Estimating Woody Biomass Supply From Thinning Treatments to Reduce Fire Hazard in the U.S. West

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Abstract*—This paper identifies timberland areas in 12 western states where thinning treatments (1) are judged to be needed to reduce fire hazard and (2) may "pay for themselves" at a scale to make investment in forest product processing a realistic option. A web-based tool—Fuel Treatment Evaluator 3.0—is used to select high-fire-hazard timberland plots from the Forest Service Forest Inventory and Analysis Program (FIA) database and provide results of simulated thinning treatments. Areas were identified where either torching or crowning is likely during wildfires when wind speeds are below 25 mph. After additional screens are applied, 24 million acres are deemed eligible for treatment (14 million acres on federal lands). Uneven-aged and even-aged silvicultural treatments analyzed would treat 7.2 to 18.0 million of the 24 million acres, including 0.8 to 1.2 million acres of wildland–urban interface area, and provide 169 to 640 million ovendry tons of woody biomass. About 55 percent of biomass would be from main stem of trees ≥7 inches d.b.h. Sixty to seventy percent of the area to be treated is in California, Idaho, and Montana. Volumes and harvest costs from two treatments on the 14 million acres of eligible federal lands are used as inputs to the fuel treatment market model for U.S. West (FTM–West) discussed in these proceedings.*

Introduction

Fire hazard is unacceptably high on many acres of forest land in the U.S. West. For some of these acres, mechanical treatments are a way to reduce fire hazard. A cohesive strategy is needed for identifying the long-term options and related funding needed to reduce fuels (GAO 2005). Given limited government budgets, one approach is to identify places where the use of woody biomass from thinning can best help pay for hazardous fuel reduction treatments and to use this information to aid in allocating funds for all types of hazardous fuel reduction treatments.

We do not attempt to identify all acres in the U.S. West where removal of woody biomass would improve resilience to undesirable fire effects nor did we set out to demonstrate that if this were done enormous volumes of wood materials could be collected. We focus on areas in surface and mixed-severity fire regime forests, where treatments are needed to reduce fire hazard.

For 12 western states (table 1), we selected timberland acres (land capable of producing 20 ft^3/acre/year and not withdrawn from timber utilization) eligible for treatment (determined in part by fire hazard level), applied several alternative silvicultural treatments to reduce hazard while seeking to maintain ecosystem integrity, and evaluated to what extent revenues from the sale of biomass may offset harvest costs. Full results of our study were reported by

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Table 1—Area treated, by state and treatment scenario (million acres).

State	Treatments for forest types other than spruce–fir and lodgepole: Uneven-aged treatments: High structural diversity: 50% BA removal limit 1A	No BA removal limit 1B	Limited structural diversity: 50% BA removal limit 2A	No BA removal limit 2B	Even-aged treatments: 50% BA removal limit 3A	No BA removal limit 3B	Treatments for spruce-fir and lodgepole, even-aged in WUI area only: 25% BA removal limit 4A	50% BA removal limit 4B
AZ	0.5	0.5	0.4	0.4	0.1	0.1	0.0	0.0
CA	4.4	4.4	3.8	3.8	1.5	1.5	0.0	0.0
CO	1.2	1.3	1.1	1.1	0.4	0.5	0.1	0.1
ID	2.4	2.5	2.2	2.2	1.1	1.1	0.4	0.4
MT	2.9	3.0	2.5	2.6	1.5	1.6	0.0	0.0
NV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NM	0.9	1.0	0.8	0.8	0.3	0.3	0.0	0.0
OR	2.2	2.2	1.8	1.8	0.9	0.9	0.0	0.0
SD	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
UT	0.4	0.4	0.4	0.4	0.2	0.2	0.0	0.0
WA	1.8	1.8	1.5	1.5	0.6	0.6	0.0	0.0
WY	0.3	0.4	0.3	0.3	0.2	0.2	0.0	0.0
Total	17.1	17.5	14.8	15.1	6.7	6.8	0.5	0.5

Skog and others (2006). Results are compared to those from a previous Forest Service assessment (Forest Service 2003).

This evaluation of potential acres to be treated and biomass to be removed is intended to be the first of several evaluation steps:

1. Identify locations across the West where hazardous fuel reduction treatments are needed and that would generate amounts of woody biomass for use that could offset treatment costs.
2. For selected localities in the West, evaluate both current market potential for using wood and prospects for expanding specific markets to use additional wood material.
3. Evaluate the social acceptability of establishing and supporting the infrastructure necessary to use sales of wood as a means for funding fire hazard reduction within the selected areas.

This paper also notes special estimates of biomass supply and treatment costs for two treatments on the 14 million acres of federal lands that are used as inputs to the fuel treatment market model for U.S. West (FTM–West) discussed by Ince and Spelter and by Kramp and Ince in these proceedings. The FTM–West model is used to evaluate the potential impact of increased biomass supply on projected conventional timber supply quantity and timber prices.

The 12 western states have 127 million acres of public and private timberland and 77 million acres of other forest land (Miles 2006a). Although other forest lands have hazardous fuels and wood from treatments that can provide higher value products, the volume and value per acre is very likely to be lower in relation to treatment costs than it is for timberland. Treatments of other forest land may provide an average 7 ovendry tons (odt) of woody biomass per acre (Perlack and others 2005) in the 12 states considered in our study compared with 24 to 34 odt/acre estimated for timberland thinning treatments.

The terms "woody biomass" and "biomass" refer to all wood in all trees—in the main stem, tops, and branches of all sizes of trees. "Merchantable wood" refers to the main stem of all live trees with a diameter at breast height (d.b.h.) ≥5 in., from 1 ft above ground to a minimum 4-inch top diameter outside the bark of the central stem, or to the point where the central stem breaks into limbs and does not include rotten, missing, and from cull.

Methods

Data used were plot-level data from the Forest Inventory and Analysis Program (FIA) of the USDA Forest Service (Smith and others 2004), with additional plot information from the National Forest System (about 37,000 plots in 12 states). The area to be treated and woody biomass to be removed were estimated as if the treatments were to be done within 1 year. In reality, the area treated and amounts removed would extend over many years. Methods were used to simulate treatments on all ownerships, and those results are explained in detail. Methods were also used to simulate treatments on federal land alone, and those results were used to provide biomass amounts and harvest costs to be used in the FTM–West market model.

Screens to Identify Area Eligible for Treatment

Of the 126.7 million acres of timberland in the 12 selected western states (Miles 2006a), 23.9 million acres passed an initial screen and were considered eligible for treatment. A second screen was applied when considering a specific silvicultural treatment, and less than 23.9 million acres actually receive simulated treatment.

Initial Screen—The initial screen was applied to two different groups of forest types: group 1, forest types with surface or mixed-severity fire regimes; and group 2, forest types with high-severity fire regimes. Group 2 includes lodgepole pine and spruce–fir forest types. Group 1 contains all other forest types.

Plots excluded from fire severity group 1 include (a) inventoried roadless areas, (b) counties west of Cascade Mountains in Oregon and Washington, where forests have a long fire return interval, (c) plots with lower fire hazard (both crowning index (CI) and torching index (TI) >25 mph, or CI alone >40 mph). For a map of inventoried roadless areas, see www.roadless.fs.fed.us/maps/usmap2.shtml

Plots excluded from group 2 include (a) all plots outside wildland–urban interface (WUI) areas, (b) inventoried roadless areas, (c) counties west of Cascade Mountains in Oregon and Washington, where forests have a long fire return interval, and (d) plots with lower fire hazard (CI and TI both >25 mph, or CI alone >40 mph).

Selected counties west of the Cascades were excluded because treatments in forests there would be designed to meet objectives other than fire hazard reduction.

Oregon counties excluded were Benton, Clackamas, Clatsop, Columbia, Coos, Curry, Lane, Lincoln, Linn, Marion, Multnomah, Polk, Tillamook, Washington, and Yamhill. Washington counties excluded were Clallam, Clark, Cowlitz, Gray's Harbor, Island, Jefferson, King, Kitsap, Lewis, Mason, Pacific, Peirce, San Juan, Skagit, Snohmish, Thurston, Wahkiakum, and Whatcom.

Of the 126.7 million acres of timberland, 67.5 million acres (53 percent) have lower fire hazard than our criteria. Of the remaining 59.2 million acres, 21.6 million acres (17 percent of all timberland) are in roadless areas or in excluded counties in Oregon and Washington. Of the remaining 37.6 million acres, 13.8 million acres (11 percent of all timberland) are in forest types with high-severity fire regimes, which leaves 23.9 million acres eligible for treatment. In total, our screens removed 81 percent of all timberland and 60 percent of acres with higher fire hazard.

Second Screen—When applying a specific silvicultural treatment, a second screen determined which eligible plots actually receive simulated treatment. Plots were not treated if they would not provide 300 ft^3 of merchantable wood per acre (about 4 odt/acre). Previous studies found that mechanical treatments that produce <300 ft^3 of merchantable wood are unlikely to cover costs of the treatment (Barbour and others 2004, Fight and others 2004).

Fire Hazard Reduction Objectives and Assumptions

Selection of Plots for Treatment—Each FIA plot was assessed for fire hazard by estimating CI and TI (Scott and Reinhardt 2001). Torching index is the 20-ft aboveground wind speed at which crown fire can begin in a specified fire environment; CI is the 20-ft wind speed at which active crown fire behavior is possible (can be sustained) in that environment. Plots were selected for treatment if CI < 25 mph alone or TI < 25 mph and CI < 40 mph (denoted hereafter as CI<25 and TI<25). The focus on crown fires is useful because, although all stands may burn under certain conditions, stands that are likely to burn in crown fires present particular suppression problems, and consequences of crown fires are more severe than those of surface fires. Plots with CI<25 or TI<25 were chosen for treatment because fires might commonly be expected to occur at wind speeds between 15 and 25 mph.

Assumptions for Calculating Torching and Crowning Indexes—Torching and crowning indexes were calculated for each plot based on (a) canopy fuel profile as computed from plot data, (b) slope steepness, (c) selected set of fuel moisture conditions corresponding to "summer drought" conditions (Rothermel 1991), and (d) use of fire behavior fuel model (FM) 9 to represent surface fuels (Anderson 1982).

Fuel model 9 is described as hardwood or long-needle pine litter. It was chosen not because we assume that all surface fuels are hardwood or long-needle pine litter, but because FM 9 results in surface fire behavior mid-range between FM 8 and 10 (other timber litter models) and FM 2 (timber grass model) (personal communication, Paul Langowski, Branch Chief, Fuels and Fire Ecology, USDA Forest Service, Rocky Mountain Region, 2004).

No single fuel model can be expected to adequately represent surface fuels in all timberlands. However, no plot data exist to characterize surface fuels. Assuming more extreme fire behavior, such as FM 10, might lead to recommending thinning where none is really needed, whereas a FM 8, which results in very low-intensity surface fires, may not identify stands at risk of crowning. Fuel model 9 was a compromise.

We also used FM 9 when computing TI and CI after thinning; that is, we assumed that the thinning treatment did not change the surface fuels enough to bump the fuel model into a higher fuel class.

Targets for Crowning and Torching Indexes after Treatment—The fuel hazard reduction objective for each plot was to increase TI and CI to >25 mph or to increase only CI to >40 mph. These objectives are intended either to keep a crown fire from starting or to prevent a crown fire from spreading if crowns are ignited.

Limits on Removal of Basal Area—In some treatment cases, we limited total basal area (BA) removal to keep canopy closure as high as practical. Opening the canopy, while reducing canopy fuels, can lead to different fuel hazard problems: (1) expose surface fuels to solar radiation and wind, which can alter surface fire behavior; (2) increase herbaceous and shrub growth, which may also change surface fire behavior; (3) enhance conifer regeneration, ultimately creating ladder fuels; and (4) increase the risk that remaining trees will be blown down by strong winds.

To the extent that additional objectives call for refinement of our treatments and more removals in local areas, we may be underestimating the amount of area that may be treated with positive average net revenue.

Long-Term Effect of Treatments on Fire Hazard—Forest stands are dynamic, as are forest fuels. The necessary frequency of treatments should be analyzed as part of a much more site-specific planning process, using tools such as FFE–FVS (Reinhardt and Crookston 2003) or fire history studies.

We acknowledge that the fuel hazard reduction treatments described here do not address constraints on land management activities specified in existing land and resource management plans and their potential effects on removals. Nor do these scenarios address the effect on importance of maintaining forest stocking, ground fuels, and other factors that may negatively contribute to CI and TI values on the ecologic health and productivity of forests.

Silvicultural Treatment Objectives and Assumptions—The thinning treatments to reduce fire hazard have an objective to move the stand toward either (1) an uneven-aged condition or (2) an even-aged condition. In addition, the objective of some treatments is to limit BA removed to limit change in stand structure.

Some authors (Graham and others 1999) have suggested that thinning uneven-aged stands in some cases does not reduce fire hazard. We address this concern by designing uneven-aged treatments that take enough trees to be effective in reducing TI, CI, and the risk of crown fire.

Timberland area was divided into forest types that tend to have (1) high-severity fire regimes (where severe fires are routine under natural conditions) and (2) surface or mixed-severity fire regimes. High-severity forest types are excluded from treatments except in WUI areas because severe fires (crown fires) are routine in these forest types under natural conditions, and thinning to avoid severe fire does not support normal fire ecology.

Treatments for Forests with Surface and Mixed-Severity Fire Regimes— Treatments 1A and 1B—uneven-aged, leaving high structural diversity—remove trees so the number of trees remaining in each d.b.h. class after treatment contribute equally toward the numerical value of residual stand density index (SDI) for the stand (Long and Daniel 1990). The final level of overall SDI is adjusted downward by simulated removal of trees across all d.b.h. classes until TI≥25 and CI≥25, or CI≥40. In scenario 1A, removals are limited to 50 percent of initial BA; in 1B, there is no limitation. This scenario results in forest structures that retain high structural diversity with intact understories of small trees.

Restricting removals to <50 percent of the original BA ensures that some semblance of an uneven-aged forest structure is maintained (Alexander and Edminster 1977, Burns 1983).

Treatments 2A and 2B—uneven-aged, limited structural diversity—attempt to achieve TI and CI goals by removing as many small trees as possible while still retaining smaller trees to ensure an uneven-aged structure. The remaining trees in a large d.b.h. class contribute more to the residual stand SDI than do trees in a smaller d.b.h. class.

The level of overall SDI is adjusted downward by simulated removal of trees until the target TI and CI values are reached (treatment 2B) or until 50 percent of the original BA has been removed (treatment 2A).

Treatments 3A and 3B—even-aged, thin from below—emulate intermediate thinning in an even-aged silviculture system where the intent is to ultimately harvest and replace the existing forest. Small trees are completely removed in successively larger d.b.h. classes until CI and TI goals are met (treatment 3B) or until 50 percent of the original BA has been removed (treatment 3A). Thinning more than 50-percent BA may fundamentally alter the character of the forest and should not be prescribed without careful consideration of all potential ecosystem effects.

Treatments for Forests with High Severity Fire Regimes—Treatments 4A and 4B—even-aged, thin from below (spruce–fir and lodgepole pine forest types)—are similar to treatments 3A and 3B, except BA removals are restricted to 25 percent of existing stocking (treatment 4A) or 50 percent of existing stocking (treatment 4B) and *are only in WUI areas.* The 25-percent removal restriction is based on published partial cutting guidelines and is necessary to avoid wind throw in shallow-rooted tree species such as spruce, fir, and lodgepole pine (Alexander 1986a,b).

Harvest Costs and Product Revenue Estimation

The cost to provide biomass ready for transport at the roadside was estimated for each plot using the Fuel Reduction Cost Simulator (FRCS) from My Fuel Treatment Planner (Biesecker and Fight 2006, Fight and others 2006). Cost estimates are made for up to eight harvesting systems, based on the number and average volume of trees in various size categories and the slope of the site. Ground-based harvesting systems include (a) manual-felling log-length system, (b) manual-felling whole-tree (WT) system, (c) mechanized-felling WT system, and (d) cut-to-length (CTL) system. Cable-yarding systems include (a) manual-felling log-length system, (b) manual-felling WT system, (c) manual WT/log-length system, and (d) CTL system.

The cost for the least expensive suitable system was assigned to each plot. We assumed that (1) harvest is only a partial cut, (2) tops and branches are collected for use when the low-cost system brings whole trees to the landing, (3) trees down to 1 inch d.b.h. are removed, (4) average distance that logs are moved from stump to landing is 1,000 ft, (5) average area treated is 100 acres, and (6) distance to move equipment between harvest sites is 30 miles. Costs might be reduced if small d.b.h. trees are not removed from the site and treated by another method (e.g., pile and burn).

We assume the product values and hauling costs used in the 2003 Assessment. Actual prices will vary by location and over time.

Delivered sawlogs (volume from main stem ≥7inches d.b.h.)	$290/10^3$ board feet
Delivered chips (volume from wood and bark <7 inches d.b.h., tops and branches of larger trees)	$30/odt
Haul distance	100 miles
Haul cost (for both sawlogs and chips)	$0.35/odt/mile

The Fuel Treatment Evaluator 3.0 (FTE), a web-based tool available for general use, was used to select areas for treatment, apply treatments to FIA plot data, and generate removal information and maps (Miles 2006b).

Findings

Area Treated and Biomass Removed

The 2003 Assessment identified 96.9 million acres of timberland for possible thinning in fire regime condition classes (FRCCs) 1, 2, and 3, with 28.5 million acres in FRCC 3. The 2003 Assessment selected plots for treatment if timber density, as measured by SDI, was greater than 30 percent of the maximum SDI for the plot forest type.

FRCC refers to the degree to which the current fire regime (including fire recurrence, intensity, severity) is different from the historical pattern, with FRCC 3 having the most divergence (see definitions at http://ncrs2.fs.fed.us/4801/fiadb/fire_tabler_us/rpa_fuel_reduction_treatment_opp.htm).

In contrast, our treatments 3A (all group 1 forest types) and 4A (group 2 forest types in WUI areas) together would treat 7.2 million acres, and treatments 1B and 4B together would treat 18.0 million acres, with 85 percent of acres in FRCCs 2 and 3.

Of the 21.2 million WUI acres identified in 12 western states (Stewart and others 2003), an estimated 4.1 million acres are in timberland. For the high-severity types, 0.5 million acres of WUI were included in treatments 4A or 4B (table 1). For all other forest types, 0.3 to 0.7 million acres of WUI were included in treatments 1A to 3B. So the total WUI area to be treated could be 0.8 to 1.2 million acres, or 20 to 30 percent of the timberland WUI acres. We could be underestimating area to the extent that communities decide to treat larger WUI areas.

Treatment 1B would thin the largest area—17.5 million acres, or about 14 percent of all timberland in the 12 western states. The highest percentage of timberland to be treated would be in California (33 percent), followed by New Mexico (24 percent), Idaho (21 percent), Montana (21 percent), and Arizona (16 percent).

The 2003 Assessment identified total possible removal of 2.1 billion (10^9) odt biomass with treatment of all 94.5 million acres of treatable timberland. Removal from 66.3 million FRCC 2 and FRCC 3 acres could provide 1.5 billion odt of biomass. If only 60 percent of FRCC 3 acres are treated (17.1 million acres), the yield would be 346 million odt of biomass.

In our assessment, we identified 7.2 to 18.0 million acres for treatment that would yield 169 million odt (smallest amount) from treatments 3A and 4A and 640 million odt (largest amount) from treatments 1B and 4B (tables 1 and 2).

The distribution of biomass removed by tree size differs greatly between the uneven-aged and even-aged treatments (table 3). In addition, the distribution for the uneven-aged treatments differs substantially from the results of the uneven-aged treatment used in the 2003 Assessment. The 2003 Assessment showed the most biomass removed from the 10-inch d.b.h. class. In contrast, our uneven-aged treatments provide most biomass in the ≥21-inch d.b.h. classes. Our uneven-aged treatments remove more because residual SDI for our treated stands is <20 percent of maximum SDI, compared with 30 percent of maximum in the 2003 Assessment. Thinning to an average 20 percent of maximum SDI is needed in our assessment to thin to achieve CI>40 when we cannot attain TI>25. We could help attain TI>25 rather than having to reach CI>40 by pruning branches to raise canopy base height and by decreasing surface fuels.

In our assessment, the proportion of all acres treated and biomass removed that comes from National Forest or all Federal land is about 55 or 60 percent, respectively, for both even-aged and uneven-aged treatments.

Fire Hazard Reduction Outcomes

Four possible fire hazard reduction outcomes were identified for the 23.9 million acres eligible for treatment:

1. Treatment is applied; both CI>25 and TI>25.
2. Treatment is applied; CI>40.
3. Treatment is applied; 50-percent BA removal limit is achieved before achieving either (1) or (2).
4. No treatment is applied; <300 ft^3 of merchantable wood could be removed.

Uneven-aged treatments with the 50-percent BA removal limit (1A and 2A) treat 71 and 61 percent of eligible acres, respectively. These treatments reach the medium or high hazard reduction goal for 44 and 30 percent of eligible

Table 2—Initial standing biomass and biomass removals from this assessment (million ovendry tons).

		Treatments for forest types other than spruce–fir and lodgepole						Treatments for spruce-fir and lodgepole, even-aged in WUI area only	
		Uneven-aged treatments							
		High structural diversity		Limited structural diversity		Even-aged treatments			
State	Initial volume on treatable timberland	50% BA removal limit 1A	No BA removal limit 1B	50% BA removal limit 2A	No BA removal limit 2B	50% BA removal limit 3A	No BA removal limit 3B	25% BA removal limit 4A	50% BA removal limit 4B
	million acres								
AZ	29.5	11.0	13.1	8.9	9.9	2.3	2.6	0.1	0.1
CA	419.2	219.5	222.4	144.8	145.2	37.4	40.1	0.2	0.3
CO	49.3	20.6	28.4	17.4	21.8	6.0	7.5	0.8	1.4
ID	171.4	68.1	83.1	57.7	63.4	26.6	29.4	6.4	10.5
MT	166.7	66.8	84.4	58.9	69.2	36.5	41.9	0.1	0.2
NV	0.9	0.3	0.3	0.2	0.2	0.1	0.1	0.0	0.0
NM	41.9	18.3	24.1	15.0	18.4	5.5	6.3	0.0	0.0
OR	210.4	76.8	88.7	53.9	56.2	25.5	26.3	0.0	0.0
SD	3.9	1.3	1.4	1.1	1.1	0.3	0.3	0.0	0.0
UT	18.2	7.5	9.8	6.9	8.0	2.9	3.2	0.0	0.1
WA	128.7	50.0	60.9	38.8	42.4	14.9	15.4	0.0	0.0
WY	17.7	7.5	10.3	7.3	8.9	3.6	4.5	0.1	0.2
Total	1,257.7	547.8	626.8	410.8	444.7	161.6	177.5	7.6	12.8

Table 3—Biomass removal by treatment and tree d.b.h. class (tons per acre).

	Treatments for forest types other than spruce–fir and lodgepole						Treatments for spruce-fir and lodgepole, even-aged in WUI area only	
	Uneven-aged treatments				Even-aged treatments			
	High structural diversity		Limited structural diversity					
d.b.h. class	50% BA removal limit 1A	No BA removal limit 1B	50% BA removal limit 2A	No BA removal limit 2B	50% BA removal limit 3A	No BA removal limit 3B	25% BA removal limit 4A	50% BA removal limit 4B
(in.)								
2.0	0.4	0.5	0.5	0.6	0.8	0.9	0.4	0.5
4.0	1.2	1.5	1.5	1.7	2.2	2.4	1.5	2.2
6.0	2.1	2.4	2.8	3.0	4.9	5.1	4.9	5.4
8.0	2.9	3.3	3.6	3.8	6.2	6.5	4.8	6.6
10.0	3.1	3.6	3.6		2.5	2.8	0.7	2.1
14.0	2.5	2.8	2.2	2.4	1.2	1.4	0.4	0.9
16.0	1.9	2.2	1.5	1.6	0.6	0.8	0.4	0.8
18.0	1.4	1.7	0.9	1.0	0.4	0.5	0.0	0.2
20.0	1.0	1.2	0.4	0.5	0.3	0.3	0.0	0.0
22+	12.5	13.2	7.6	7.7	0.7	0.6	0.0	0.0
Total	32.0	35.8	27.7	29.5	24.2	26.0	16.6	24.5

acres, respectively (table 4). When the BA limit is removed (1B and 2B), a slightly greater percentage of acres is treated (72 and 62 percent, respecively), all reach a hazard reduction target, and biomass removal increases 14 percent (548 to 627 million odt) and 8 percent, respectively.

The even-aged treatment with the 50-percent BA removal limit (3A) treats 28 percent of all eligible acres but reaches the medium or high hazard reduction goal for only 7 percent of the eligible acres (table 4). When the 50-percent limit is removed (3B), 28 percent of acres are treated and all these treated acres reach the medium or high hazard reduction goal. Moving from treatment 3A to 3B requires a 10-percent increase in biomass removals, which includes the biomass from the additional 1 percent of acres treated.

In general terms, for forest area where there is the need to obtain a minimum level of merchantable wood to yield positive average net revenue and a restriction on BA removal, our results suggest that the uneven-aged treatment would more likely achieve one of the hazard reduction targets than would an even-aged treatment—in our example, 44 percent or 30 percent, compared with 7 percent.

If raising TI is a priority, then even-aged treatments are more effective than uneven-aged treatments. However, even-aged treatments are less likely to produce 300 ft^3 of merchantable wood and provide positive net revenue from sale of products.

Treatment Costs, Product Revenues, Net Revenues

Average treatment costs per acre for even-aged treatments are about the same as for uneven-aged treatments for the acres selected for each treatment, though fewer acres are selected for even-aged treatments because fewer acres are able to provide 300 ft^3/acre.

Table 4—Fire Hazard outcomes (percentage of treatable acres).

	Goal attainment						
Treatment	Low (50% BA limit is reached) (treatment is made but BA limit is reached)	Medium CI>40 only	High CCI&TI >25	Total achieving a medium or high target	Total receiving some treatment	Not treated (provides less than 300 ft^3 merchantable wood/acre)	Total
1A	28	21	22	44	71	29	100
2A	31	18	12	30	61	39	100
3A	21	4	3	7	28	72	100
1B	0	23	49	72	72	28	100
2B	0	14	48	62	62	38	100
3B	0	6	22	28	28	72	100

Average net revenues per acre are positive without subsidy for all treatments on gentle slopes and for uneven-aged treatments 1A, 1B, and 2B on steep slopes (table 5). With a $20/green ton subsidy for chips, average net revenues per acre are also positive for uneven-aged treatments 2A and for even-aged treatment 3B on steep slopes. Even with a subsidy, even-aged treatment 3A on steep slopes incurs a net cost per acre. With the subsidy, we could relax the 300-ft^3 merchantable wood requirement for all treatments on gentle slopes and still attain positive average net revenue.

Treatment Costs—The estimated cost to harvest and move biomass to the roadside is less than $1,000/acre for about 50 percent of acres treated for all treatments except treatment 4A, for which estimated costs are lower. Acres on gentle slopes (≤40 percent) tend to cost less, and acres on steep slopes (>40 percent) cost more.

Even though the even-aged treatments call for more trees to be harvested per acre on average, harvesting cost per acre is lower than or about the same as for uneven-aged treatments, which harvest fewer trees. This may be explained in part by the fact that we selected the lowest cost harvesting system for each plot analyzed. Costs for even-aged treatments would also be kept low by the requirement to provide a certain volume in larger trees to provide 300 ft^3/acre.

Biomass Revenues—The estimated delivered value of biomass per acre varies from $1,600 to $,2600, excluding treatments 4A and 4B, if the main stem volume of trees ≥7 in. d.b.h. goes to higher value products and the remainder is delivered as fuel chips. If all volume goes for chips, the delivered value varies from $430 to $640/acre.

For uneven-aged treatments 1A and 1B, about 67 percent of biomass is merchantable wood from trees ≥7 in. d.b.h. For even-aged treatments 3A and 3B, about 50 percent of biomass is merchantable wood from trees ≥7 in. d.b.h. Also, biomass removed per acre is greater for treatments 1A and 1B than for treatments 3A and 3B. As a result, if merchantable wood goes to higher value products, the revenue from the uneven-aged treatments 1A and 1B is $800 to $1,200/acre more than for even-aged treatments 3A and 3B. If all wood goes for chips, treatments 1A and 1B provide only $50 to $100 more per acre than do treatments 3A and 3B.

Table 5—Estimated treatment costs, and revenuesa minus fuel treatment costs when larger diameter logs are sold for higher value products or for chips.

	Average treatment cost ($/acre)		Net revenue (cost) with merchantable wood used for higher value products ($/acre)		Net revenue (cost) with merchantable wood used for chips ($/acre)		Net revenue (cost) with merchantable wood used for higher value products and chips given a subsidy of $20 per green ton ($/acre)	
Treatment	Slope ≤40%	Slope >40%	Slope ≤40%	Slope >40%	Slope ≤40%	Slope >40%	Slope ≤40%	Slope >40%
1A	903	1,774	619	(256)	(1,064)	(1,933)	1,039	163
2A	844	1,831	343	(453)	(978)	(1,867)	757	(32)
3A	854	1,966	(112)	(833)	(973)	(1,882)	391	(368)
4A	692	1,811	(144)	(726)	(766)	(1,550)	202	(478)
1B	986	1,839	686	(9)	(1,161)	(1,917)	1,159	479
2B	882	1864	356	(120)	(1,023)	(1,909)	798	114
3B	902	1975	(86)	(762)	(1,024)	(1,892)	441	(255)
4B	952	1,822	(18)	(266)	(1,073)	(1,615)	421	36

[a] Product value assumptions: delivered sawlog value, $290/mbf; delivered chip value, $30/od ton; transport cost, $0.35/od ton; haul distance, 100 miles.

Net Revenue (Costs) from Treatments—Average net revenue from uneven-aged treatments is positive for gentle slopes ($340 to $690/acre) and negative for steep slopes (–$9 to –$450/acre). Average net revenue for even-aged treatments is $400 to $700 less than that for uneven-aged treatments in the same slope category (table 5). Net revenues for treatments on steep slopes are least negative for uneven-aged treatments 1B and 2B (–$9 and –$120/acre, respectively).

In comparison to the uneven-aged treatment analyzed in the 2003 Assessment, our uneven-aged treatments (1A, 1B, 2A, 2B) provide about the same net revenue per acre for sites with gentle slopes ($350 to $700/acre). For steep slopes, however, our net revenue per acre is about $700 less and negative, whereas the estimates from the 2003 Assessment are positive. This difference could be due to the difference in plots selected.

If a subsidy of $20/green ton is provided for chips delivered to a mill, then the net revenue is positive for all treatments on gentle slopes and uneven-aged treatments 1A, 1B, and 2B (table 5). For these treatments and revenues, we could relax the requirement for 300 ft^3/acre and treat more acres.

Biomass Removal Maps—Areas where biomass removal from thinning on timberland is most likely to provide net revenues per acre include northern California, northern and central Idaho, western Montana, central and northern Oregon, and Washington. Smaller acreages include central to southern Colorado, central/east Arizona, and northern New Mexico. The timberland in WUI areas receiving simulated treatment is found primarily in northern California, northern Idaho, western Montana, western Washington, and central Colorado (figs. 1 and 2).

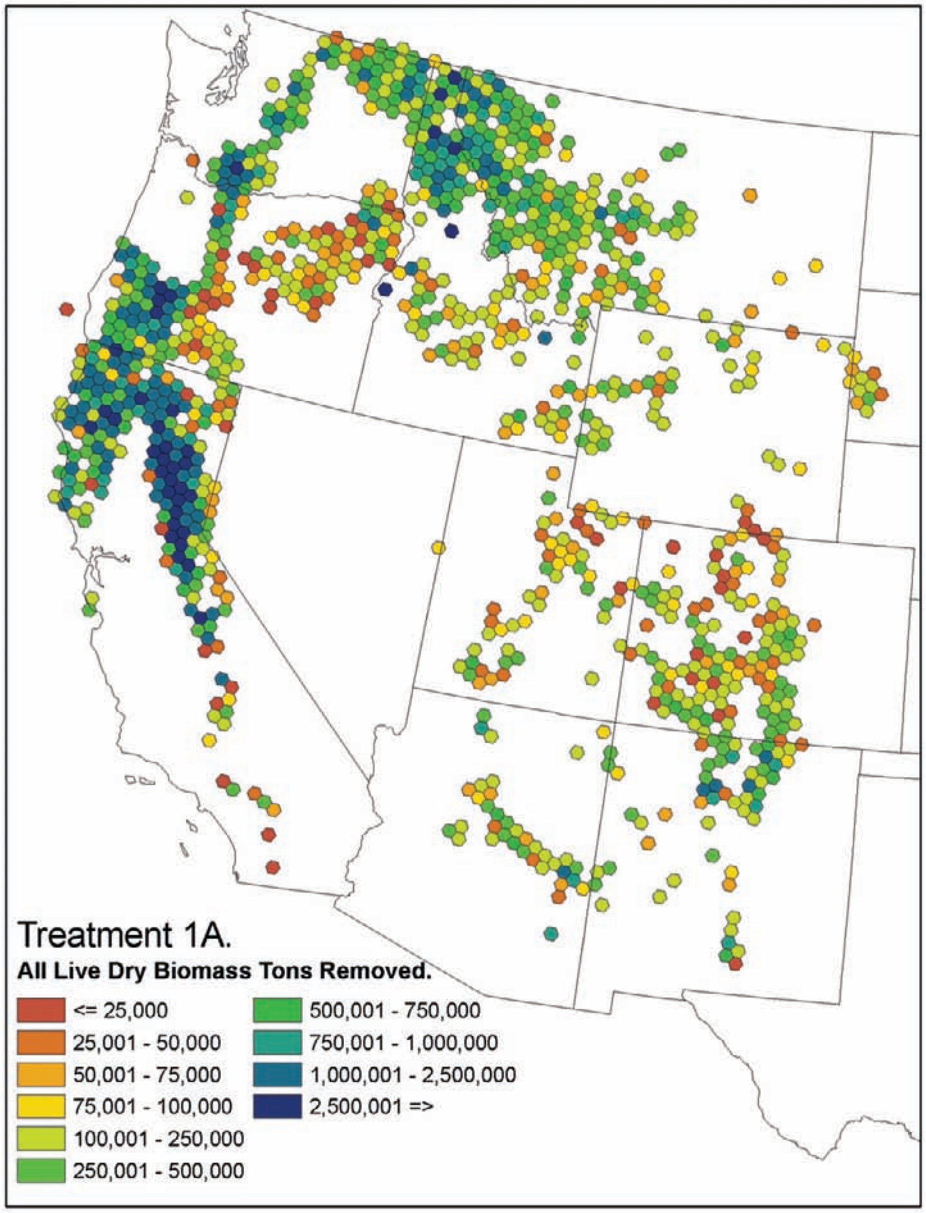

Figure 1—Total biomass removed per 160,000-acre area for uneven-aged treatment 1A (tons).

Estimates of Biomass Removed and Harvest Costs Used in the FTM–West Model

Two sets of treatments were applied to the 14 million acres of federal timberland judged eligible for treatment. These are treatments 1A and 4A and treatments 3A and 4A. Volumes and harvest costs from these treatments are used as inputs to the FTM–West market model described by Ince and Spelter and by Kramp and Ince in these proceedings. Unevenaged treatments 1A and 4A combined (SDI treatment) treat 10.9 million acres and provide 347 million tons (23.2 billion ft^3) at an average cost of $1,531/acre ($0.719/ft^3). Even-aged treatments 3A and 4A combined (TFB treatment) treat 5.6 million acres and provide 148 million tons (9.9 billion ft^3) at an average cost of $1,420/acre ($0.807/ft^3).

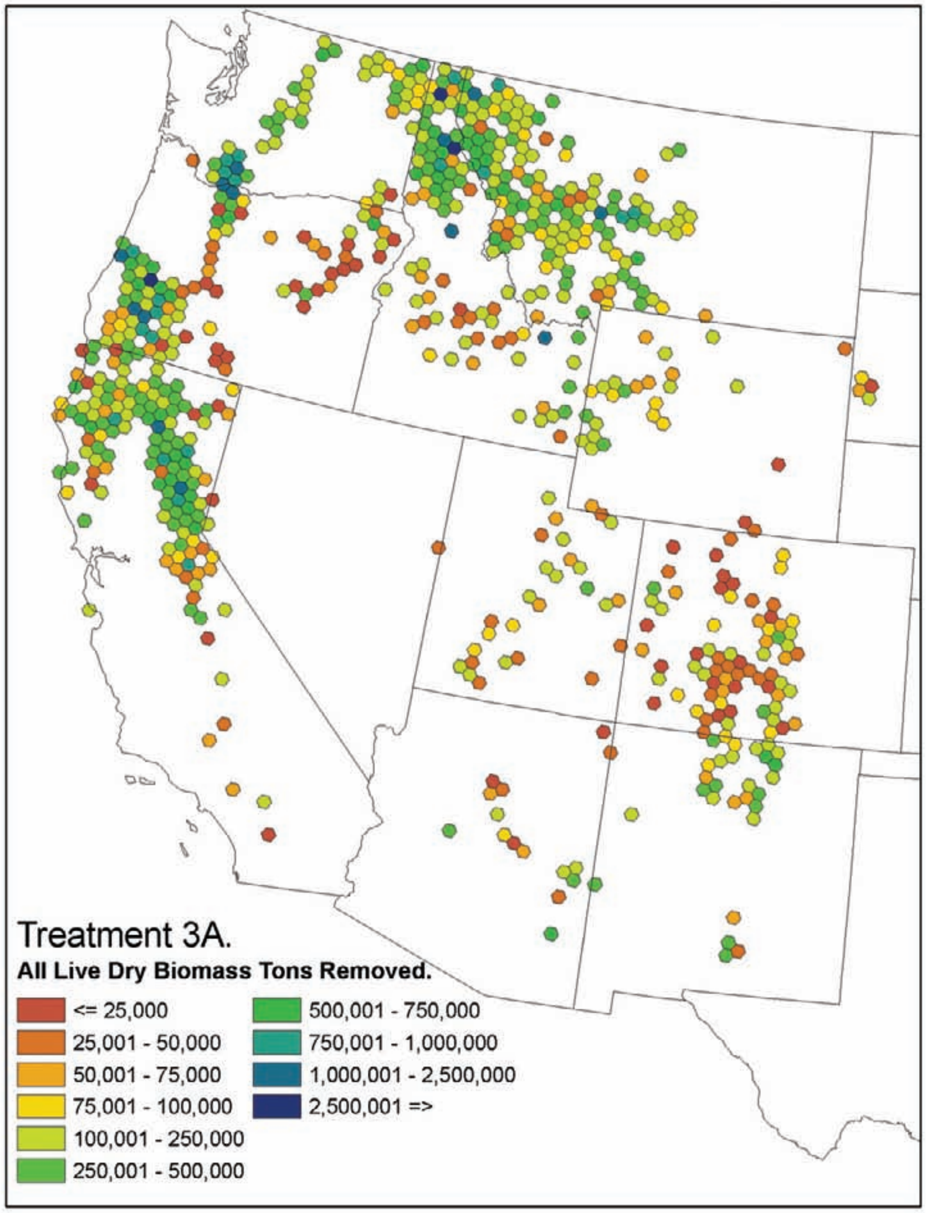

Figure 2—Total biomass removed per 160,000-acre area for even-aged treatment 3A (tons).

Summary

The proportion of the 23.9 million eligible acres that can be thinned and provide positive net revenue from the sale of biomass products varies substantially, depending on whether an even- or uneven-aged silvicultural treatment is used and whether removals are limited or not limited to taking 50 percent of initial BA.

Under our assumptions, uneven-aged treatments will be able to treat a higher proportion of acres with resulting positive net revenue than will even-aged treatments. Moreover, for treated acres, if BA removal is limited to 50 percent limit, then uneven-aged treatments are more likely to attain one of our hazard reduction targets (CI>25 and TI>25, or TI>40) than are the even-aged treatments.

Both uneven-aged and even-aged treatments are able to meet hazard reduction targets on all acres if we remove the BA removal limits and the requirement to provide 300 ft^3/acre of merchantable wood. But the hazard reduction benefit of removing the BA limit may be limited or offset by the effect of a more open canopy and more greatly altered stand structure. The data on costs and revenues suggest that if uneven-aged treatments were used everywhere, revenues could cover a notably higher proportion of costs than if even-aged treatments were used everywhere.

If we assume a $20/green ton subsidy for chips, average revenue is positive for all treatments on gentle slopes and increases the most for even-aged treatments (about $500/acre) because they provide the most chips. Revenue for uneven-aged treatments increases about $410/acre.

The eligible acres and treated acres are predominately in California, Idaho, and Montana, which include 65 to 70 percent of the treated acres for both uneven-aged and even-aged treatments. There are an estimated 21.2 million acres of WUI area in the 12 western states studied, of which an estimated 4.1 million acres is timberland. Treatments would cover 20 to 30 percent of this timberland

Given the concern about removing large trees by uneven-aged thinning, it may be possible to reduce large tree harvest by pruning or reducing surface fuels to increase torching index rather than thinning to reach a high crowning index. Supplementary treatments are likely to increase harvest costs and decrease net revenue per acre.

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References

Alexander, R.R. 1986a. Silvicultural systems and cutting methods for old-growth Spruce–fir forests in the Central Rocky Mountains. Gen. Tech. Rep. RM-126. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO. 33 p.

Alexander, R.R. 1986b. Silvicultural systems and cutting methods for old-growth lodgepole pine forests in the Central Rocky Mountains. Gen.Tech. Rep. RM-127. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO. 31 p.

Alexander, R.R.; Edminster, C.B. 1977. Uneven-aged management of old-growth spruce–fir forests: Cutting methods and stand structure goals for the initial entry. Res. Pap. RM-186. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO. 12 p.

Anderson, H.E. 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. www.fs.fed.us/rm/pubs_int/int_gtr122.pdf

Barbour, R.J.; Fight, R.D.; Christensen, G.A.; Pinjuv, G.L.; Nagubadi, R.V. 2004. Thinning and prescribed fire and projected trends in wood product potential, financial return, and fire hazard in Montana. Gen. Tech. Rep. PNW-GTR-606. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Biesecker, R.L.; Fight, R.D. 2006. My fuel treatment planner: A users guide. Gen. Tech. Rep. PNW-GTR-663. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR. 31 p. www.fs.fed.us/pnw/data/myftp/myftp_home.htm

Burns, R.M. 1983. Silvicultural systems for the major forest types of the United States. Agric. Hdbk. 445. U.S. Department of Agriculture, Forest Service, Washington, DC. 191 p.

Fight, R.D.; Barbour, R.J.; Christensen, G.A.; Pinjuv, G.L.; Nagubadi, R.V. 2004 Thinning and prescribed fire and projected trends in wood product potential, financial return, and fire hazard in New Mexico. Gen. Tech. Rep. PNW-GTR-605. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR. 48 p.

Fight; R.D.; Hartsough, B.R.; Noordijk, P. 2006. Users guide for FRCS: Fuel reduction cost simulator software. Gen. Tech. Rep. PNW-GTR-668. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR. 23 p.

Forest Service. 2003. A strategic assessment of forest biomass and fuel reduction treatments in western states. U.S. Department of Agriculture, Forest Service, Washington, DC. www.fs.fed.us/research/pdf/Western_final.pdf

GAO. 2005. Wildland fire management—Important progress has been made, but challenges remain to completing a cohesive strategy. GAO-05-147. January. U.S. Government Accounting Office, Washington, DC. 32 p.

Graham, R.T.; Harvey, A.E.; Jain, T.B.; Tonn, J.R. 1999. The effects of thinning and similar stand treatments on fire behavior in western forests. Gen. Tech. Rep. PNW-GTR-463. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station Portland, OR. 27 p.

Long, J.N.; Daniel, T.W. 1990. Assessment of growing stock in uneven-aged stands. West. J. Applied For. 5(3):93–96.

Miles, P.D. 2006a. RPA 2002 Tabler/Mapmaker, Version 1.0. U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN. Feb. 6, 2006. http://ncrs2.fs.fed.us/4801/fiadb/rpa_tabler/webclass_rpa_tabler.asp

Miles, P.D. 2006b. Fuel Treatment Evaluator 3.0. U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN. January 2006. http://ncrs2.fs.fed.us/4801/fiadb/fire_tabler_us/rpa_fuel_reduction_treatment_opp.htm http://www.ncrs2.fs.fed.us/4801/fiadb/FTE_Version3/WC_FTE_version3.asp

Perlack, R.D.; Wright, L.L.; Turhollow, A.F.; Graham, R.L.; Stokes, B.J.; Erbach, D.C. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion ton supply. Oak Ridge National Laboratory, Oak Ridge, TN. 60 p. http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf

Reinhardt, E.D.; Crookston, N.L. (eds). 2003. The fire and fuels extension to the forest vegetation simulator. Gen. Tech. Rep. RMRS-GTR-116. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Rothermel, R.C. 1991. Predicting behavior and size of crown fires in the Northern Rocky Mountains. Res. Pap. INT-438. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Scott, J.H.; Reinhardt, E.D. 2001. Assessing crown fire potential by linking models of surface and crown fire behavior. Res. Pap. RMRS-RP-29. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Skog, K.E.; Barbour, R.J.; Abt, K.; Bilek, E.T.; Burch, F.; Fight, R.D.; Hugget, B.; Miles, P.; Reinhardt, E.; Shepperd, W. 2006. Evaluation of silvicultural treatmentments and biomass use for reducing fire hazard in western states. Res. Pap. FPL-RP-634. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI. 29 p.

Smith, W.B.; Miles, P.D.; Visage, J.S.; Pugh, S.A. 2004. Forest resources of the United States. Gen.Tech. Rep. NC-241. U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN. 137 p.

Stewart, S.I.; Radeloff, V.C.; Hammer, R.B. 2003. Characteristics and location of the wildland–urban interface in the United States. In: Proceedings, 2nd International Wildland Fire Ecology and Fire Management Congress, Orlando, FL, November 19, 2003. http://silvis.forest.wisc.edu/Publications/PDFs/Stewart_etal_2003.pdf http://silvis.forest.wisc.edu/Library/Stats/uswuistats.pdf