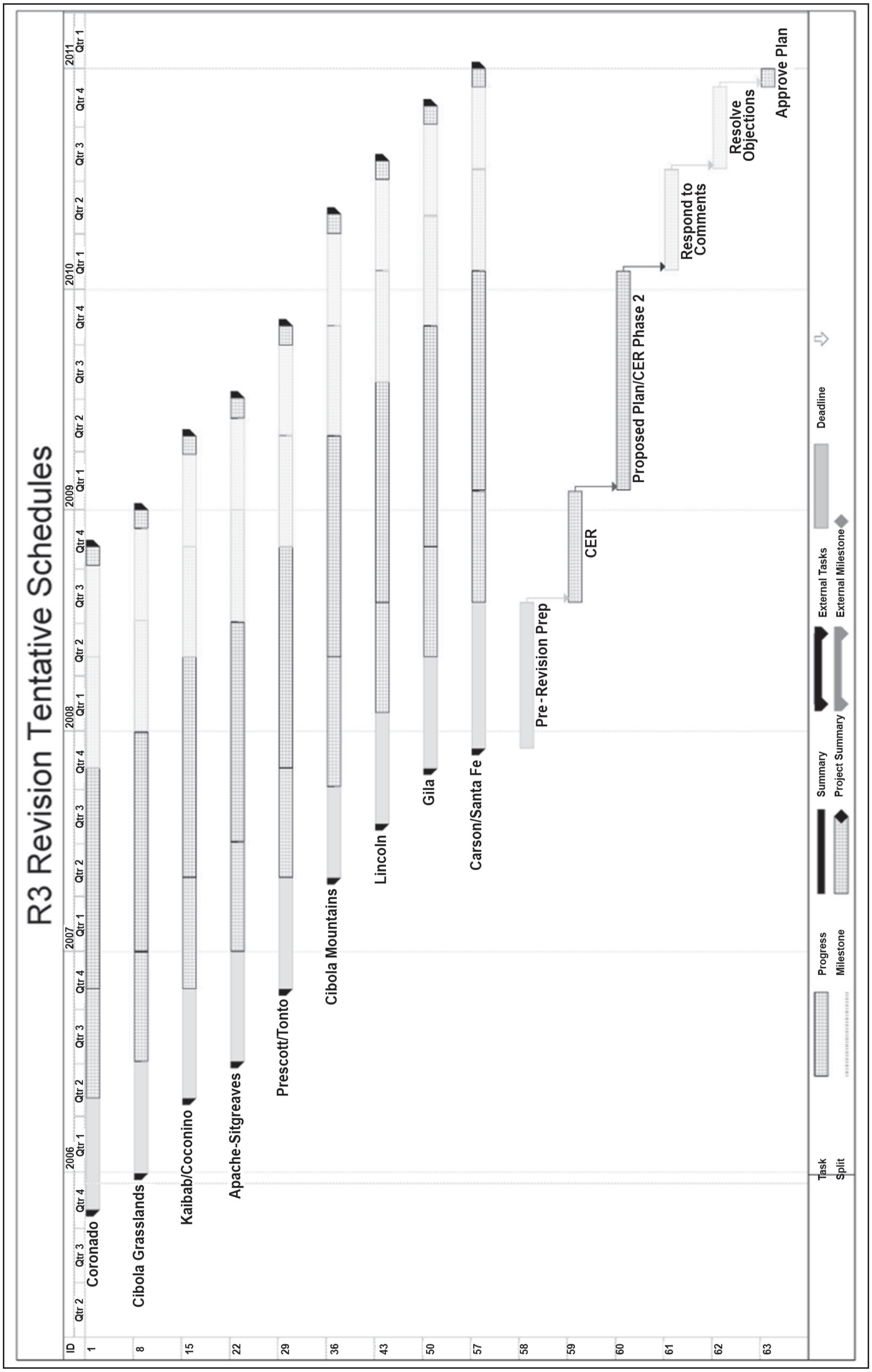

Figure 7—Southwestern Region forest plan revision timetable.

Table 11—Transition probabilities from the group selection prescription based on FVS projections

	To Destination States						
From State	A	D	E	I	J	K	Total
D		.95	.05				1.00
E			1.00				1.00
H		.90	.08		.03		1.00
I			1.00				1.00
J	.06	.41			.53		1.00
K			.50		.10	.40	1.00
L		.23	.30	.06	.23	.17	1.00
M		.09	.73	.18			1.00

Table 12—Transition probabilities from group selection prescriptions based on professional judgment

	To Destination States						
From State	A	D	E	I	J	K	Total
D					1.00		1.00
E						1.00	1.00
H					1.00		1.00
I						1.00	1.00
J					1.00		1.00
K						1.00	1.00
L						1.00	1.00
M						1.00	1.00

the effects of management activities, we only needed to use FVS to categorize conditions before and after treatment. As we completed our initial FVS process, it became apparent that these assumptions needed to be modified for the group selection treatment type (Rx E, table 3).

Table 11 lists the destination states immediately following implementation of the group selection prescription (Rx E). Post-treatment destination states and the resulting wood volume estimates describe the immediate effects of *one group selection entry* rather than a *number of entries that would create several groups* over several cutting cycles. A major objective for applying a group selection silvicultural system is to convert existing even-aged stands to uneven-aged structures. A minimum of five entries in succession on the same stand acres is needed to be successful. A more realistic modeling approach of group selection silviculture would have resulted in a more complex VDDT model with more model states and many more transitions (tracking relative age, time since disturbance, etc.).

Instead, we pursued a simplified approach. We assumed that the group selection management system would provide the "predominance of uneven-aged dynamics" which is characterized by states J and K (table 1; Triepke et al. 2011). These assumptions were implemented in the VDDT model as displayed in table 12. The results were consistent with the group selection FVS runs applied over time to develop the Long Term Sustained Yield Capacity (LTSYC) for each of our PNVTs (Youtz 2011).

Applications

The methods and models described in this paper are currently being used by the national forests in Arizona to assist in their development of revised land management plans (for example, Higgins and Kleindienst 2011). They are also currently being utilized as a point of departure for large area assessments (Hemstrom 2012) and are being linked to global climate change models to assess effects of climate change on forest ecosystems (Kerns et al. 2012). The main contribution of this work has been to demonstrate the use of the FVS model and related software to estimate the effects of disturbance activities in an STM. It is our intent that others can benefit from this process.

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