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Managing Forest Structure and Fire Hazard—A Tool for Planners

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ABSTRACT

Fire planners and other resource managers need to examine a range of potential fuel and vegetation treatments to select options that will lead to desired outcomes for fire hazard and natural resource conditions. A new approach to this issue integrates concepts and tools from silviculture and fuel science to quantify outcomes for a large number of treatment options in dry forest stands in the western United States. Five silvicultural options (thinning from below to 50 trees per acre [tpa]; 100, 200, and 300 tpa; or no thinning) are considered in combination with three surface fuel treatments (pile and burn, prescribed fire, or no treatment), resulting in a range of alternative treatments for each representative stand. The Fire and Fuels Extension of the Forest Vegetation Simulator (FFE-FVS) was used to calculate (1) immediate effects of treatments on surface fuels, fire hazard, potential fire behavior, and forest structure (including visualizations); and (2) a 50-year time series of treatment effects at 10-year increments. These fuel treatment scenarios can be used as a starting point for examining alternatives for National Environmental Policy Act documents and other applications that require scientifically based information to quantify the effects of modifying forest structure and surface fuels. Forest managers also can develop customized treatments for specific locations and resource objectives. Scenarios and output can be used to inform ecological, economic, and sociological evaluations of the effects of fuel and vegetation treatments.

Keywords: fire management, forest thinning, Forest Vegetation Simulator, fuel treatment, silviculture

Federal agencies in the United States have a strong policy and management focus on reducing fuels that have accumulated in dry forest ecosystems from which fire has been excluded for up to a 100 years. For example, the Healthy Forests Restoration Act of 2003 provides affirmative direction for increased fuel treatments to reduce accumulated fuels and reduce the risk of large and severe fires. As federal agencies and other institutions increase the amount of land area subjected to fuel treatments, they will need guidelines to develop alternatives for achieving desired future conditions. These alternatives need to consider options for silvicultural manipulation of stands, as well as surface fuel treatments.

Science-based rationale and quantitative guidelines are especially needed for regulatory documentation associated with fuel management and planning. The US National Environmental Policy Act (NEPA) requires that alternatives be considered in the development of environmental impact statements, environmental assessments, and associated documentation. These alternatives typically contain qualitative and quantitative descriptions of proposed management actions for a particular forest stand or landscape.

The scientific basis for fuel anti vegetation treatments is documented in recent syntheses (Graham et al. 2004, Peterson et al. 2005) and numerous publications (e.g., Kalabokidis and Omi [1998], Sandberg et al. [2001], and Pollet and Omi [2002]). Although these publications are helpful in establishing a scientific framework for fuel treatment planning, analytical tools (e.g., Peterson et al. [2006]) are needed to calculate expected outcomes of specific types of fuel treatments (typically forest thinning and surface fuel modification).

The USDA Forest Service recently completed a multidisciplinary research effort to develop an analytical toolkit that facilitates quantitative and qualitative evalua-

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tion of fuel treatment options (McCaffrey and Graham, this issue), including forest structure and fire hazard, economic costs and benefits, environmental consequences, and social values (Hazardous Fuels Planning website). Relationships between forest structure and fire hazard are discussed in this article, and the other topics will be discussed in subsequent issues of the *Journal of Forestry.*

Objectives

The *Guide to Fuel Treatments in Dry Forests of the Western United States* (hereafter referred to as the *Guide;* Johnson et al. [2006]) summarizes potential outcomes of applying; alternative combinations of thinning and surface fuel treatments on dry forestlands in the western United States. It facilitates a quantitative analysis and review of the alternatives in terms of fuels, forest stand attributes, and potential fire behavior. The *Guide* examines lower to midelevation dry forest stands with high stem densities and heavy ladder fuels, which are currently common because of fire exclusion. These stands are the focus ofpotential management activities intended to modify forest structure and fuels to reduce crown fire hazard on public lands (Figure 1).

The central concept of the *Guide* is that information and data from silviculture and fire science must be linked to (1) assist decisionmaking about fuel treatments and (2) provide quantitative guidelines for fuel treatment that allow consideration of desired future conditions for multiple resources. Integration of various disciplines is critical because of the potentially far-reaching effects of fuel treatments on desired conditions for wildlife, water, timber production, and recreation. Scenarios and output are generated for a 50-year time series after each combination of thinning and surface fuel treatment. The *Guide* is intended for use by fire managers, silviculturists, and other resource specialists interested in evaluating the effects of fuel treatments. Visualizations and tabular data in a standard format allow identification of fuel treatment alternatives targeted at achieving specific management objectives.

The *Guide* covers a broad range of possible treatments and stand conditions. The effects of fuel treatments are quantified for surface fuels, fire hazard, potential fire behavior, and forest structure. The Fire and Fuels Extension of the Forest Vegetation Simulator (FFE-FVS; Reinhardt and Crookston 2003) was used to calculate a variety of fuel treatment combinations (five levels of thinning X three types of surface fuel modification) for each of 24 representative forest stands). Output from FFE-FVS runs is summarized for each stand with visualizations and extensive tabular data. In addition, changes in forest structure and fuels are calculated for 50 years posttreatment at lo-year increments, so that long-term stand conditions can be assessed. Although the *Guide* contains many scenarios, it is intended as a starting point. Users are encouraged to become familiar with FFE-FVS, do their own simulations, and calculate effects of treatments specific to their own location and management situations.

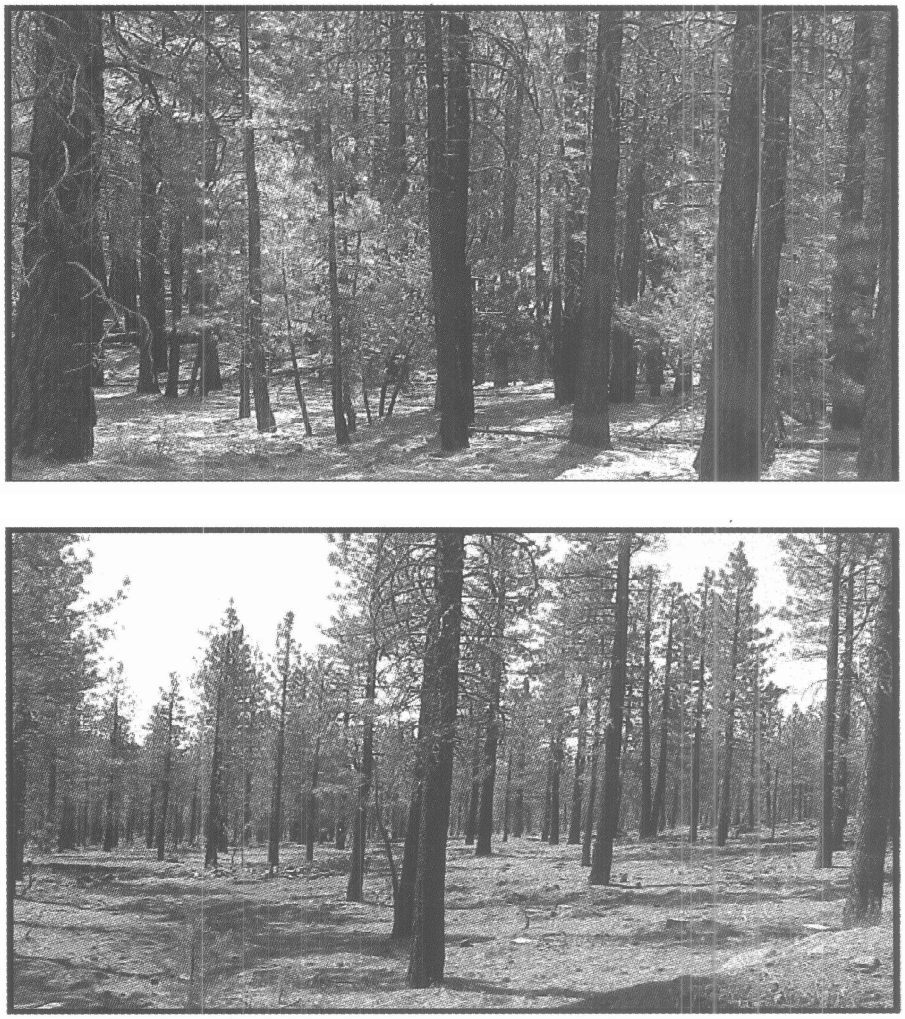

Figure 1. A dry forest with ponderosa pine overstory in which the stand was thinned to 100 tpa, with the objective of reducing crown fire hazard. Slosh created by thinning was removed from the stand. Note the change in ladder fuels, canopy continuity, ancl canopy bulk density in the lower image. (Photos from Lassen National Forest.)

Analytical Approach

FFE-FVS links fbrest growth simulation modeling with fire behavior modeling to produce outputs that inform management of forest stands, fuels, and fire. FFE-FVS requires input of forest stand attribute data (species, dbh, and height), although accurate fuels data are helpful. Because FFE-FVS is widely used by resource managers and is regarded as a robust analytical tool, it has high credibility for applications in fuel management.

Scenarios displayed in the *Guide* are intended to represent a range of dry forest types in the western United States, specifically those forests dominated by ponderosa pine (*Pinus ponderosa*), mixed conifer (often including Douglas-fir *[Pseudotsuga menziesii]* as a codominant), and pinyon-juniper

(*Pinus* spp.; *Juniperus* spp.). Stands selected for analysis had high stem densities and had not experienced recent fire or thinning. At least one stand was selected from each biogeographic region for which an FVS variant (growth modeling version developed for specific species and locations) has been developed, with an effort to represent a range of site characteristics. Only stands at relatively low elevations and slopes less than 40% were considered as potential candidates for fuel treatment.

Fuel treatment scenarios are organized by Forest Service regions in the western United States. Data were obtained for ponderosa pine, mixed conifer, and pinyon-juniper in the FSVeg database from national forests in the Northern, Rocky Mountain, Southwestern, Intermountain, Pacific Southwest Region, and Pacific Northwest Regions. These data were converted into FVS-ready files, and model default values were used as initial surface fuel loading. Fuel loadings were assigned based on dominant cover type and percent cover; rules for assigning values vary for different FVS variants.

FFE-FVS allows users to specify loadings for surface fuels, litter, and duff. Twenty-foot wind speed and temperature can be adjusted also. Default live fuel moisture and duff fuel moisture for each variant was used. Moderate (75th percentile highest value) and severe (98th percentile highest value) historical fire weather data from each geographic area were obtained from the USDA Forest Service Predictive Service Division and the Western Regional Climate Center (Desert Research Institute, Reno, Nevada). Remote Automated Weather Stations (RAWS) located in the vicinity of each national forest were identified using geographic information system coverages of federal landownership and latitude/longitude coordinate information of all hourly RAWS data archived at the Western Regional Climate Center. Data used in the climatology percentile calculations were for the period of record between 1985 and 2004.

The FVS is an individual-tree growth-and-yield model for major forest tree species, forest types, and stand conditions (Dixon 2003). An FFE-FVS portfolio was developed for each national forest using the FVS-ready files, historical fire weather data, and default surface fuel loadings. The portfolio was projected 50 years to observe potential fire behavior under moderate and severe weather. A total of 24 candidate stands was selected. Each stand was depicted as a three-dimensional image to observe the horizontal and vertical distribution of stand structure and overstory fuels. For each candidate stand, 13 FFE-FVS key files were developed according to the treatment matrix (Figure 2).

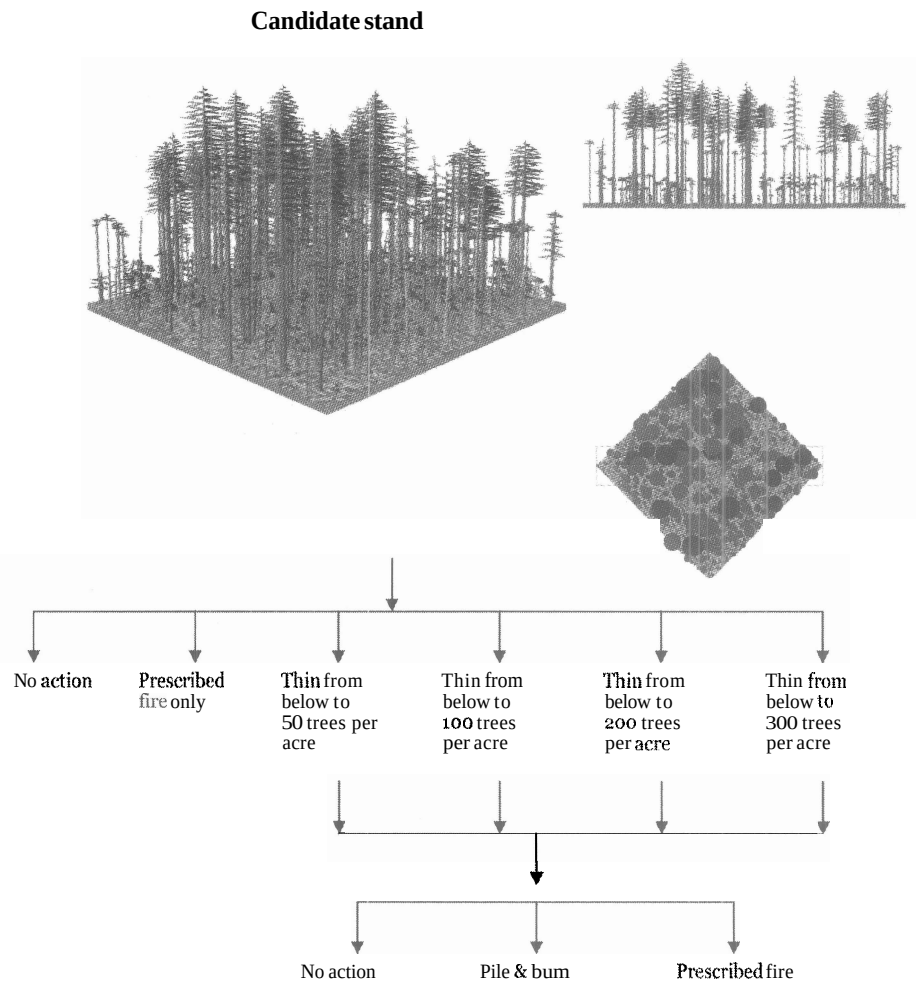

Figure 2. Conceptual diagram of the process used to simulate the effects of fuel treatments for a forest stand in FFE-FVS.

The *Guide* displays treatment effects on stand structure, surface fuel loading, and potential fire behavior. The potential fire behavior report is generated for moderate and severe fire weather scenarios and provides information about expected fire type, flame length, crown fire potential, and tree mortality, given the weather and stand structure conditions.

Limitations of the Analytical Approach

The fire behavior outputs generated by FFE-FVS depend on stylized fuel models (Anderson 1982) rather than actual fuels. When silvicultural treatments are implemented in FFE-FVS, the actual activity fuels or slash created is not used to estimate potential fire behavior. FFE-FVS has the capacity to simulate and track fuel loadings by size class over time, although the model does not use the loadings directly as inputs for calculating fire behavior. Instead, FFE uses the loadings and other stand characteristics to select one or more models from 13 fuel models, each of which represents a range of fuel conditions in which fire behavior may be expected to respond similarly to changes in fuel moisture, wind, and slope. The "dynamic option" in FFE that was used here selects one or more fuel models based on fuel loads and other stand characteristics, calculates fire intensity from each one, and then computes a weighted average flame length by interpolating factors such as fuel loading or canopy cover. This approach provides flame lengths that change more gradually as stand conditions change than those com-

puted from a "static" approach with a single fuel model.

FVS simulates growth and mortality typically using cycles of 10 years, whereas FFE operates on a 1-year cycle. Occasionally, this leads to model behavior that is an artifact of combining the two time steps and is not intended to represent a real phenomenon (Reinhardt and Crookston 2003). Discontinuous behavior is particularly evident in indicators that depend in part on canopy base height — canopy base height itself, torching index, potential tree mortality, and fire type. For example, regeneration often occurs in pulses, and a stand passes a critical point after which vulnerability to torching sharply increases or decreases.

Live fuels (herbaceous plants and shrubs), which can contribute significantly to fire behavior, are not dynamically tracked in FFE-FVS. Their biomass and contribution to fuel consumption are only nominally represented as a fixed amount that depends on percent cover and dominant tree species. In addition, decomposition rates are not sensitive to aspect, elevation, or potential vegetation type in FFE-FVS, although these rates can be controlled by the user.

Fuel Treatment Scenarios and Outputs

Fuel treatment scenarios analyzed in the Guide were determined following extensive feedback from federal resource managers, including beta-tests with two national forests. The scenarios cover a range of potential thinning and surface fuel treatments that would be reasonable and appropriate alternatives for NEPA analysis and similar documentation. They are intended to illustrate representative situations that might be encountered in operational management and planning, not to be comprehensive of all possible treatments.

Silvicultural Options

The following silivicultural options are considered (Figure 2):

- No action.
- Thinning from below to 300 trees per acre (tpa; regeneration = 75 tpa).
- Thinning from below to 200 tpa (regeneration = 75 tpa).
- Thinning from below to 100 tpa (regeneration = 225 tpa).
- Thinning from below to 50 tpa (regeneration = 225 tpa).

Thinning from below (or low thinning) refers to removal of stems starting from smallest to increasingly larger stems until the target density is reached. For all options, no trees larger than 18 in. dbh are allowed to be harvested, to retain larger, more fire-resistant individuals. In reality, this upper dbh limit could be higher or lower. In the scenarios presented here, regeneration of new seedlings is assumed to occur at the aforementioned densities, with relatively more seedlings in the lower density stands.

Thinning from below is the most commonly used approach to modify stand structure, density, and fuels, although other silvicultural approaches are available (Graham et al. 1999). Thinning as used in FVS is applied equally across a given stand. In practice, variable density thinning — a spatial pattern of tree clumps and openings — can be used to achieve the same final tree density and attain greater heterogeneity in stand structure but is not considered here because it cannot be represented in FVS.

Exploratory runs of FFE-FVS indicate that thinning to densities greater than 300 tpa rarely changes fuel conditions enough to modify fire hazard significantly from initial stand conditions. Some managers prefer to use basal area as a target for thinning. This measurement may be more appropriate for even-aged stands with relatively low variability in tree size. Basal area is calculated for each thinning treatment, so both basal area and stem density are available for all scenarios.

Surface Fuel Treatments

The following fuel treatment options are considered for all types of stands (Figure 2):

- No surface fuel treatment.
- Pile and burn.
- Prescribed burning (broadcast).

In practice, techniques used for modification of activity fuels and residual surface fuels vary considerably, as does the effectiveness of those techniques. The options included in the Guide are intended to capture the more common approaches currently used in the field and to represent moderately high effectiveness. In the "prescribed fire only" option for each scenario, regeneration is assumed to not occur, because the large number of dead stems and residual wood on the forest floor after fire preclude growing space for seedlings. Successful use of prescribed fire as the only fuel treatment would be challenging in stands with dense ladder fuels and high loadings of surface fuel.

Using the Guide

Output for each scenario in the *Guide* is organized as follows:

Page 1. Initial stand conditions, including a stand visualization.

Figure 3. Initial stand conditions for a mixed conifer stand with ponderosa pine overstory on the Deschutes National Forest, Oregon. Stand structure and fuel attributes include quadratic mean diameter = 7.0 in., density = 947 tpa, basal area = 252 ft²/ac, canopy cover = 62%, canopy base height = 3 ft, canopy bulk density = 0.13 kg/m³, surface fuels less than 3 in. = 5 tn/ac, total surface fuels = 17 tn/ac. Different crown shapes represent different tree species.

Page 2. Visualizations for four thinning treatments (surface fuel treatments can not be shown in images produced by FVS).

Page 3. Fuel, fire behavior, and fire effects (percent basal area mortality) for all possible combinations of thinning and surface fuel treatments, immediately after treatments.

Pages 4–5. Fuel, fire behavior, and snags for all possible combinations of thinning and surface fuel treatments for 1, 10, 20, 30, 40, and 50 years after treatment (no subsequent treatments during the 50-year period are considered).

Page 6. Fuel, fire, snags, and forest stand attributes for no thinning/no surface fuel treatment versus prescribed fire only for 1, 10, 20, 30, 40, and 50 years after treatments.

Page 7. Forest stand attributes for four treatments for 1, 10, 20, 30, 40, and 50 years after treatments, without surface fuel treatment.

Pages 8–9. (1) Summary of fire behavior fuel models assigned by FFE-FVS for all possible combinations of thinning and surface fuel treatments for 1, 10, 20, 30, 40, and 50 years after treatments; (2) summary of fire weather values used in FFE-FVS simulations for moderate and severe conditions.

Page 10. Narrative describing highlights of FFE-FVS output for different fuel treatment alternatives.

Table 1. Excerpt from data tables in the *Guide* (Johnson et al. 2006), showing sample data on forest structure, fuels, and predicted fire behavior (under severe weather conditions) for the example scenarios in the text.

Stand attributes	Scenario	Years posttreatment				
		10	20	30	40	50
Quadratic mean diameter (in.)	NA	7.4	7.9	8.4	8.9	9.4
	50	14.2	14.5	14.9	15.3	15.7
	100	16.6	17.2	17.8	18.5	19.1
Density (tpa)	NA	865	785	712	647	588
	50	153	150	146	143	140
	100	147	144	139	134	130
Basal area (fflac)	NA	262	268	274	280	285
	50	167	173	178	183	189
	100	221	233	242	250	258
Canopy cover (%)	NA	62	62	61	61	61
	50	36	37	37	38	39
	100	47	48	48	49	49
Canopy base height (ft)	NA	3	4	4	5	5
	50	54	54	51	52	5
	100	35	38	39	39	39
Canopy bulk density (kg/m^3)	NA	0.12	0.13	0.13	0.14	0.15
	50	0.04	0.04	0.04	0.04	0.04
	100	0.09	0.10	0.10	0.11	0.11
Surface fuels less than 3 in. (tnlac)	NA	5	5	5	5	5
	50	2	2	2	2	2
	100	3	3	3	3	3
Total surface fuels (tn/ac)	NA	19	19	22	25	27
	50	7	8	9	9	10
	100	9	11	13	13	13
Flame length (ft)	N.4	3	3	4	4	4
	50	5	5	5	5	5
	100	3	3	3	3	3
Crowning index (milhr)	NA	22	22	21	20	19
	50	51	50	49	49	49
	100	28	26	26	25	25

Data for initial conditions (Figure 3) and thinning scenarios of no action (NA), 50 tpa (50), and 100 tpa (100) (Figure 4) are shown for a 50-yr simulation generated by FFE-FVS.

An Example

The following step-by-step approach is used to illustrate how to interpret output for a specific scenario—a ponderosa pine stand on the Deschutes National Forest (see Figure 3). The management objective is to make the stand as resilient to fire as possible by reducing fuels sufficiently to have minimal crown fire hazard under severe weather conditions. Pile-and-burn surface fuel treatment is used in this example for illustrative purposes, but other options could be available in practice.

Step 1. The Deschutes National Forest is in Region 1 (Oregon), so that section of the Guide should be consulted. The south central Oregon—northeastern California FVS variant was used in the FFE-FVS simulations for this scenario.

Step 2. Stand characteristics are described in Figure 3. Stem density is high (947 tpa) due to fire exclusion, with a dense understory of white fir (Abies concolor) creating ladder fuels into the ponderosa pine overstory. Basal area is relatively high (252 ft^2/ac), indicating potential for timber production and for large trees and snags for wildlife habitat. Surface fuel loadings are very high (15 tn/ac), with high fine fuel (5 tnlac) and very high duff loadings (10 tnlac) typical of a long period of fire exclusion. These conditions are conducive to crown fire, because although predicted flame length is relatively low, canopy base height is low also (Table 1).

Step 3. Thinning to 50 or 100 tpa appears visually to be the only treatments that would reduce ladder fuels sufficiently to reduce crown fire hazard (Figure 4). Canopy base height needs to be raised considerably. Retention of large ponderosa pine helps accomplish this objective and improves fire resilience because this species resists surface and crown fire.

Step 4. From this point on, inferences are derived from the extensive tabular output in the Guide (see Johnson et al. [2006]; excerpts are summarized in Table 1). If fire was to occur in the stand without any treatment, it would likely initiate a crown fire. Thinning to 50 or 100 tpa with pile-and-burn surface fuel treatment confers considerable fire resilience on the stand by increasing canopy base height, decreasing canopy bulk density, decreasing canopy cover, and increasing crowning index. It is highly unlikely that flames could reach the canopy or carry through the canopy of the stands that have been thinned and had surface fuel treatments.

Step 5. We now examine the long-term effects of fuel treatments (Table 1). Surface fuel treatment had a major effect on reducing fine surface fuels and total surface fuels over time, especially for the 50-tpa treatment. The potential for crown fire remains low for approximately 40 years in the 50-tpa treatment, and then increases as surface fuels increase, and canopy base height de-

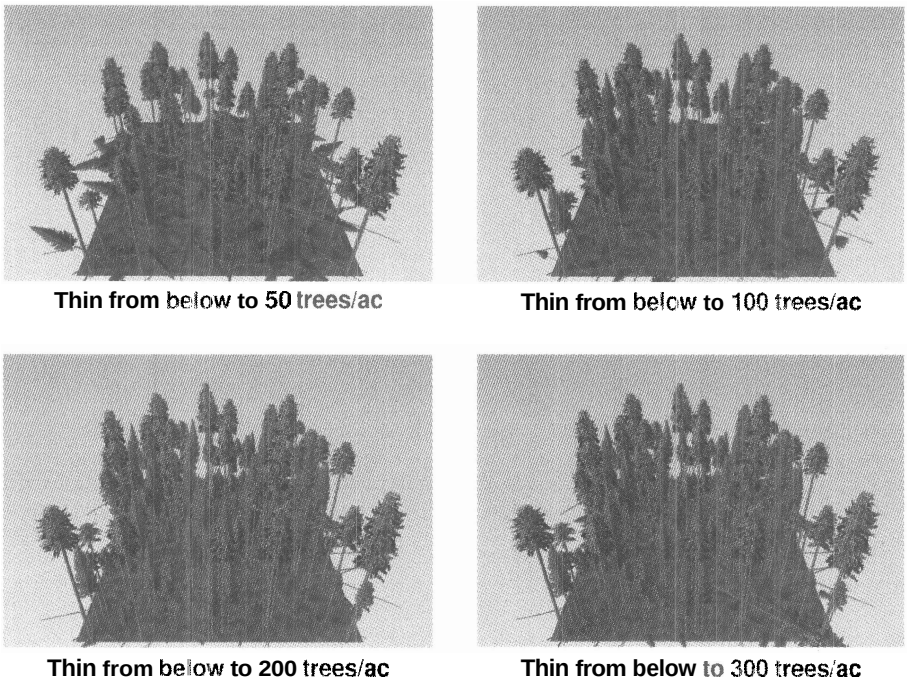

Figure 4. Four thinning scenarios for the stand in Figure 3, using thinning from below with an upper dbh limit of 18 in. Different crown shapes represent different tree species.

creases due to growth of regenerating trees. Thinnings of *50* and *100* tpa appear to have similar long-term effects on fuels and fire, although fuels accumulate more rapidly over time, and canopy bulk density is about twice as high in the 100-tpa thinning. In reality, the accuracy of FFE-FVS at *40+* years is probably much lower than earlier in stand development; so, inferences about later decades should be made cautiously.

Inferences for Planning. Evaluation of the foregoing information indicates that thinning to either *50* or *100* tpa with associated surface fuel treatment probably would meet the objective of reducing crown fire hazard. This reduction will last for about *40–50* years, after which additional fuel treatment may be needed to reduce the risk of crown fire. The 100-tpa thinning has the benefit of more snags and cover, which could benefit certain types of wildlife. As with any fuel treatment, all relevant resources (water, wildlife, recreation, and more) generally are considered in the decisionmaking process.

Conclusions

The *Guide* illustrates how silviculture and fire science can be integrated to provide information that assists planning and decisionmaking about fuel treatments. Because this approach is based on well-established principles and tools, the information is scientifically credible and appropriate for a wide range of documentation. Inferences about fuel treatment alternatives require subjective judgments about preferred options, although interpretations can be recorded and included in appropriate documents.

The scenarios contained in the *Guide* are focused on dry forest stands with high stem densities and fuel accumulations—these are the types of stands for which treatments to reduce fire hazard are most likely to be effective. The FFE-FVS output indicates that in many cases that additional fuel treatment may be necessary at *30+* years after initial treatment, as stem density and fuels increase over time. Subsequent maintenance treatments are likely to be less extreme and less costly. For example, it may be possible at many locations to use prescribed fire as the only treatment to remove fine surface fuels and kill regenerating understory trees.

Managers will likely face situations that require adjustment of treatment strategies suggested in the *Guide*. For example, the data tables might suggest that thinning to *50* tpa is required to minimize fire hazard, but that level of thinning may be unacceptable from a visual perspective. In that case, it will be necessary to use the output for *100* or *200* tpa, perhaps with more frequent surface fuel treatment than prescribed in the *Guide*, to meet both fire hazard and aesthetic objectives. In addition, the *Guide* assumes that fuel treatments are effective at removing fuels, whereas this does not always occur in practice. Therefore, it may be necessary to interpolate the output provided in data tables or to run additional simulations with FFE-FVS to accurately represent local conditions.

The *Guide* by design integrates silviculture and fire management. However, it is best used by an even broader group of interdisciplinary resource specialists (e.g., Peterson et al. [2006]) focused on planning fuels treatments but with an eye toward effects on all resources. Tabular data and visualizations in the *Guide* provide the logic and quantitative guidelines needecl to identify relevant stand conditions and management alternatives for a particular geographic location. The planning team can then start with a common data set based on published scientific information; the process for evaluating the effects of fuel treatments has already been developed, and can be cited as part of the NEPA process. The *Guide* cannot present all possible combinations of conditions and treatments, but because it is based on readily available tools, the planning team can emulate the approach in the *Guide* to develop cases that more accurately represent local conditions and management options. If public input is required, visual images of forest stand structure and treatments can be readily communicated to general audiences in public meetings.

In some cases, scenario output in the *Guide* may appear inaccurate to experienced users. FFE-FVS attempts to mathematically represent the complex interaction of forest growth, fuels, and fire. It is intended to inform decisions, not make decisions, and interpretation of output should be tempered by expert judgment about local resource conditions. It is often prudent to compare the relative magnitude of output between fuel treatment options or between time periods, rather than to compare the actual magnitude of output. Using multiple parameters, rather than a single one, generally is more appropriate for making decisions about the effectiveness of a particular fuel treatment. Identifying patterns and trends of outputs can be more valuable than focusing on individual numbers in the scenario tables.

Literature Cited

ANDERSON, H. 1982. *Aids to determining fuel models for estimating fire behavior*. USDA For. Serv. Gen. Tech. Rep. INT-122. 22 p.

DIXON, G.E. (COMPILER). 2002. *Essential FVS: A user's guide to the Forest Vegetation Simulator*. USDA For. Serv. Internal Rep., Forest Management Service Center, Denver, CO. 193 p.

GRAHAM, R.T., A.E. HARVEY, T.B. JAIN, AND J.R. TONN. 1999. *The effects of thinning and similar stands treatments on fire behavior in western forests*. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-463. Portland, OR. 27 p.

GRAHAM, R.T., S. MCCAFFREY, AND T.B. JAIN. 2004. *Scientific basis for changing forest structure to modify wildfire behavior and severity*. USDA For. Serv. Gen. Tech. Rep. GTR-RMRS-120. Fort Collins, CO. 43 p.

HAZARDOUS FUELS PLANNING WEBSITE. 2007. forest.moscowfsl.wsu.edu/fuels; last accessed Jan. 15, 2007.

JOHNSON, M.C., D.L. PETERSON, AND C.L. RAYMOND. 2006. Guide to fuel treatrnents in dry forests of the western United States. USDA For. Serv. GTR-PNW-686. Portland, OR.

KALABOKIDIS, K.D., AND P.N. OMI. 1998. Reduction of fire hazard through thinning/residue disposal in the urban interface. *Int. J. Wildl. Fire* 8:29–35.

MCCAFFREY, S. AND R.T. GRAHAM. 2007. Science information for informing forest fuel management in dry forests of the western United States. *J. For.* 105(2):73–76.

PETERSON, D.L., M.C. JOHNSON, D. MCKENZIE, J.K. AGEE, T.B. JAIN, AND E.D. REINHARDT. 2005. *Forest structure and fire hazard in dry forests of the western United States*. USDA For. Serv. Gen. Tech. Rep. GTR-I'NW-628. Portland, OR.

PETERSON, D.L., L. EVERS, R.A. GRAVENMIER, AND E. EBERHARDT. 2006. *Analytical and decision support for managing vegetation and fuels: A consumer's guide*. USDA For. Serv. GTR-PNW-690. Portland, OK (in press).

POLLET, J., AND P.N. OMI. 2002. Effect of thinning and prescribed burning on crown fire severity in ponderosa pine forests. *Int. J. Wildl. Fire* 11:1–10.

REINHARDT, E.D., AND N.L. CROOKSTON (TECH. EDS.). 2003. *The Fire and Fuels Extension to the Forest Vegetation Simulator*. USDA For. Serv. Gen. Tech. Rep. GTR-RMRS-116. Ogden, UT. 209 p.

SANDBERG, D.V., R.D. OTTMAR, AND G.H. CUSHON. 2001. Characterizing fuels in the 21st century. *Int. J. Wildl. Fire* 10:381–387.