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ScienceDirect
Forest Policy and Economics 10 (2008) 373 – 385
Forest Policy and Economics
www.elsevier.com/locate/forpol

Timber product output implications of a program of mechanical fuel treatments applied on public timberland in the Western United States

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Abstract

This study reports the results from a 5 year simulation of forest thinning intended to reduce fire hazard on publicly managed lands in the western United States. A state simulation model of interrelated timber markets was used to evaluate the timber product outputs. Approximately 84 million acres (34 million hectares), or 66% of total timberland in the western United States, is publicly managed; of this 78 million acres (31.6 million hectares) are managed by the federal agencies. We considered three budget scenarios using a least-expensive highest-hazard area first policy. Our intention with this simulation is not to definitively answer questions about where or how to conduct treatments to reduce fire hazard on public lands but rather to begin to develop tools that can be used to inform such a policy debate. Considerable development of this tool is still needed before it will be useful for that purpose. Our initial simulations nonetheless provide insight into what might happen if available funds were allocated to the least-expensive highest-hazard areas across the west. Using assumptions of (1) an annual "subsidy" (payments for treatments), (2) the treatment costs, (3) the priority ranking by forest type, (4) fire hazard level, and (5) the wildland–urban interface (WUI) status, the simulation suggests that lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), spruce (*Picea* spp.)–fir (*Abies* spp.) and Douglas-fir (*Pseudotsuga menziesii*) are projected to be major forest types treated in the West. A combination of our treatment ranking assumptions and the low total treatable WUI acres on public timberland caused the model to concentrate almost exclusively on all the WUI stands and non-WUI ponderosa pine forest type at the budget of $150 million and $300 million. With the further increase of budget, a large proportion of treated acres are lodgepole pine and spruce–fir forest types using the thin-from-below approach. About 41% of the volume removals are sawtimber for all the public timberland treated under the low budget scenario ($150 million/year), 58 for moderate budget ($300 million/year), 50 for the high budget scenario ($1500 million/year). Under the moderate budget case ($300 million a year), about 19% of the total wood removed is projected to come from trees less than 5-inches (12.7 cm) in diameter at breast height (dbh), and another 16% of the biomass is expected from trees 20-inches (50.8 cm) dbh and above.
Published by Elsevier B.V.

Keywords: Timber product; Fuel treatment; Timberland; Biomass; Modeling; Fire hazard; Wildfire

1. Introduction

Land managers and the American public have become aware that the vegetative conditions of some forests in the United States make them subject to larger, more severe wildfires than was the case in the past (Hann et al., 1997). The central reason for this is the apparent long run accumulation of "fuels", i.e., flammable plant materials, including trees of various sizes (Peterson et al., 2005) that contribute to the ignition and burning of forest stands. This has occurred because of past forest practices such as fire suppression and livestock grazing (Parsons and DeBenedetti, 1979; Bonnicksen and Stone, 1982; Parker 1984; Chang, 1996; Hann et al., 1997; Covington et al., 1997; Fule et al., 1997). Fire managers and policy makers have therefore concluded that the buildup of forest fuels demands attention, including development of strategic planning tools to evaluate the fuel conditions at a variety of spatial scales and consider alternate fire hazard reduction scenarios (Western Governor's Association, 2001; Healthy Forest Restoration Act of 2003).

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1389-9341/$ - see front matter. Published by Elsevier B.V.
doi:10.1016/j.forpol.2008.01.002

In practice, forest managers have relatively few options for reducing forest fuels. The most frequently used include: prescribed fire, mastication or mowing (basically grinding or chopping small trees and surface fuels and leaving the residue in place), and removal of wood from the forest (Fight and Barbour, 2005). Prescribed fire is by far the most common method used on federally administered land in the United States (Rey and Scarlett, 2004). A drawback to even wider use of prescribed fire is that fuel loads are frequently so high prescribed fire is difficult to control. In these situations some form of mechanical fuel treatment is often used as a way to prepare the stand for prescribed fire or wildland fire use (allowing naturally occurring fires to burn as long as they accomplish predetermined management goals). Significant barriers exist in the widespread application of mechanical fuel treatments and cost is a major factor limiting their use (Fight and Barbour, 2005). Thinning has, however, received much attention because it is the only method with the potential to generate revenues that could partially or wholly offset the costs of fire hazard reduction programs. Several studies have shown that significant timber volumes could derive from a western U.S. fuel treatment program (USDA FS, 2005; U.S. Department of Energy and U.S. Department of Agriculture, 2005; Skog et al., 2006) and that these treatments can have net timber market benefits (Abt and Prestemon, 2006). This study provides detail on the kinds of raw materials that could derive from a program designed to allocate the budget available for thinning to reduce fire hazard in some very simple ways across the western United States. Developing techniques to evaluate different policies for allocating federally appropriated funds could provide important information for public land managers, policy makers, and potential buyers of woody materials removed during fire hazard reduction treatments who need to understand how such products would integrate into local markets.

The objective of this study is to examine how mechanical fuel treatment programs of differing sizes applied on publicly administered lands in the western United States would affect timber product outputs. The report is based on a simulation model that contains assumptions regarding the types of silvicultural treatments that might be used to reduce wildfire hazard at the stand scale, the way federal resources might be allocated, and the financial costs of implementing treatments. The model assumes that all revenues derived from the sale of wood removed during treatments are returned to the U.S. Treasury, as occurs with conventional timber sales on federally administered lands today. Other contracting authorities are available to federal land management agencies and use of these could greatly alter the results by allowing reinvestment of revenues from the sale of timber to fund additional treatments. We chose not to model these funding authorities to keep our analysis focused on the question of how different levels of subsidy alter the amounts and types of wood removed during fire hazard reduction treatments. The way stand scale treatments are distributed across the landscape could also influence the effectiveness of treatments (Finney, 2003). Using techniques proposed by Finney (2005) could greatly reduce the cost of broad scale treatments but as yet they remain theoretical and have not been implemented at an operational scale.

Our approach is to model different levels of subsidy by allocating resources to the areas with the highest-hazard and lowest treatment cost but with no geographic stratification of funding beyond the 12 western States. The 12 western states included in this study are: Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, South Dakota, Utah, Washington and Wyoming. This is not the way federal fire hazard reduction funds are actually allocated but it does provide us with an understanding of how a very simple policy, concentrated in the part of the country that consumes the majority of wildfire suppression spending today, will perform. In future iterations, we intend to add the ability to allocate funds to finer scales, e.g., Forest Service Regions, National Forests, Bureau of Land Management (BLM) State Offices, BLM Districts, etc. We also intend to include the ability to reinvest the funds gained by selling timber into additional fire hazard fuel reduction treatments.

Using the current model we display the diameter distributions of treated biomass by State, forest type and the major tree species. This information creates a picture of the types of material that would be removed during fire hazard reduction treatments. It will inform general discussions about how such material could be used and, therefore, the ease with which federal agencies will dispose of wood removed during fire hazard reduction treatments. We also provide mapped information about the area treated and the amount of material removed under each of our simulated policies. As techniques to refine this information are perfected, they will provide state, county, and local officials with an idea of the amount and type of material that could become available in their areas. This will help them to understand what sorts of proposals to establish wood processing facilities they should support.

2. Methods

The simulation model underlying the analysis is one developed by Prestemon et al. (2006). It is a two-stage model of fuel treatments and global timber markets, and seeks to maximize treated area by hazard level using linear goal program in the first stage. The second stage is a spatial equilibrium model that maximizes social net welfare (Samuelson, 1952; Takayama and Judge, 1964) in domestic and international timber markets subject to the area treated in the first stage. The model can be run for a single year or for as many years as desired. One version of this model was reported by Abt and Prestemon (2006), but the one reported by Prestemon et al. (2006) differs in many ways (these include the type of mechanical fuel treatment applied, based on the pre- and post-treatment torching and crowning indices; and the ability to apply the program over many decades and progressively treat risky landscapes). The outputs of this model are: (1) A listing of locations and types of forests treated by state, ownership, wildland–urban interface status, forest type, and wildfire hazard level; and (2) The timber market consequences of the chosen treated locations. The model treats landscapes in either the South, the West, or both.

The model's basic unit of observation is the forest stand, which permits an evaluation of how alternative programs might

Table 1
Major forest type rankings for fuel treatment priority in western states (rank 1 to 10 from high to low priority, based on expert opinion)

Forest Type	AZ	CA	CO	ID	MT	NM	NV	OR	SD	UT	WA	WY
Ponderosa pine	1	1	1	1	1	1	1	1	1	1	1	1
Lodgepole pine		2	2	3	3		2	3		2	3	2
Douglas-fir	2	5	3	6	6	2	3	7		3	7	4
Fir–spruce	3	3		7	7	3	4	4	4	4	5	5
Larch			4	2	2			2			2	
Western white pine		4		5	4		5	5			4	
Aspen-birch				4	5				3			3
White-red-jack pine									2			
Pinyon–juniper	4	6	5	9	9	4	6	6	6	5	6	6

AZ = Arizona, CA = California, CO = Colorado, ID = Idaho, MT = Montana, NM = New Mexico, NV = Nevada, OR = Oregon, SD = South Dakota, UT = Utah, WA = Washington, WY = Wyoming.

affect stands of differing characteristics. The data for the evaluation derive from Forest Inventory and Analysis (FIA) periodic inventory plots maintained by the U.S. Forest Service. Periodic inventory surveys were conducted every 5 to 10 years for each state. The most recent periodic inventory data for each state were assembled in the 2002 RPA database (Forest and Rangeland Renewable Resource Planning Act) (Smith et al., 2004).

In the first stage of the two-stage simulation model of Prestemon et al. (2006), weights on acres are based partially on the current fire hazard level, as determined using torching and crowning indices. The torching index (TI) of a stand is defined as the wind speed at 20-ft above ground at which a crown fire can initiate in a specified fire environment. The crowing index (CI) is the wind speed at 20-ft above ground at which active crown fire behavior is possible in that environment (Scott and Reinhardt, 2001). Lower values of TI and CI indicate higher hazardous fuel conditions.

Following Prestemon et al. (2006), three fire hazard levels are defined for this analysis, although these are the basis for the treatments applied in this study, they are not the focus of the scenarios that we evaluate. High, medium or low fire hazard is assigned to each FIA plot based on its calculated crowing and torching indices. If both TI<25 mph and CI<25 mph, then fire hazard is high, if TI>=25 mph and CI<25 mph, then fire hazard is medium, if TI<25 mph, 25 mph=<CI<40 mph, then fire hazard is low. A plot is not treated if: both TI and CI are at least 25 mph, or CI is at least 40 mph, or the plot is all hardwood, or the algorithm was unable to determine crown bulk density and canopy base height for the plot, which are necessary to compute TI & CI. The area treated and volume derived from thinning a particular FIA plot in order to raise TI and CI are then expanded using the area expansion factor applicable to that FIA plot.

Priority for treating risky locations in the West, as simulated for this analysis, is based on wildland–urban interface (WUI) status—whether a plot is found within or outside of the WUI—and forest type. The WUI Interface is the area where houses meet or intermingle with undeveloped wildland (USDA and USDI, 2001). Plots in the WUI have increased potential for loss of private property during wildfire events (Abt and Prestemon, 2006). In this study we used area mapped by Radeloff et al. (2005) to identify WUI and evaluate only those WUI areas on public land. The definition of WUI used here includes both interface and intermix community. Areas where houses and wildland vegetation intermingle are referred to as intermix WUI. Developed areas that abut wildland vegetation are characterized as interface WUI (Radeloff et al., 2005). In both interface and intermix communities, housing must meet or exceed a minimum density of one structure per 40 acres (16 ha). The output of the model is state-based, therefore, the second step of this study is to disaggregate the state treatment information to fine scale. Each individual treatable plot in the

Table 2
Total and treatable area on public timberland (1000 acres)

State	Total timberland			Treatable (federal)			Treatable (non-federal)		
	Federal	Non-federal	Total	WUI	Non WUI	Total	WUI	Non WUI	Total
AZ	2438.0	11.6	2449.6	23.5	372.0	395.5	0	0	0
CA	10130.4	168.0	10298.4	35.7	990.9	1026.6	0	36.2	36.2
CO	8020.3	362.8	8383.1	115.4	2386.3	2501.7	6.4	105.0	111.4
ID	12596.4	1005.3	13601.7	1177.6	2243.5	3421.1	0	412.1	412.1
MT	12505.6	721.9	13227.5	54.6	3475.1	3529.7	8.5	283.7	292.2
NM	2828.7	119.4	2948.1	30.1	798.2	828.3	0	90.5	90.5
NV	264.5	16.4	281.0	0	20.6	20.6	0	8.2	8.2
OR	14171.7	931.3	15103.0	25.9	2046.5	2072.5	0	57.3	57.3
SD	967.5	55.3	1022.8	6.4	125.1	131.5	0	0	0
UT	3585.7	219.0	3804.7	10.1	537.6	547.7	0	29.6	29.6
WA	6088.3	2275.9	8364.2	1.9	978.3	980.3	11.2	263.1	274.3
WY	4092.5	202.7	4295.2	11.4	738.4	749.8	0	33.1	33.1
Total	77689.7	6089.7	83779.4	1492.7	14712.6	16205.3	26.1	1318.7	1344.8

WUI = Wildland–urban interface.
AZ = Arizona, CA = California, CO = Colorado, ID = Idaho, MT = Montana, NM = New Mexico, NV = Nevada, OR = Oregon, SD = South Dakota, UT = Utah, WA = Washington, WY = Wyoming.

Table 3
Treatable and treated area on public timberland (1000 acres)

State	Treatable (Total)	Scenario			Percent treated (%)		
		150 M	300 M	1500 M	150 M	300 M	1500 M
AZ	395.5	181.6	186.5	360.6	45.9	47.2	91.2
CA	1062.8	20.6	149.0	971.5	1.9	14.0	91.4
CO	2613.1	73.0	176.7	1055.7	2.8	6.8	40.4
ID	3833.2	285.4	434.0	1334.9	7.4	11.3	34.8
MT	3821.8	91.5	120.8	1195.6	2.4	3.2	31.3
NM	918.8	157.7	162.1	663.9	17.2	17.6	72.3
NV	28.8	0.0	0.0	25.3	0.0	0.0	87.8
OR	2129.8	38.7	172.3	1245.5	1.8	8.1	58.5
SD	131.6	36.3	112.3	131.6	27.6	85.3	100.0
UT	577.3	2.6	12.7	342.7	0.5	2.2	59.4
WA	1254.6	0	0	133.5	0.0	0.0	10.6
WY	782.9	0	20.5	285.0	0.0	2.6	36.4
Total	17550.1	887.4	1547.0	7745.8	5.1	8.8	44.1

AZ = Arizona, CA = California, CO = Colorado, ID = Idaho, MT = Montana, NM = New Mexico, NV = Nevada, OR = Oregon, SD = South Dakota, UT = Utah, WA = Washington, WY = Wyoming.

RPA database is evaluated to determine if the model will simulate its treatment based on the information provided by the model output and the basic assumptions. For the WUI timberland, all fire hazard levels are included, while only the high and medium fire hazard plots were included for treatment for the non-WUI plots.

Treatment costs for each plot in the West were calculated through implementation of the Fuel Reduction Cost Simulator (FRCS) (Fight et al., 2006) in the Fuel Treatment Evaluator (FTE). Approximately 25% of plots failed to produce a valid estimate of costs, so an ordinary least squares (OLS) procedure was used to generate an estimated equation for treatment cost using data from the other 75% of plots and then applying the OLS equation estimates to estimate the costs for the remaining 25% and for all of the southern plots. These OLS equations included information on the site and stand; details are available from Prestemon et al. (2006). Haul costs from site to mill were assumed to be \$1/mbf/mile and \$0.35/bone-dry ton/mile. Haul distances were approximated by the distance to the nearest five sawmills and the nearest two pulpwood consuming mills (pulp, particleboard, chip mill) from the forested center of the county in which FIA plots are located. The source of the mill location data are the mill maps produced by Prestemon et al. (2005).

We simulated the effects of three levels of annual allowable subsidies (i.e., payments for treatments): \$150 million, \$300 million, and \$1.5 billion. We did not incorporate a tree growth model into our analysis so we limited our simulations to a 5 year period. To understand how such subsidies would affect the market, it is desirable to continue treatments over many years, but without projecting stand growth we did not feel this was appropriate. We only simulated treatments on public timberland (federal and non-federal) in the western U.S. Timberland is forest land that is producing or is capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation. Areas qualifying as timberland have the capability of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included.

The selection of inventory plots for simulated treatments was made based on an assumption of treatment priority by forest type (Table 1) and the WUI spending requirements. Spending in WUI was set at 50% of the annual budget to reflect direction in the Healthy Forest Restoration Act of 2003. Simulated prescriptions were the same as prescriptions 1A (uneven aged management with a 50% original basal area removal limit) and 4A even aged management with a 25% original basal area removal limit described by Skog et al. (2006). The even aged or thin-from-below prescription was used in lodgepole pine and spruce–fir forest types. Basal area removal was limited to 25% of the original basal area to avoid windthrow which is a problem when these types of stands are thinned (Alexander, 1971, 1977; Veblen and Hadley, 1989). This prescription results in removal of mainly smaller size trees because the smallest trees are removed first and either the fire hazard reduction goal was achieved or the 25% basal area removal limit was reached and thinning is stopped before larger trees are cut. All other forest types were treated with a stand density index-based (SDI) treatment so that after treatment

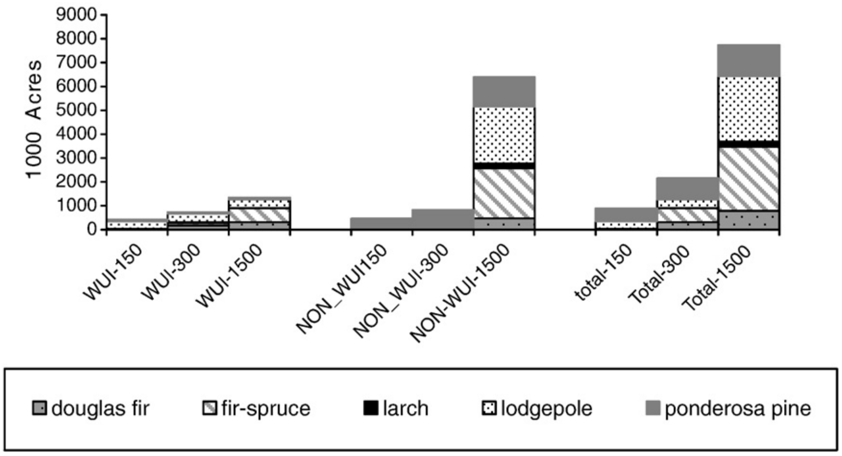

Fig. 1. Treated acres on public timberland in 5-years for the west states.

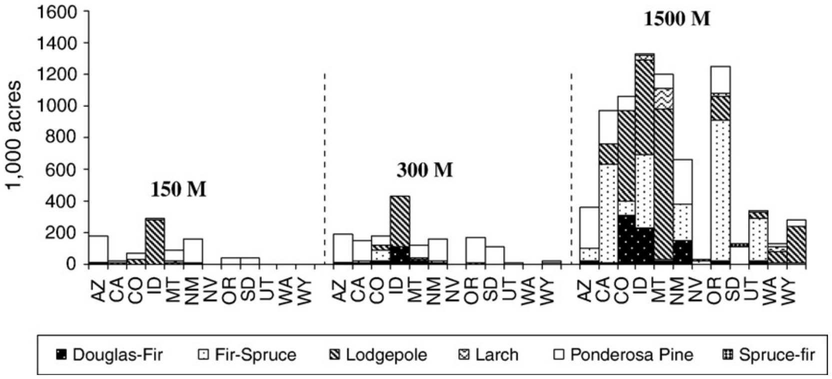

Fig. 2. Treated acres by forest type and state on public timberland (150m, 300m, 1500m).

each diameter class contributes equally to the residual SDI (Long and Daniel, 1990). The uneven aged or SDI treatment removes trees of all diameters to achieve both crowning and torching objectives. Using a SDI criterion by forest type allowed a uniform prescription approach across a wide range of ecosystems (USDA FS, 2005). Adding the thin-from-below approach allowed a lighter touch management system in forest types that are more sensitive to windthrow after thinning.

As appropriate to forest type these two prescriptions were applied to all eligible inventory plots. The basic scenario is: (1) treat the forest type based on rank, that is, treat the rank 1 (forest type) first, then rank 2, and so on; (2) spend 50% of the budget on WUI following the forest type priority (Table 1) unless there is no WUI left for treating, and (3) spend the next 50% of the budget on the non-WUI following forest type priorities (Table 1). The budget level cases referred to earlier are labeled 150 M, 300 M and 1500 M.

Most of the counties west of the Cascade Crest in Washington and counties in Oregon west of the Cascade mountains and north of Douglas County are excluded from fuel treatment. These counties are excluded because fire hazard reduction is not a primary management concern in those areas (Golden, Personal Communication). Excluded Oregon counties are Benton, Clackamas, Clatsop, Columbia, Coos, Curry, Lane, Lincoln, Linn, Marion, Multnomah, Polk, Tillamook, Washington and Yamhill; the excluded Washington counties are Clallam, Clark, Cowlitz, Gray's harbor, Island, Jefferson, King, Kitsap, Lewis, Mason, Pacific, Peirce, San Juan, Skagit, Snohmish, Thurston, Wahkiakum and Whatcom.

The ranking of forest types for fuel treatment is listed in Table 1 for each state. This ranking is based on consultations with experts in the field and the judgment of the authors. Ponderosa pine type generally ranks highest because fire suppression has resulted in high stand densities with frequently heavy fuel loads in nearly all landscapes of this forest type. The background natural fire regime in most of the area of this forest type would produce much more open stands of larger trees of fire-resistant species. Ponderosa pine forest also may generate economically useful materials in the course of fuel treatment. In addition, many human developments are in these lower- to mid-elevation forest types, elevating the hazards of economically damaging fires and hence raising the likelihood that treating such forests would yield positive net benefits. The spruce–fir forest type tends to occur at high elevations, within environments where wildfire is less frequent but of medium to high severity. Fire suppression has likely caused some increase in stand densities and fuel loads for this forest type, but not as much as in ponderosa pine, interior Douglas-fir and dry mixed conifer forest types. In addition, much of this forest type is at upper elevations, in wilderness, or is not adjacent to highly developed areas. Therefore, immediate hazards to structures and

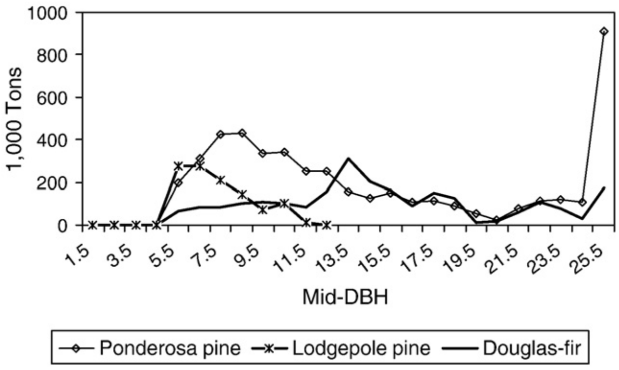

Fig. 3. Diameter at breast height (DBH) distribution of removed merchantable wood product on public timberland by major forest types (including all species) in western states under annual budget of 300 million dollars (300 M).

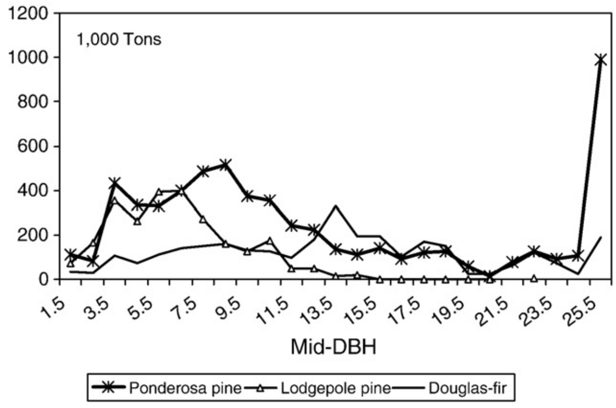

Fig. 4. Diameter distribution of removed total biomass by major tree species on public timberland in western states under annual budget of 300 million dollars (300 M).

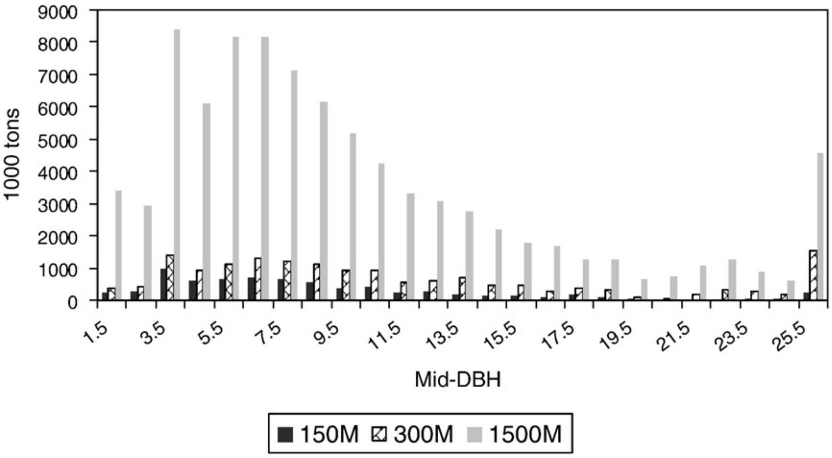

Fig. 5. Diameter at breast height (DBH) distribution of biomass removals on public timberland for the western states under each scenario.

people from wildfires in these locations are lower, implying lower priority. The apparent increase in insect activity in lodgepole pine in recent years could argue for thinking about the ranking of this forest type in future analyses.

In our simulations, we rank lodgepole pine lower than ponderosa pine, interior Douglas-fir, and spruce–fir because lodgepole pine stands normally occur in medium to high severity fire regimes with naturally high fuel loads. The combination of wildfire and insect outbreaks usually creates conditions where stand-replacing disturbances occur every 100 to 200 years. Fire suppression, therefore, may have had a less dramatic effect on lodgepole pine forests than forests at lower elevations in low severity, high-frequency fire regimes. Pinyon (*Pinus* spp.)–juniper (*Juniperus* spp.) woodlands are generally at the lowest elevations of closed forest and woodlands. While effects are variable, fire suppression has often produced open stands of larger trees with little understory and abundant bare soil. These stands can certainly experience high severity wildfire under the right wind and weather conditions, but understory fuels are often low enough to inhibit fire spread.

3. Results

There are 127 million acres (51.4 million hectares) of timberland for all ownership in the 12 western states, in which 84 (34 million hectares) million acres is public timberland,

Table 4
Total product output (removal) from fuel treatment on public timberland by States (thousand tons)

State	150 M			300 M			1500 M		
	Total biomass	Total merchantable wood product	Sawtimber materials	Total biomass	Total merchantable wood product	Sawtimber materials	Total biomass	Total merchantable wood product	Sawtimber materials
AZ	1755	1034	591	1827	1073	596	4513	2340	1396
CA	190	83	48	1752	964	734	15357	7753	5502
CO	576	310	114	1325	693	228	10230	5052	1471
ID	2370	743	89	5295	2629	1488	18095	8905	4335
MT	605	229	121	900	357	192	11521	4175	1198
NM	1212	480	198	1247	480	198	8163	3894	2163
NV	0	0	0	0	0	0	132	53	12
OR	268	201	130	2614	1881	1385	9872	6626	4047
SD	290	113	40	980	449	122	980	449	122
UT	15	9	8	75	31	12	3286	1174	317
WA	0	0	0	0	0	0	2032	1046	590
WY	0	0	0	214	76	12	2639	1051	301
Total	7281	3204	1340	16230	8633	4968	86820	42519	21455

AZ = Arizona, CA = California, CO = Colorado, ID = Idaho, MT = Montana, NM = New Mexico, NV = Nevada, OR = Oregon, SD = South Dakota, UT = Utah, WA = Washington, WY = Wyoming.

Total biomass — total gross biomass oven dry weight, it is the total above ground biomass of trees 1.0 in. diameter or larger, including all tops and limbs (but excluding foliage);

Total merchantable wood product — the net volume of wood in the central stem of trees 5.0 in. diameter or larger, from 1-foot stump to a minimum 4-inch top of diameter outside of bark, it is converted to weight based on wood densities of western tree species;

Sawtimber materials — the net volume of wood in the central stem of commercial species trees of sawtimber size (9.0 in. minimum for softwood and 11.0 in. minimum for hardwood), from 1-foot stump to a minimum top of diameter outside of bark (7.0 in. for softwood and 9.0 in. for hardwood), it is converted to weight based on wood densities of western tree species.

Table 5
Projected product output (removal) from fuel treatment on public timberland by State (tons/acre)

State	150 M			300 M			1500 M		
	Total biomass	Total merchantable wood product	Sawtimber materials	Total biomass	Total merchantable wood product	Sawtimber materials	Total biomass	Total merchantable wood product	Sawtimber materials
AZ	9.66	5.69	3.25	9.80	5.75	3.20	12.52	6.49	3.87
CA	9.22	4.03	2.33	11.76	6.47	4.93	15.81	7.98	5.66
CO	7.89	4.25	1.56	7.50	3.92	1.29	9.69	4.79	1.39
ID	8.30	2.60	0.31	12.20	6.06	3.43	13.56	6.67	3.25
MT	6.61	2.50	1.32	7.45	2.96	1.59	9.64	3.49	1.00
NM	7.69	3.04	1.26	7.69	2.96	1.22	12.30	5.87	3.26
NV	NA	NA	NA	NA	NA	NA	5.22	2.09	0.47
OR	6.93	5.19	3.36	15.17	10.92	8.04	7.93	5.32	3.25
SD	7.99	3.11	1.10	8.73	4.00	1.09	7.45	3.41	0.93
UT	5.77	3.46	3.08	5.91	2.44	0.94	9.59	3.43	0.93
WA	NA	NA	NA	NA	NA	NA	15.22	7.84	4.42
WY	NA	NA	NA	10.44	3.71	0.59	9.26	3.69	1.06
Total	8.20	3.61	1.51	10.49	5.58	3.21	11.21	5.49	2.77

AZ = Arizona, CA = California, CO = Colorado, ID = Idaho, MT = Montana, NM = New Mexico, NV = Nevada, OR = Oregon, SD = South Dakota, UT = Utah, WA = Washington, WY = Wyoming.

Total biomass — total gross biomass oven dry weight, it is the total above ground biomass of trees 1.0 in. diameter or larger, including all tops and limbs (but excluding foliage);

Total merchantable wood product — the net volume of wood in the central stem of trees 5.0 in. diameter or larger, from 1-foot stump to a minimum 4-inch top of diameter outside of bark, it is converted to weight based on wood densities of western tree species;

Sawtimber materials — the net volume of wood in the central stem of commercial species trees of sawtimber size (9.0 in. minimum for softwood and 11.0 in. minimum for hardwood), from 1-foot stump to a minimum top of diameter outside of bark (7.0 in. for softwood and 9.0 in. for hardwood), it is converted to weight based on wood densities of western tree species.

including 78 million acres (31.6 million hectares) managed by federal agencies. Plots meeting the fire hazard criteria are summarized as treatable acres, once additional exclusions are made to accommodate some west-side counties of Oregon and Washington (Table 2). Approximately 17.6 million acres (7.1 million hectares), or 21% of total public timberland, are

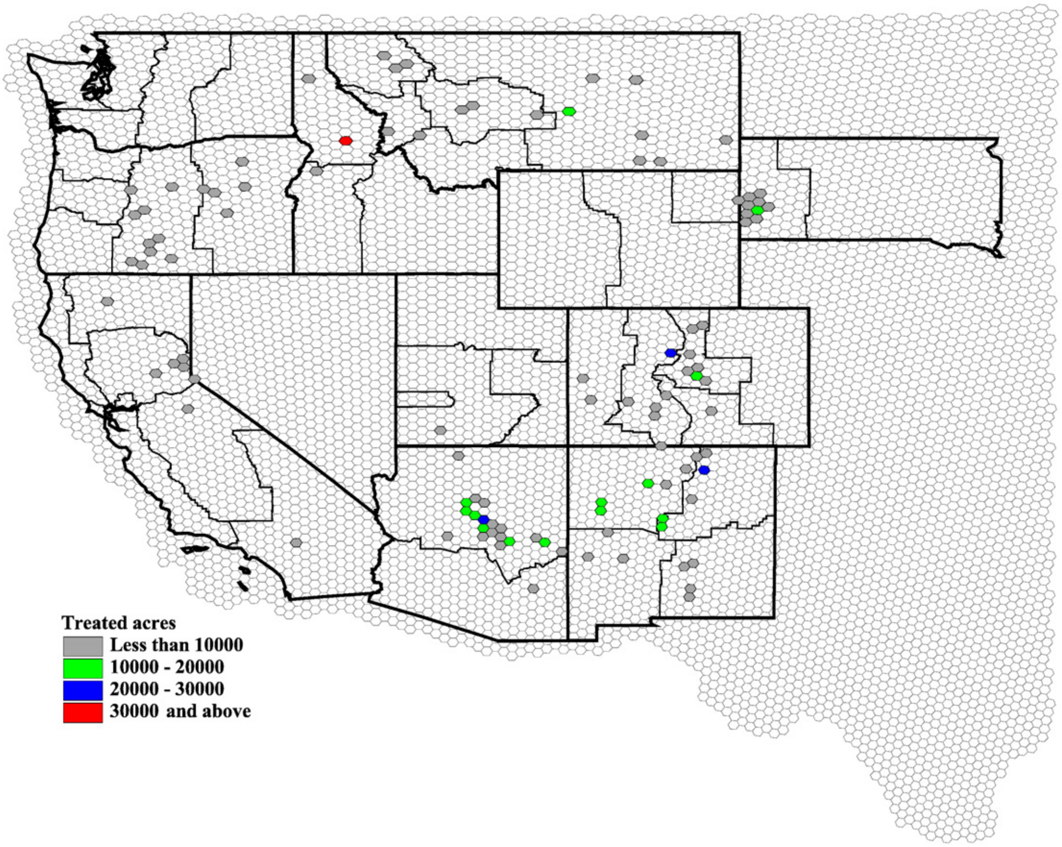

Fig. 6. Total projected treated area on public timberland per 160,000 acres under annual budget of 150 million dollars.

defined as treatable public timberland based on the criteria described above (Table 2). The percentages of treated areas relative to treatable area in 5-year simulation period are 5%, 9% and 44% respectively for the \$150 M, \$300 M, and \$1500 M subsidy scenarios (Table 3).

Most of the treatable area (91%) is non-WUI, and 92% of public timberland is managed by federal agencies, the remainder is managed by state and local agencies. The majority of federal timberland is administered by the USDA Forest Service. The treated areas in each state are highly dependent on the annual subsidy (combined federal budget appropriation for fuels treatments for the Forest Service and Department of Interior Agencies), treatment costs, and the mix of forest types available for treatment. Under the 300 M subsidy case, the percent treated area relative to treatable area ranges from 0% to 85% for the western states with about 9% on average for the whole west. About 28% of the treatable WUI will be treated at the 150 M subsidy assumption (150 M), 48% at 300 M, and 88% at 1500 M. Fig. 1 illustrates the area treated by forest type and WUI status based on the assumptions used in this simulation. Ponderosa pine, lodgepole pine, and spruce–fir are projected to be major forest types treated in the West. There are, however, considerable differences in the forest types treated in the WUI and non-WUI areas. In WUI lodgepole pine and spruce–fir are the major types while ponderosa pine and Douglas-fir are common types in non-WUI areas. It seems likely that analyses that include private land will have more ponderosa pine and Douglas-fir because federally administered lands tend to be at higher elevations and private lands tend to be at lower elevations. Accordingly WUI associated with federally administered lands would tend to include a greater proportion of higher elevation forests types such as lodgepole pine and spruce–fir.

Idaho has an abundance of high-priority, relatively low treatment cost forest types. This makes it the state with the largest treatment areas over the course of this five year simulation (Fig. 2). Other states with high treatment areas include Oregon, Montana, California, and Colorado, while less attention is paid to states with relatively less WUI and more expensive forest types—South Dakota, Wyoming, Utah, Washington, and Arizona. If the simulation were run for a longer time period additional areas would be treated making results more uniform around the west.

Fig. 3 shows the breast height (dbh) diameter distribution for each major forest type. The results displayed in this figure represent all species simulated for removal from inventory plots (stands) that were identified as a particular forest type. The diameters of removed lodgepole pine stands tend toward smaller size trees, while a large portion of potential removals of ponderosa pine stands are from large size trees. This outcome is a result of the SDI-based ponderosa pine type treatment versus the thin-from-below prescription applied to lodgepole pine and spruce–fir. Stem weights shown exclude trees that are less than 5-inches in dbh because the Forest Service inventory process does not tally the volume (in this case displayed as stem weight) of these small trees

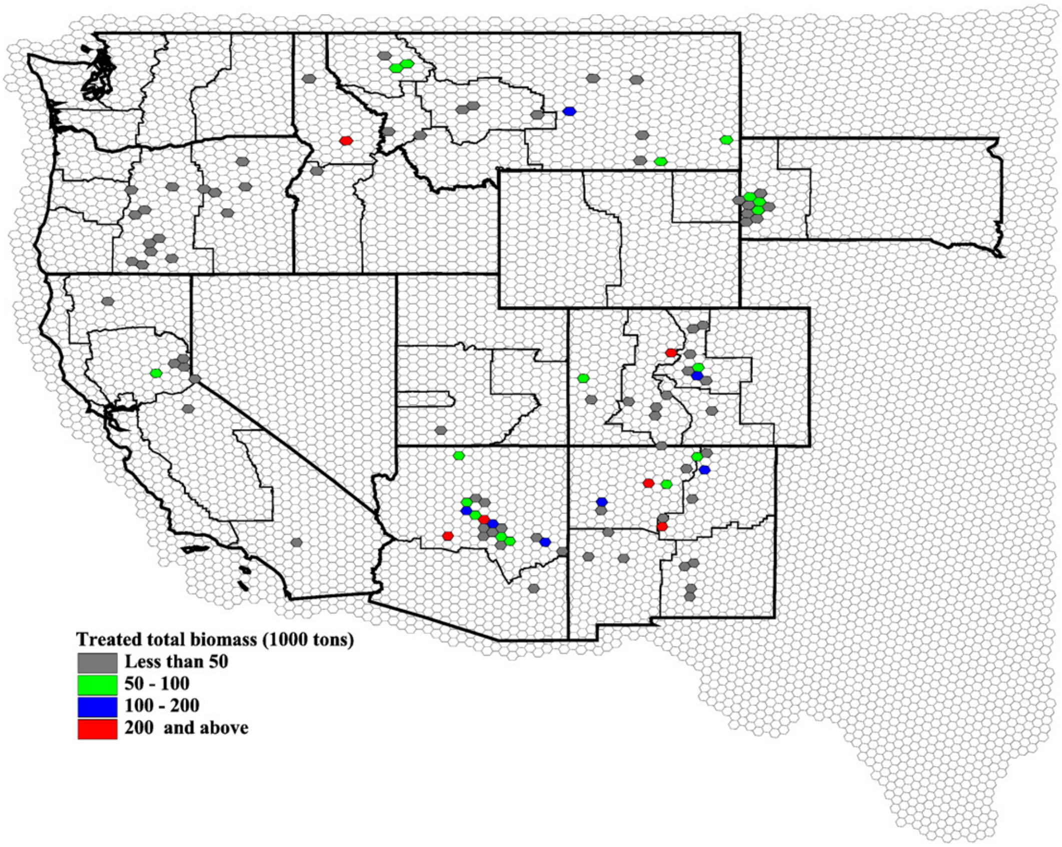

Fig. 7. Total projected biomass removals in public timberland per 160,000 acres under annual budget of 150 million dollars.

but does track their total weight (biomass). In practice, the number of small trees killed by the fuel treatments is potentially large, even though the aggregate volume is low.

We assumed that treatment of softwood forest types was generally higher priority than hardwood forest types (Table 1), so more than 95% of the product output from treatment is softwood tree species both in terms of total volume and total biomass removals. Volume refers to net volume of wood in the central stem of sample tree 5.0 in. diameter or larger, from a 1-foot stump to a minimum 4-inch top diameter outside bark. Total biomass is the total gross biomass ovendry weight for live trees, which is the total above ground biomass of a sample tree 1.0 in. diameter or larger, including all tops and limbs (but excluding foliage). The total biomass treated on public timberland in western states is illustrated by diameter distribution for the major tree species in Fig. 4. This figure differs from Fig. 3 in that it reports total weights (biomass) of individual species regardless of which forest type they came from. The total biomass removals from all fuel treatments are shown in Fig. 5. Again, the projected removals from trees 25-inch (63.5 cm) and above happens because of the treatment method used for this study (SDI for most forest types treated) and removal of those trees is required to meet the 25 MPH or greater CI threshold. A combination of our treatment ranking assumptions and the low total treatable WUI acres on public timberland caused the model to concentrate almost exclusively on WUI at the budget of \$150 million and \$300 million. All the non-WUI acres treated under the low and moderate budgets are Ponderosa pine forest type which is ranked first in all western states and treated with SDI approach, and leads to higher sawtimber percentage. However, with the further increase of budget, for example, \$1.5 billion, a large proportion of the treated acres are lodgepole pine and spruce–fir forest types using the thin-from-below approach (Fig. 1). This leads to a decrease sawtimber percentage of total treated volume. For this study, about 41% of the potential volume removals are sawtimber for all of the public timberland treated under low subsidy scenario (150 M), 58% for the moderate subsidy (300 M) and 50% under high subsidy scenario (1500 M).

Table 4 shows the product removals for each state and Table 5 shows the output of the treatment under each scenario, on a per unit area bases. Under the moderate subsidy scenario, Oregon shows the highest output at per unit area, followed by California and Idaho. With a very high subsidy (1500 M), however, California and Washington have the highest output on a per unit area basis.

A geographical characterization of the 5-year simulations helps to visualize program magnitude variations across space (Figs. 6–11 for the 150 M, 300 M, and 1500 M programs, respectively). These maps of treatment volumes are reported for 160,000-acre land area hexagons. The maps also include FIA survey unit (a group of contiguous counties for sampling in each state) and state boundaries. As the maps illustrate, biomass volumes generated are highest in Idaho, Oregon, Arizona,

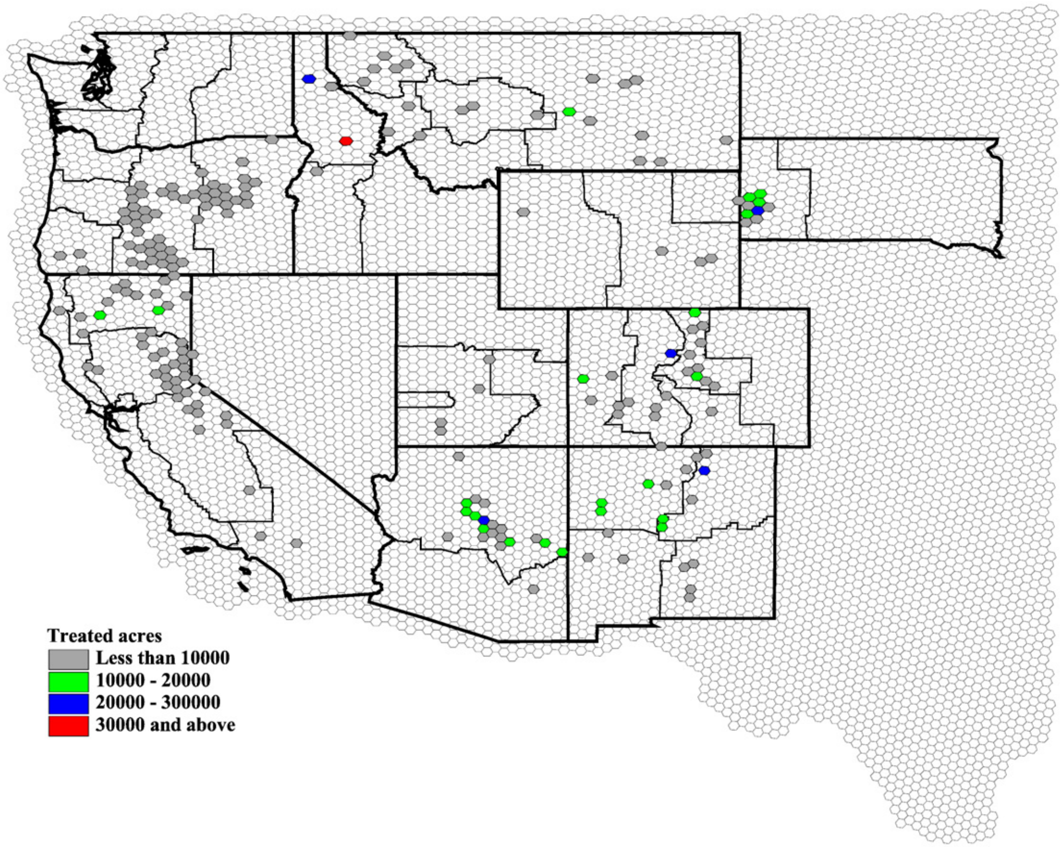

Fig. 8. Total projected treated area on public timberland per 160,000 acres under annual budget of 300 million dollars.

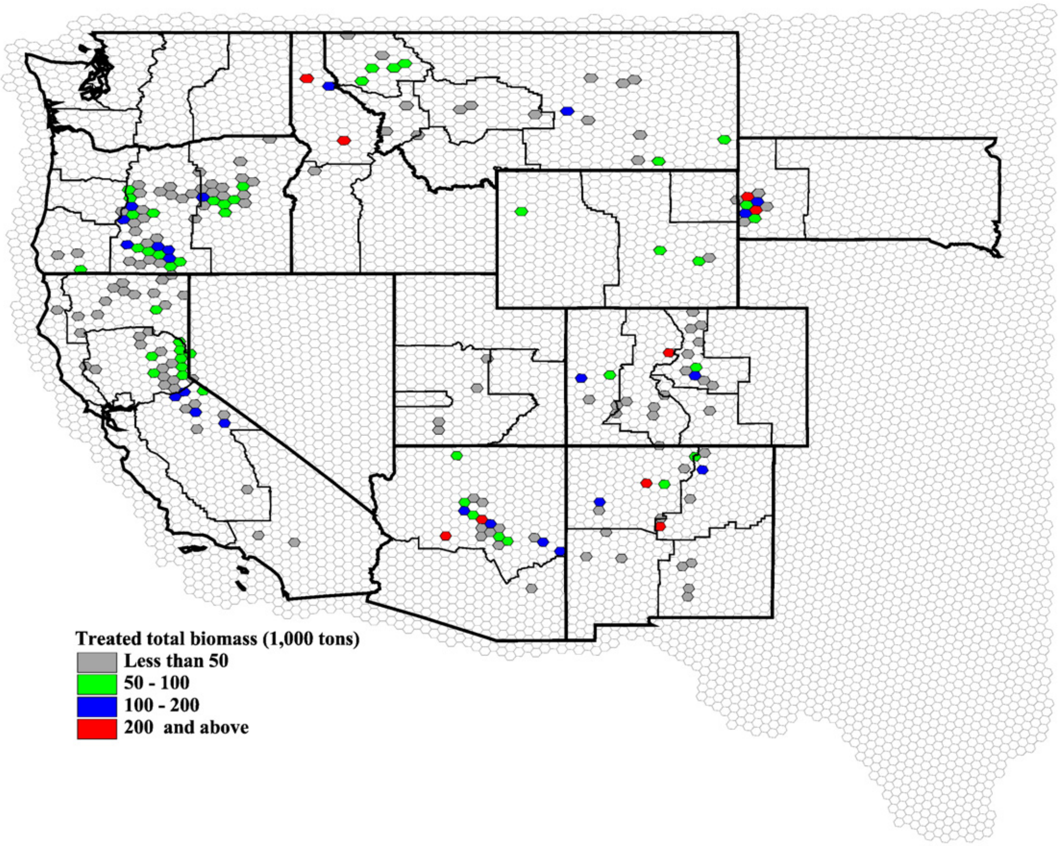

Fig. 9. Total projected biomass removals in public timberland per 160,000 acres under annual budget of 300 million dollars.

Colorado and New Mexico under the moderate subsidy scenario (300 M). Though a smaller portion of area is projected for treatment in California, the volume and biomass removed is relatively large. This occurs because of the structure of the forest types and the method used for treating the different forest types.

4. Discussion

When a least-cost highest-hazard first policy is applied across the entire western United States, the product output from fire hazard reduction treatments on public timberland depends on what forest types are treated in each state, the degree of subsidy, and the type of fuel treatment applied. States receiving the most attention in this simulated treatment program are the ones containing large amounts of publicly administered WUI timberland, states with large areas of publicly administered high-priority forest types such as ponderosa pine, and states with public forests that are relatively inexpensive to treat. If we were to change the rules for the simulation the results would be markedly different. For example, if we included private land in the analysis, particularly if we included privately owned WUI, we would expect major differences in allocation of resources to treat those areas before general forests or in preference to lower priority forests types even if they were located in WUI. The abundance of WUI treatments in relatively low priority forest types, lodgepole pine and spruce–fir, (Fig. 2) is probably a result of a shortage of higher priority forest types, such as ponderosa pine and Douglas-fir, under public management (Fig. 1). This occurs because we did not include the option of treating private land in this analysis. Shifting WUI treatments from the longer fire return interval forests to the shorter ones would certainly alter the mix of tree species and sizes removed during treatments.

When thin-from-below methods are applied, as is the case for lodgepole pine and spruce–fir types, much of the timber product output is of small diameter, e.g., less than 12 in. (30.5 cm) at breast height. When SDI-based treatments are used, as is the case for ponderosa pine in this study, larger diameter trees are identified for cutting. Our analysis does not address the political question raised by Brown (2003), Aplet and Wilmer (2003), Hulsey and Ripley (2006) about whether these larger trees should be harvested or not. It does, however, suggest that given the measures of treatment effectiveness we chose to evaluate reduction in fire hazard (TI and CI improvement) that it may be necessary to remove some larger trees (Figs. 3–5). Whether the number of trees in the >25 in. (63.5 cm) dbh class our model projected for removal is necessary to accomplish landscape scale fire hazard reduction goals or not remains open to question. As more localized plans are developed questions about fire spread, which we could not address in this analysis, will come into play. Examining questions about the balance between the changes in stand structure or the distribution of stand conditions across the landscape that inevitably occur as a

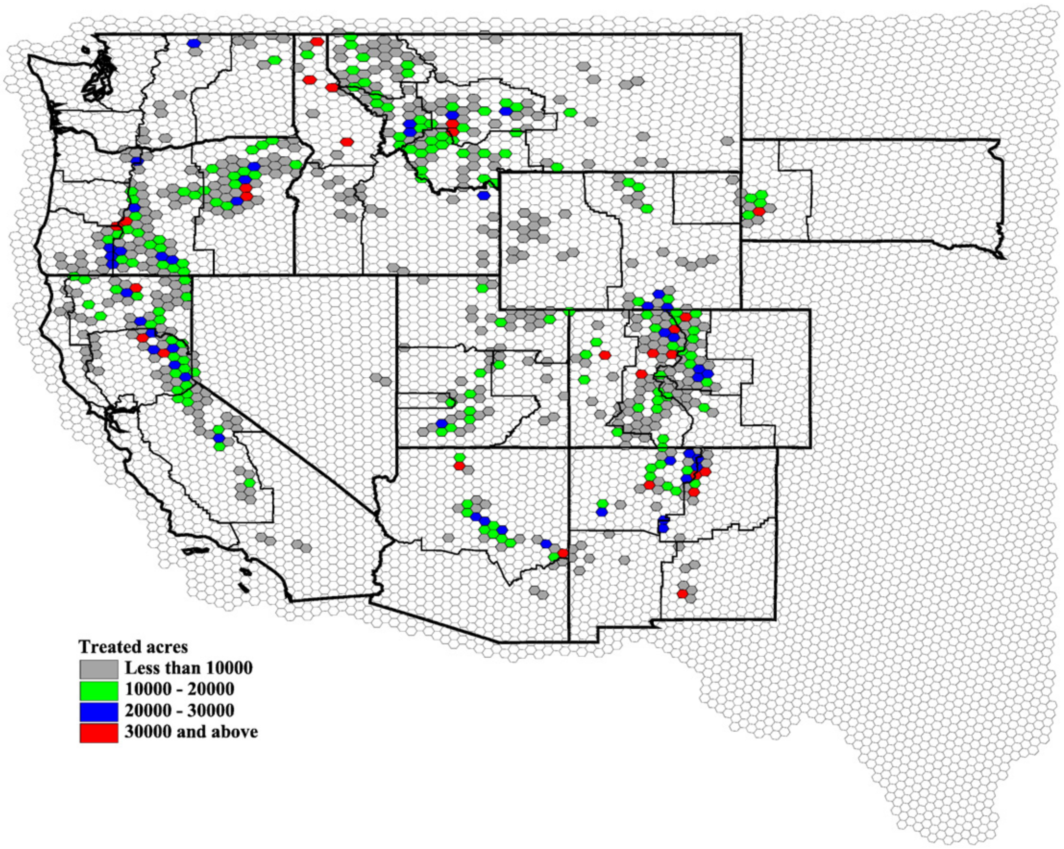

Fig. 10. Total projected treated area on public timberland per 160,000 acres under annual budget of 1500 million dollars.

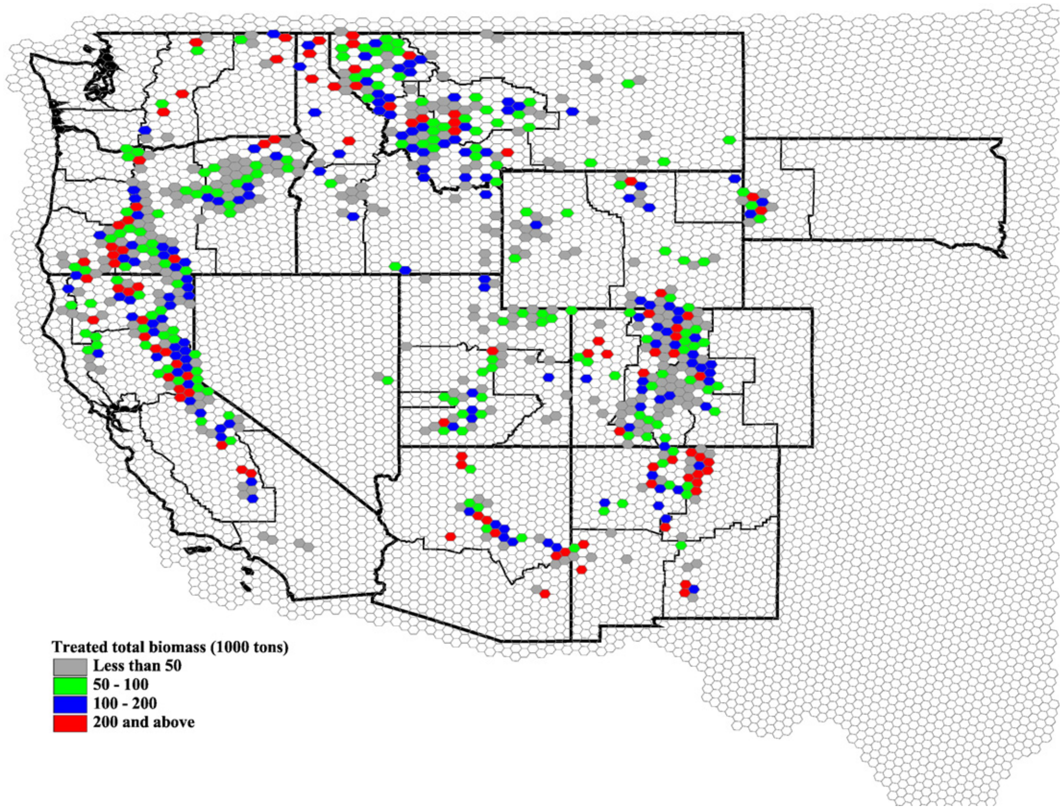

Fig. 11. Total projected biomass removals in public timberland per 160,000 acres under annual budget of 1500 million dollars.

result of fire hazard reduction treatments and damage that could occur if there were a fire (Kline, 2004) may help to clarify whether it is advisable to remove the larger trees identified in this analysis. Kline's (2004) approach addresses the question of what types of treatments might be effective in a more technical light than the political considerations often raised about whether or how to address fire hazard issues. Using this approach one could focus more on the biophysical outcome of various management scenarios and leave the political discussion for another arena.

This analysis is much more useful in addressing questions that arise at the west-wide scale than those associated with how to manage a particular stand or watershed. Figs. 6–11 provide a good illustration of how the model allocates resources and how results might change with different levels of subsidy. At the lowest funding level using a least-expensive highest-hazard area first approach treatments are scattered around the west and other than along the Mogollon Rim in central Arizona and a small area in western South Dakota no substantial contiguous areas are treated in the first 5 years of the program (Figs. 6 and 7). Doubling the subsidy to $300 M causes treatments to become concentrated in several states and clusters of treatments in areas such as the Sierra Nevada Mountains in eastern California and the Blue Mountains in northeastern Oregon begin to emerge (Figs. 8 and 9). All three of the areas where treatments cluster in Figs. 6–9 are areas where federal land managers have placed a priority on reducing fire hazard. Some other priority areas, such as the Front Range of the Rocky Mountains in central Colorado or the mountains of western Montana, do not appear until the subsidy level is increased to $1500 M. Clearly these areas are high-priority areas within their regions and additional refinement of the modeling methods are needed before they will be useful for detailed policy analysis.

The scattered appearance of treatment at the lowest subsidy level is, however, probably of interest in itself even if neither the Forest Service nor Department of Interior allocates funds at the west-wide scale. These maps (Figs. 6 and 7) suggest that making substantial progress with a budget of $150 M would require considerable thought so that treatments are targeted to the parts of the landscape where they actually reduce fire hazard in the highest priority places. In other words, at the $150 M funding level federal land managers cannot afford to be wrong very frequently. They need to use mechanical treatments in places where prescribed fire is not appropriate and they need to implement effective treatments. This could be difficult given the current political climate where powerful forces are brought to bear both to influence where and how fire hazard reduction treatments are done often without a broad scale sense of where the highest-hazard areas are actually located.

5. Conclusions

Although this study does not lay out a prescription for how to treat publicly administered forests to reduce wildfire hazard, it does provide information useful to policy makers: it illustrates where early attention could be focused in a large-scale treatment program in order to simultaneously achieve fire hazard reduction at minimum cost. It also provides information for wood processors of potentially removed treatment materials. What our analysis documents is the timber product outputs by species which could result from a western treatment program. It, therefore, presents a tool for evaluating the implications of alternative programs that policy makers and land managers may consider when seeking and achieving fire hazard objectives in fire prone landscapes of the United States.

On average, more than half the volume removed will be sawtimber. Thirty percent of the total biomass is from trees less than 5-inch under the low subsidy case, 19% for the moderate subsidy case and 24% for high subsidy case. Lodgepole pine, ponderosa pine and spruce–fir are projected to be major forest types treated in the West. Idaho, Montana, Oregon and Colorado will be the major western states for fuel treatment regarding the acres to be potentially treated on public timberland.

The analysis leaves substantial room for additional analyses. One analysis would be to evaluate the spatial and timber product implications of including the southern U.S. in a nationwide federal and state fuel treatment program. Another would carry out longer simulations, which would show the long run timber product output implications of such programs for wood processors in the West and South. Finally, the modeling approach shown here could be used to evaluate different kinds of mechanical fuel treatments, which could differ from the ones applied. For example, one analysis could evaluate how the timber product output volumes would be affected by the application of a thin-from-below prescription for all forest types.

Acknowledgments

Thanks to Miles Hemstrom of the Pacific Northwest Research Station, Forest Service, for his expertise and time ranking of Western States forest types for fuels treatments. Also, thanks to Robert J. Huggett of Southern Research Station, Forest Service, for his work on primary data process and preparation.

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