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Evaluation of Silvicultural Treatments and Biomass Use for Reducing Fire Hazard in Western States

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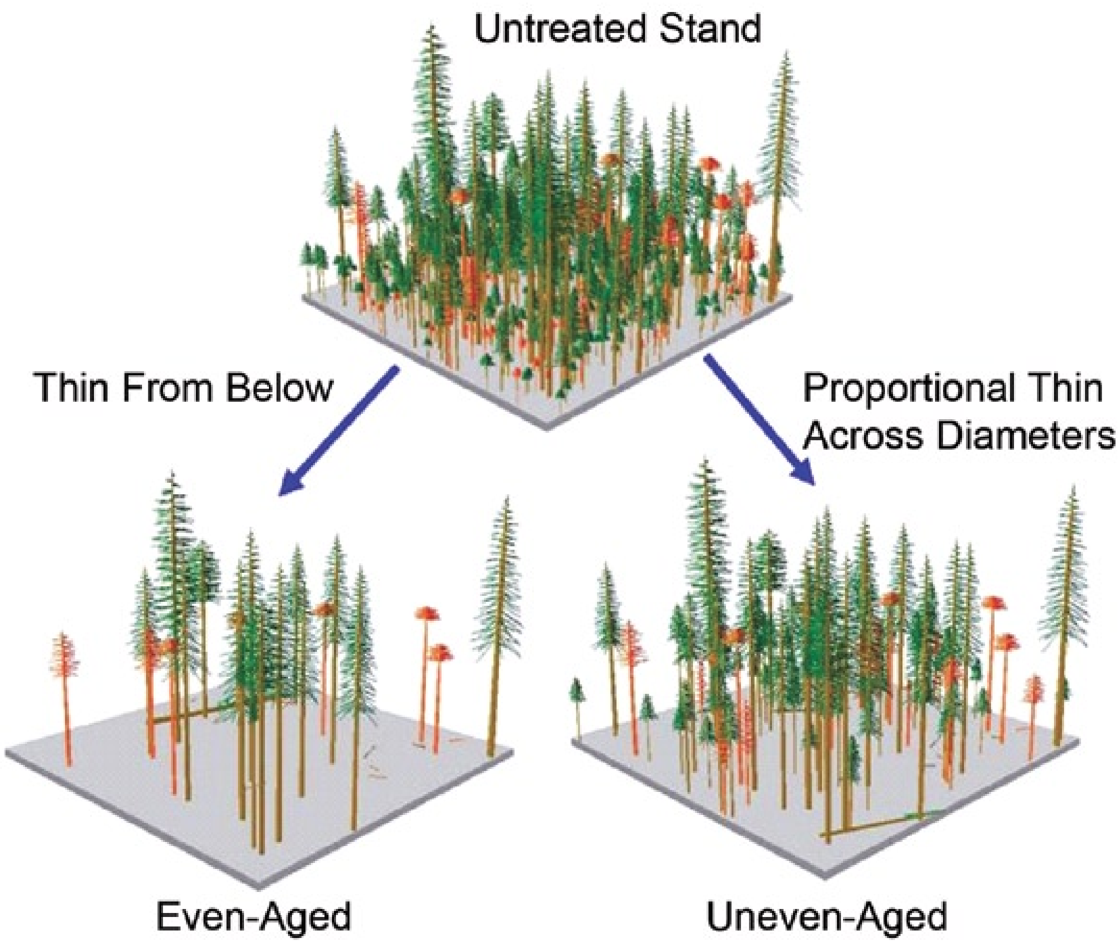

Abstract

Several analyses have shown that fire hazard is a concern for substantial areas of forestland, shrubland, grassland, and range in the western United States. In response, broad-scale management strategies, such as the National Fire Plan, established actions to reduce the threat of undesirable fire. Available budgets are insufficient to pay for vegetative management on all acres where fire threat is considered unacceptable. The purpose of this report is to begin to identify locations in the west where fire hazard reduction treatments have a potential to “pay for themselves” at a scale and over a long enough time to make investment in additional forest product processing infrastructure a realistic option. The resulting revenues from these activities could presumably subsidize treatment for other locations. Accordingly, we concentrate on areas where wood removed during fire hazard reduction treatments has the potential to support a forest products infrastructure. Areas for treatment were selected by the criterion where either torching or crowning is likely during wildfires when wind speeds are below 25 mph. We considered thinning treatments designed to result in either even-aged or uneven-aged stand conditions. If there are ecological limitations on basal area that is allowed to be removed and there is a need to obtain a certain amount of merchantable wood volume to help cover costs, then uneven-aged treatments appear more likely to achieve one of our hazard reduction targets. Thinning to maintain an uneven-aged structure could be more controversial because it removes larger trees, although the revenue from such treatment covers harvest costs more frequently than does revenue from thinning to maintain an even-aged structure. The removal of large trees by uneven-aged thinning may be reduced by supplementary treatments to increase torching index rather than thinning to reach a high crowning index. Treatments analyzed would treat 7.2 to 18.0 million acres, including 0.8 to 1.2 million acres of wildland urban interface area, and would provide 169 to 640 million oven-dry tons of woody biomass (e.g., main stem, tops, and limbs). About 55% of biomass would be from sawlogs. Sixty to 70% of acres to be treated are in California, Idaho, and Montana. To prepare an example estimate of annual harvest amount for the 12 selected western states, we assume acres needing treatment are divided into two parts of equal area. For half the acres, an uneven-aged treatment would be applied if at least 300 ft^3 of merchantable wood is removed; for the other half, an even-aged treatment would be applied if at least 300 ft^3 of merchantable wood is removed. Under this scenario, treatment of 0.5 million acres/year would generate 14.6 million oven-dry tons of biomass per year or about 29% of the current level of roundwood removals for the selected states.

Keywords: hazardous fuel reduction, simulation, FIA data, biomass utilization, harvesting costs, western states

Acknowledgments

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SI conversion factors

Inch–pound unit	Conversion factor	SI unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
cubic foot (ft^3)	0.0283	cubic meter (m^3)
mile	1.61	kilometer (km)

Contents

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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 2005a). 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. This allocation process would direct funds available for prescribed fire, mastication, hand or machine pile and burn, and thinning to where they could accomplish the most in terms of verifiable fire hazard reduction. Ultimately, we want to identify areas that are large enough to support commercial-scale wood processing options based on an objectively defined fire hazard reduction program. This will allow funding for other types of treatments to be concentrated in areas where the removal and sale of wood is not the most appropriate solution to the threat of fire. As a result, this analysis is not intended to identify every acre where treatments might “pay for themselves,” but rather to provide a strategic insight into the scope and scale of the potential to use wood removals to finance activities in broad geographic regions.

We do not attempt to identify all acres 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, which is known to be true. We focus only on areas in surface and mixed severity fire regime forests, where treatments are needed to reduce fire hazard. We do not attempt to include areas that may need treatment for other reasons, and our results should not be taken to include all areas that may need thinning treatments.

Our analysis began with several assumptions:

- Some forest types and geographic locations are better suited to our alternate thinning strategies because they are effective fire hazard reduction treatments that would tend to produce more merchantable timber.
- The existing infrastructure for wood product manufacturing is suited to process the kinds of materials removed.
- There is a realistic potential to establish new infrastructure.
- The political climate is favorable toward these activities.

Our analysis is intended to cover aspects of each of these criteria. To aid agencies to refine a cohesive strategy for reducing fuels, our assessment is intended to show where and by how much mechanical treatments that remove woody biomass could potentially cover costs of hazardous fuel reduction treatments. This knowledge could help determine which treatment strategies should be applied in various locations across the West.

Our study focuses on evaluating treatments to reduce fire hazard on timberland[1] (versus other forest land), covers all ownerships, and identifies locations likely to have a higher proportion of trees that may be used for higher value products, which may help offset treatment costs. The 12 western states assessed in this study (see footnote to Table 1) have 127 million acres of timberland and 77 million acres of other forest land (Miles 2006). Part of our intent is to identify large areas where wood supply could sustain businesses to use biomass from thinning. We focus on timberland, where the value of products is more likely to cover treatment costs. While other forest land has hazardous fuels and wood from treatments 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 oven-dry tons (odt) of

[1]Timberland is forest land capable of producing in excess of 20 ft^3 of wood per acre per year at culmination of mean annual increment (age where annual growth is greatest) and is not withdrawn from timber utilization by statute or administrative regulation. Other forest land is not capable of supporting this level of growth.

woody biomass per acre (Perlack and others 2005) in the 12 states considered in our study compared with the 24 to 34 odt/acre estimated for our timberland thinning treatments. We underestimate the acres that can be treated with net positive revenue to the extent that some portion of other forest area may, on average, provide biomass value in excess of treatment costs.

This assessment consists of three phases:

Phase I—Identify, across the West, locations where hazardous fuel reduction treatments are needed that would also generate substantial amounts of woody biomass for use that could offset treatment costs.

Phase II—Select specific localities in the West and evaluate the current market potential for using wood and prospects for expanding specific markets to use additional wood material.

Phase III—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 areas identified in Phases I and II of the project.

This paper presents the results from Phase I. For 12 western states, we selected timberland acres eligible for treatment (determined in part by fire hazard level), applied several alternate 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. We compare the results of our analysis to results from a previous Forest Service assessment (Forest Service 2003). As in the assessment reported here, the 2003 Assessment estimated potential biomass removals by applying silvicultural treatments to plot data. Our analysis is more detailed in selecting and treating plots for fire hazard, in calculating and comparing harvest costs to product revenue, and in mapping locations of removals.

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 (dbh) ≥5 in., from 1 ft above ground to a minimum 4-in. 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 form cull. We assign a higher value to merchantable wood ≥7 in. dbh and assign a lower (chip) value to merchantable wood in smaller trees and all sources of non-merchantable wood. Non-merchantable wood refers to all wood not classified as “merchantable.” Both merchantable wood and non-merchantable wood can be used for products. Note that merchantable wood can be used for both higher value products, such as lumber, plywood, oriented strandboard (OSB), and pulp, and for lower value products, such as chips for fuel. Non-merchantable wood is most likely to be used for low value products, but a small amount may be used for higher value products.

Methods

The primary data for this assessment were plot-level data compiled by the Forest Inventory and Analysis Program (FIA) [2] of the USDA Forest Service (Smith and others 2004), with additional plot information from the National Forest System. The design of the FIA plot system is intended to provide an error of no more than ±3% with 95% confidence for estimates of an area of 1 million acres. Estimates of larger areas would have a lower percentage of error. Each plot represents a forest area of about 3,400 acres. The plot data indicate current stand conditions on all timberland in the West. In our analysis, the area to be treated and woody biomass to be removed were estimated as if the treatments were to be done in 1 year. In reality, the area treated and amounts removed would occur over many years.

The methods are divided into the following sections: (1) screens for determining plot eligibility for treatment and plots actually receiving simulated treatment, (2) fire hazard reduction objectives and assumptions, (3) silvicultural objectives and assumptions, (4) estimation of harvesting costs, (5) estimation of product revenues and net revenues, and (6) computations using the Fuel Treatment Evaluator.

Screens for Determining Plots Eligible for Treatment, and Plots Receiving Simulated Treatment

Of the 126.7 million acres of timberland in the 12 selected western states, 23.9 million acres passed an initial screen and were considered eligible for treatment (Table 1). A second screen was applied when considering a specific silvicultural treatment, and fewer than 23.9 million acres may actually receive simulated treatment.

Initial Screen

The initial screen was applied to two different groups of forest types: (1) forest types with surface or mixed severity fire regimes and (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:

- Inventoried roadless areas[3]
- Counties west of Cascade Mountains in Oregon and

[2]The FIA program has been in continuous operation since 1928. It collects, analyzes, and reports information on the status and trends of America’s forests: how much forest exists, where it exists, who owns it, and how it is changing. The latest technologies are used to acquire a consistent core set of ecological data about forests through remote sensing and field measurements. The data in this report are summarized from about 37,000 permanent field plots in the western United States.

[3]For a map of inventoried roadless areas, see www. roadless.fs.fed.us/maps/usmap2.shtml

Table 1—Timberland areas screened as eligible for treatment in 12 western states[a]

	Area (10^6 acres)						
	1	2	3	4	5	6	7
Forest type group	Timberland	Lower fire hazard acres in col. 1 removed	Inventoried roadless area in col. 2 removed	Selected counties in Oregon and Washington in col. 3 removed	Non-WUI portion of col. 4	WUI portion of col. 4	Acres eligible for treatment
Spruce–fir and lodgepole pine types	32.5	23.3	15.5	14.9	13.8	1.1	1.1 col. 6 only
Other forest types	94.2	35.8	30.3	22.7	21.9	0.8	22.7 col. 5 + 6
Total	126.7	59.2	45.8	37.6	35.7	1.9	23.9

[a]Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, South Dakota, Utah, Washington, Wyoming.

Washington, where forests have a long fire return interval[4]
- Plots with lower fire hazard; both crowning index (CI) and torching index (TI) >25 mph or CI alone >40 mph

Plots excluded from Group 2 (lodgepole pine and spruce–fir forest types):

- All plots outside wildland urban interface (WUI) areas
- Inventoried roadless areas
- Counties west of Cascade Mountains in Oregon and Washington, where forests have a long fire return interval
- Plots with lower fire hazard (both CI and TI >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, and our treatments that are designed to reduce fire hazard may not be designed to meet those objectives. Those forests do not tend to burn with surface and mixed severity fires and have long fire return intervals. For results when treatments are applied to timberland in those counties, see the section on results with alternate assumptions about thinning treatments.

Of the 126.7 million acres of timberland, 67.5 million acres (53%) have lower fire hazard by our criteria (Table 1). Of the remaining 59.2 million acres, 21.6 million acres (17% 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% 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% of all timberland and 60% of acres with higher fire hazard.

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

Second Screen

A second screen was applied when applying a specific silvicultural treatment; it determined which eligible plots actually receive simulated treatment. Plots were excluded (not treated) if they would not provide 300 ft^3 of merchantable wood per acre (about 4 odt). The 300-ft^3 removal requirement is to assure that the treatment could provide a minimum amount of revenue from higher value products (pulpwood, sawlogs or veneer logs as opposed to lower value products such as chips for fuel from small trees and branches) to meet our objective to identify treatment areas where product revenues are more likely to cover treatment costs. Previous studies have found that mechanical treatments that produce less than 300 ft^3 of merchantable wood are unlikely to cover costs of the treatment (Barbour and others 2004, Fight and others 2004). For results when treatments are applied to plots that would provide less than 300 ft^3 of merchantable wood per acre, see the section on results with alternate assumptions about thinning treatments.

It is certainly possible that we may have underestimated (or overestimated) the number of acres that could be treated with a positive net revenue if various assumptions are incorrect and are changed; for example, some "other" forest land may have significant volumes of high value wood; treatment is applied to some high severity fire regime forest types; treatment is applied to some forests west of the Cascades in Oregon and Washington; or prices are higher or lower for wood products. We suggest our screens as a reasonable starting point for understanding what area may be treatable with positive net revenue.

Fire Hazard Reduction Objectives and Assumptions

Selection of Plots for Treatment

Each FIA timberland plot was assessed for fire hazard by estimating crowning index and torching index (Scott and Reinhardt 2001). Plots were selected for treatment if CI < 25 alone or TI < 25 mph and CI < 40 (designated hereafter as CI<25 and TI<25) (Table 2). Torching index

Table 2—Fire hazard reduction objectives and assumptions

- Select for treatment each plot where CI<25 *or* TI<25 and CI<40
- Hazard reduction targets: Remove trees on each plot until
  - CI>25 and TI>25 *or*
  - CI>40 (but TI<25)
- Fuel model (ground fuels) is 9 (timberland average) and remains the same after thinning
- Drought severity assumption: Drought summer (1 h = 4%, 10 h = 5%, 100 h = 7%, live = 78%) (Rothermel 1991)

(TI) is the 20-ft aboveground wind speed at which crown fire can initiate in a specified fire environment; CI is the 20-ft wind speed at which active crown fire behavior is possible in that environment. For both indexes, lower values indicate more hazardous fuel conditions. In other words, if crown fire activity can occur even under low wind conditions, the stand is more vulnerable. The focus on crown fires is useful because, while 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. A threshold lower than 25 mph would not protect all stands in this common range against fires. A higher threshold was not chosen because we felt that it unrealistic to try to protect stands against extreme wind speeds that seldom occur. Choosing a higher threshold would result in more extreme thinning treatments on individual plots.

Assumptions for Calculating Torching and Crowning Indexes

Torching and crowning indexes were calculated for each plot based on

- canopy fuel profile as computed from plot data,
- slope steepness,
- selected set of fuel moisture conditions corresponding to “summer drought” conditions (Rothermel 1991) chosen to represent average wildfire scenario, and
- use of fire behavior fuel model 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 fuel model 9 results in mid-range surface fire behavior 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. Surface fuels tend to be extremely variable both within and between stands. Surface fuels may in fact be heavier (resulting in more extreme fire behavior) or lighter (resulting in less extreme fire behavior) in any given stand. However, no plot data exist to characterize surface fuels. Using a fuel model that results in more extreme fire behavior such as fuel model 10 might lead to recommending thinning where none is really needed to reduce fuel hazard, while a fuel model such as fuel model 8 that results in very low intensity surface fires may not have the sensitivity to identify stands at risk of crowning. Fuel model 9 was used as a compromise that is conservative (does not recommend excessive thinning) while still sensitive to the effect of ground fuels on fire hazard.

We also used fuel model 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. Again, this assumption was chosen to be conservative. We assume that the treatments will minimally increase surface fuels, and they will be implemented in such a way that this is true; for example, with whole tree yarding or piling and burning activity fuels.[5] We also assume that the fuel treatments do not reduce surface fuels, because we do not want to exaggerate the effects of the treatments on potential fire behavior. In fact, where necessary and as determined on a project level, surface fuels may indeed be reduced in conjunction with the thinning activity, resulting in additional hazard reduction.

Analysis of fuel hazard in this work is thus limited to canopy fuels. Surface fuels are an important component of the fuel conditions at any site. This analysis does not include the important effects of surface fuels on potential fire behavior for two reasons: (1) data were not available and (2) treatment under consideration is thinning, which directly affects canopy fuels in a consistent way. We made conservative and across-the-board assumptions about surface fuels. If fuel treatment projects are implemented in any areas identified by this study, detailed prescriptions will need to be developed that look at the existing surface fuels and their potential contribution to crown fire initiation, the possible need to treat the existing surface fuels, and the need to treat any activity fuels created by thinning (that is, branch material and non-merchantable trees).

[5]Our analysis assumes minimal increase and does not allow surface fuels to increase in that the harvesting systems (and associated harvest costs) include removing thinned trees down to 1 in. dbh and removing tops and branches of all thinned trees with minimal amounts left behind.

Targets for Crowning and Torching Indexes After Treatment

The fuel hazard reduction objective for each plot was to increase TI and CI to above 25 mph or to increase only CI to above 40 mph. These objectives are intended to either keep a crown fire from starting or to prevent a crown fire from spreading if crowns are ignited. For some plots, data on both live and dead trees were used to compute CI and TI. For other plots, data were only available for live trees because older protocols had been used to collect the data.

Effect of Treatments on Fire Hazard

Tree thinning increases TI and CI in different ways. The TI is increased by increasing canopy base height, so that the canopy fuels are further from the surface and less likely to be ignited by a surface fire. The CI is increased by reducing the canopy bulk density; that is, by making the canopy fuels less dense so that crown fire is less likely to "run" from tree to tree.

In some cases, a stand may be very open-grown and have low canopy bulk density and associated high CI (low risk of crown fire spread), but each crown is long (may reach close to the ground), so canopy base height and TI are low (high risk of torching). In this case, even an intense level of thinning may not accomplish the TI objective. This situation is reflected in a number of stands in the data set. In these stands, the CI objective (>25 mph) can easily be met by limited thinning, but not the TI objective (>25 mph). For this situation, we increased thinning until CI was at least 40 mph, even though TI might still be less than 25 mph. Removing additional trees might increase CI to a greater extent, but since TI would not increase correspondingly we judged that overall stand replacement fire hazard was not further reduced.

Limits on Removal of Basal Area

In some treatment cases, we limited total basal area (BA) removal. One objective for limiting BA removal is to keep canopy closure as high as practical. Opening the canopy, while reducing canopy fuels, can lead to different fuel hazard problems: (1) opening the canopy exposes surface fuels to solar radiation and wind, which can alter surface fire behavior; (2) opening the canopy can lead to increased herbaceous and shrub growth, which may also change surface fire behavior; (3) opening the canopy can enhance conifer regeneration, ultimately creating ladder fuels; and (4) decreasing BA/acre in some forest types can increase the risk that remaining trees will be blown down by strong winds. We elected to use BA to drive the prescription engines used in the fuel treatment evaluator because it is a uniformly measured metric common to all forest inventory data. While canopy closure is more directly applicable to fire behavior, it is not uniformly defined and is subject to variation based on stem size, stocking, canopy architecture, and the methodology by which it is measured.

We also recognize that limiting removals to a 50% reduction in BA may not achieve the complete fuel treatment objective and may also leave some forests susceptible to epidemic bark beetle outbreaks. While these levels of thinning may reduce the potential for crown fire, they will not likely be sufficiently aggressive to prevent significant tree mortality in dry forest types during drought. However, we intend these treatments to be the first step in a continuing management process that can eventually achieve a full suite of management goals, including reducing crown fire and torching. We should also point out that the limitations we impose here are applied at the landscape and larger scales of FIA inventory data and not at smaller scales—where it is certainly acceptable and proper silviculture to remove the majority or all stocking to regenerate forests, improve wildlife habitat, or even provide fuel breaks. Limiting BA removals to 50% at the landscape scale provides ample opportunity to affect such changes at smaller scales. However, removing over half the stocking from the large forested land areas being considered in this effort may be both ecologically and socially ill-advised. Therefore, we feel that the stocking limits we have imposed here provide a reasonable estimate of initial fuel hazard reduction treatments that can be applied in western forest types. 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. Fuel hazard reduction treatments were chosen to reduce torching and crowning indexes in the stands as they currently exist. We know, however, that fuel treatment effects change over time, and that eventually fuels will need to be retreated. Our ultimate goal in treating fuels is to create healthy, resilient stands in which fire can play its natural role. In lower elevations and drier forest types, such stands might be expected to burn fairly frequently, mostly in surface fires that remove the shrubs and excess conifer regeneration and that maintain the stand in an open condition. Canopy fuels in such stands will typically be elevated and sparse, and surface fuel loadings will be low. Subsequent fuel treatments in these stands might be relatively inexpensive, large, low-intensity prescribed fires. The necessary frequency of such 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 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. Clearly, other management objectives will sometimes override the application of fuel hazard reduction treatments.

This analysis was not meant to be a detailed, site-specific fuel treatment plan. If fuel treatments are to be conducted, they must be planned and assessed in terms of their specific locations, values of adjacent resources, proximity of adjacent fuels, and likely rates-of-spread and weather conditions at the time of burn. For example, information on most likely wind direction with regard to terrain should be taken into account when assessing the potential of a fuel treatment to mitigate hazard in a specific planning area. This analysis is instead a broad-scale analysis meant to identify general regions where fuel hazard appears to be high and enough volume is present to make it feasible to think that the treatments would not have to be substantially subsidized.

As a general indicator of fuel hazard we have used the torching and crowning indexes. These metrics indicate the vulnerability of a stand to crowning: torching index reflects vulnerability to crown fire initiation, while crowning index reflects vulnerability to sustained crown fire. In using these metrics, we implicitly assume that our goal in treating fuels is not to reduce fire occurrence, but to reduce crown fire occurrence. Crown fires are more difficult to suppress than are surface fires, have a far greater rate of spread than do surface fires, and result in near total stand mortality; surface fires tend to be more acceptable in terms of both fire behavior and fire effects, and they may have a positive effect on the stand and on fuel hazard reduction.

Finney (2001) has suggested that an optimal pattern of fuel treatments may result in reduced fire spread across a landscape as a result of fire flanking through untreated areas rather than spreading in a forward direction. This largely theoretical concept has not been integrated into our analysis here. However, if fuel treatment should be scheduled, this kind of analysis could be conducted to design the most strategically valuable layout of treatment units and to assess the potential of those treatments to reduce landscape-level rate of spread. Any treatment that results in surface fire rather than crown fire will almost certainly result in reduced rate of spread, however, since crown fires are more exposed to wind and have much higher intensity than that of surface fires burning in similar fuels.

Effects of Treatments on Other Resources

Surface fuels, including shrubs, conifer regeneration, and woody debris, contribute to torching behavior and fire hazard. However, they can be important resources in their own right. Shrubs may be important as browse for large mammals. Conifer regeneration cannot be eliminated completely without eliminating the future stand. Woody debris is important for nutrient cycling, soil quality, and small animal habitat. Site-specific treatment plans may need to acknowledge these resources and allow for their continued presence on a site, probably through small-scale variability.

Silvicultural Objectives and Assumptions

The thinning treatments used in this paper to reduce fire hazard have an objective of either (1) moving the stand toward an uneven-aged condition or (2) moving the stand toward an even-aged condition. In addition, the objective of some treatments is to limit the amount of basal area removed; that is, to limit the amount of change in stand structure. For forest types prone to wind throw, there is a further restriction on removal of basal area to reduce wind throw risk.

Although some authors (Graham and others 1999) have suggested that thinning uneven-aged stands does not reduce fire hazard in some cases, the uneven-aged treatments described in this study were specifically designed to take enough trees to reduce TI, CI, and the risk of crown fire. The treatments remove most of the smaller trees (ladder fuels) and some larger trees as well.

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. spruce–fir and lodgepole pine forest types are in the high severity category, and all other forest types are in the surface or mixed severity category. Spruce–fir and lodgepole pine types also have high wind throw risk when stands are heavily thinned. Treatments may also differ between wildland urban interface (WUI) areas and wildland areas.

Development of Prescriptions

The silvicultural prescriptions used in this analysis were developed in collaboration with USDA Forest Service regional silviculturists and fuel specialists. The need for this analysis was discussed with regional silviculturists at the USDA Forest Service National Silviculture workshop in Granby, Colorado, in 2003. Two regional silviculturists, Michael Landrum and Barry Bollenbacher, volunteered to work with the authors of this paper to develop prescriptions.

In June 2004, the authors held a special meeting of silviculturists and fuel specialists in Denver, which included Landrum, Bollenbacher, regional fuels specialist Paul Langowski, and others. Participants discussed both uneven-aged and even-aged treatments, particularly the validity of uneven-aged management to mimic landscape-scale effects. Consensus was reached that the prescriptions and approach were valid.

The resulting prescriptions and screening approach were presented to the larger group of silviculturists and fuel specialists at the USDA Forest Service National Silviculture workshop at Lake Tahoe, Nevada, in 2005, along with the complete study plan and preliminary results. Preliminary results were also reviewed by Langowski and Susan Stewart, the leader of the USDA Forest Service National Program for Fuels Reduction.

This process allowed us to use a set of generic prescriptions that could be applied broadly across the conifer forests of the West and that were credible from both silvicultural and fire hazard reduction perspectives.

Table 3—Treatment scenarios by silviculture method[a]

Land area, forest type, and silvicultural method	Treatment by limit on basal area removed: Up to 50%	No limit	Up to 25%
All land (all forest types except spruce–fir and lodgepole pine)			
Uneven-aged—Thin all diameters, leaving greater numbers of small trees	1A	1B	—
Uneven-aged—Thin all diameters, leaving fewer small trees, and more large trees	2A	2B	—
Even-aged—Thin from below	3A	3B	—
WUI land only (spruce–fir and lodgepole pine only)			
Even-aged—Thin from below until CI and TI goals are met	4B	—	4A

[a]Fuel hazard reduction objectives are to thin until CI>25 and TI>25 *or* CI≥40, subject to specified limits on proportion of basal area that may be taken.

Spruce–fir and lodgepole pine forest types are excluded from treatments except in WUI areas. The reason for this exclusion is that 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. The reason for thinning these types in WUI areas is concern for public safety, and thinning is substituted for normal recurring severe fire (Table 3).

These are only potential treatments, and the actual selection of fire hazard reduction activities by public or private land owners may differ. The selection of treatments will vary by location and will be influenced by detailed local land management constraints from applicable land and resource management plans. Private owners of lodgepole pine or spruce–fir stands might, in fact, choose to thin them to reduce fire hazard on their land, although it seems likely that when markets are available, these treatments will resemble commercial timber harvests more than the prescriptions described here.

Forest health related treatments are another reason why both public and private land managers might choose to treat these forest types. For example, there is growing evidence that the likelihood of unusually large outbreaks of bark beetles is becoming more common in the interior West. This is believed to be a result of global warming (Logan and Bentz 1999, Powell and Logan 2005). Treatment of these forest types when they occur over large expanses of mature stands will undoubtedly be proposed to alter stand structural conditions in an attempt to mitigate the impact of insect outbreaks. Again, it is uncertain how such treatments would be designed, because simply thinning the stands might not have the desired result.

Salvage logging to remove dead trees could also add considerably to the potential supply of biomass and merchantable timber. However, in recent years, new salvage operations have generally been quite contentious when they occur on public land, and they tend to focus on larger commercial-sized trees.

Treatments for Forests With Surface and Mixed Severity Fire Regimes

Treatments 1A and 1B, uneven-aged, high structural diversity—Under these treatments, the number of trees remaining in each dbh class after treatment is intended to contribute equally toward the 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 dbh classes until TI≥25 and CI≥25, or CI≥40. For treatments 1A and 1B, the intent of the SDI calculation method is to remove trees to reduce overall SDI, to have trees remaining in each dbh class contribute an equal amount to SDI, and to have the overall treatment meet a fire hazard target.

In Scenario 1A, removals are limited to 50% of initial basal area; in 1B, there is no limitation. These scenarios result in treated forest structures that retain high structural diversity while retaining intact understories of small trees.

Achieving CI targets under this scenario is usually accomplished by removal of some trees from the larger dbh classes, which lowers crown bulk density. The TI targets can be achieved if the stand does not contain large numbers of small trees or the crowns are not low to the ground. When removals are restricted to less than 50% of the original basal area, we avoid impairing the integrity of the overstory forest under this uneven-aged scenario. This limit is based on author experience (W. Shepperd) and published uneven-aged silviculture guidelines (Alexander and Edminster 1977, Burns 1983) and was imposed to ensure that some semblance of an uneven-aged forest structure is maintained after treatment.

Treatments 2A and 2B, uneven-aged, limited structural diversity—In these scenarios, we attempted to achieve TI and CI goals by removing as many small trees as possible while still retaining sufficient numbers of smaller trees to ensure a continued uneven-aged structure. Trees are removed so that the remaining trees in a large dbh class contribute more to the residual stand SDI than do trees in a smaller dbh classes. For treatments 2A and 2B, the SDI calculation method thins to a disproportional distribution of SDI over dbh classes to meet a fire hazard target. We used a distribution that retains more of the larger trees while maintaining a residual distribution of trees where each successively larger dbh class has fewer trees than the preceding smaller dbh class. This is different from treatments 1A and 1B, where each dbh class in the residual stand contributes equally toward the SDI.

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% of the original basal area has been removed (treatment 2A). This scenario typically produces stands with open understories that contain some small trees, but usually retains a good stocking of trees in the largest diameter classes. However, as in treatments 1A and 1B, CI goals are difficult to achieve when tree crowns are low to the ground. These situations illustrate that fire risk reduction goals cannot always be achieved by just removing trees. Further treatment using either mechanical pruning or prescribed fire may be needed to raise live crown height and achieve TI goals.

Treatments 3A and 3B, even-aged, thin from below— These treatments emulate an intermediate thinning in forests being managed under 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 dbh classes until CI and TI goals are met (treatment 3B), or until 50% of the original basal area has been removed (treatment 3A). Although the 50% BA removal restriction may prevent CI and TI goals from being achieved, more drastic thinning fundamentally alters the character of the forest and should not be prescribed without careful consideration of all potential ecosystem effects. We assumed that these even-aged treatments to reduce wildfire risk would be intermediate treatments to control forest stocking prior to maturity and not harvest treatments meant to regenerate the forest. While heavier removals might be justified to reduce crown fire risk, those cases require a full analysis of ecosystem trade-offs.

These scenarios best suit forest types subject to surface or mixed-severity fire regimes and should not be used with tree species subject to wind throw. In some cases, these scenarios fail to achieve TI goals in spite of the complete removal of the smallest dbh classes. This usually occurs when stocking consists of long-crowned tree species, or in very open-grown conditions with low live-crown heights. This again illustrates the need to utilize pruning or prescribed fire to reduce wildfire risk.

Treatments for Forests With High Severity Fire Regimes

Treatments 4A and 4 B, even-aged, thin from below (spruce–fir and lodgepole pine forest types)—These treatments are similar to treatments 3A and 3B, except BA removals are restricted to 25% of existing stocking (treatment 4A) or 50% of existing stocking (treatment 4B). The 25% removal restriction is based on published partial cutting guidelines and is necessary to avoid wind throw in shallow-rooted tree species like spruce, fir, and lodgepole pine (Alexander 1986a,b). This restriction further limits the achievement of CI and TI goals. The dilemma in these cases is finding a means to reduce crown fire risk without having the forest unravel from wind throw. In these forest types, which are typically subject to stand replacement fire regimes, the solution may have to be achieved at the landscape scale rather than within individual stands, and may involve patch cutting or type conversion of some stands to non-forest to break up the continuity of fuels within landscapes.

Estimation of Harvesting Costs

Harvesting cost, the cost to provide biomass ready for transport at the roadside, was estimated for each plot using the Fuel Reduction Cost Simulator (FRCS) calculation routine from My Fuel Treatment Planner[6] (Biesecker and Fight 2005, Fight and others 2006). The FRCS estimates harvest cost, 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:

- Manual-felling log-length system—Trees felled manually and manually cut to log length, then transported to landing by tractive vehicles.
- Manual-felling whole-tree (WT) system—Trees felled manually and whole trees transported to landing by tractive vehicles.
- Mechanized-felling WT system—Mechanized felling and transport of whole trees to landing by tractive vehicles.
- Cut-to-length (CTL) system—Trees felled by mechanized single-grip harvesters; limb and buck trees and resulting logs transported to landing by tractive vehicles.

Cable-yarding systems:

- Manual-felling log-length system—Trees felled manually and manually cut to log length, then conveyed to the landing by cable yarder.
- Manual-felling WT system—Trees felled manually and whole trees conveyed to the landing by cable yarding.
- Manual-felling WT/log-length system—Trees felled manually; trees to be sold as sawlogs bucked, then conveyed; trees to be sold as chips, conveyed as whole trees by cable yarder to the landing.
- CTL system—Trees felled by mechanized single-grip harvesters; limb and buck trees and logs conveyed to landing by cable yarder.

For both ground and cable systems, whole trees may be cut into logs at the landing; logs to be hauled in log form are

[6]See www.fs.fed.us/pnw/data/myftp/myftp_home.htm

loaded on trucks; and logs, tops, and branches to be chipped are processed and blown into chip vans.

The cost for the least expensive system suitable for the site was assigned to each site. For our calculations, we assume (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 in. dbh 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 may be reduced if small dbh trees are not removed from the site and treated by another method (e.g., pile and burn). While it is our intent to estimate costs that include removal of branches and tops, we chose to allow log-length systems (which do not remove tops and branches) to ensure we could assign a harvest cost to almost all plots. Where stand conditions permit their use, WT systems will tend to be less expensive than CTL systems. To the extent that log-length systems are chosen, we may have underestimated actual harvest costs that would include removal and chipping of all tops and branches.

Estimation of Product Revenue

We assume the same product values and costs for hauling as those used in the 2003 Assessment to allow comparison of results:

Delivered sawlogs (vol. from main stem ≥7 in. dbh) = $290/10³ board feet (mbf)

Delivered chips (vol. from wood and bark <7 in. dbh, tops and branches of larger trees) = $30/odt

Haul distance = 100 miles

Haul cost = $0.35/odt/mile

The assumed prices are used only as a means to give a rough estimate of the extent to which wood revenue from alternate treatments may cover costs. Actual prices vary by location and over time. To retain similar prices over time, if woody biomass supply is increased, it would be necessary to expand the number and/or capacity of businesses to use wood.

Computations and the Fuel Treatment Evaluator

The Fuel Treatment Evaluator 3.0 (FTE), a web-based tool, was used to select areas for treatment, apply treatments to FIA plot data, and generate removal information and maps.[7] The FTE is flexible in changing many but not all the features of the analysis. Many different features can be varied, including (1) treatment areas by state, county, and circle about a point or polygon, (2) forest types to be treated, (3) minimum cubic feet of merchantable wood removed, (4) maximum slope for treated plots, (5) land ownership, (6) wildland urban interface (WUI) or non-WUI, and (7) silvicultural treatments 1A through 4B. Features that cannot be changed include the CI and TI limits for selecting a plot (that is, 25 mph) and CI and TI targets after treatments.

[7]For Fuel Treatment Evaluator 3.0, see http://ncrs2.fs.fed.us/4801/fiadb/fire_tabler_us/rpa_fuel_reduction_treatment_opp.htm

Findings

Area Treated

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% of the maximum SDI for the plot forest type.

Our assessment imposed the following additional or different screens on plots and identified 23.9 million acres for thinning. Taken together, these restrictions define the following timberland as "eligible" for treatment:

- Plots with (1) CI<25 or (2) TI<25 and CI<40 are included.
- Wetter counties west of the Cascade Mountains in Oregon and Washington are excluded.
- Inventoried roadless areas are excluded.
- High severity fire regime forest types are excluded (lodgepole and spruce–fir), except in WUI areas.

After treatments were applied to these 23.9 million acres, we selected only the area that would provide 300 ft³ (about 4 odt) of merchantable wood per acre. The final number of acres to be treated ranges from 7.2 to 18.0 million acres depending on the treatment (Table 4). Treatments 3A and 4A together would treat 7.2 million acres total and treatments 1B and 4B together would treat 18.0 million acres total. Acres receiving simulated treatment come from all FRCCs,[8] but more than 85% are from FRCCs 2 and 3 (Table 5).

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 based on the number of FIA timberland survey plots (and the acres they represent) that fall within WUI boundaries in these states. The WUI acres included for treatment come from both the high severity and surface/mixed severity forest type groups. For the high severity types (spruce–fir and lodgepole pine), 0.5 million acres of WUI were included for treatment (4A or 4B, Table 5). For all other forest types, 0.3 to 0.7 million acres of WUI were included as part of treatments 1A to 3B (Table 5). So, the total WUI area to be treated could be

[8]Fire regime condition classes (FRCCs) refer to the degree to which the current fire regime (fire recurrence, intensity, severity, etc.) 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

Table 4—Area treated by State and treatment scenario

	Area treated (10^6 acres)							
	Treatments for forest types other than spruce–fir and lodgepole pine						Treatments for spruce–fir and lodgepole pine; even–aged treatments in WUI area only	
	Uneven-aged treatments				Even–aged treatments			
	High structural diversity		Limited structural diversity					
	50% BA removal limit	No BA removal limit	50% BA removal limit	No BA removal limit	50% BA removal limit	No BA removal limit	25% BA removal limit	50% BA removal limit
State	1A	1B	2A	2B	3A	3B	4A	4B
AZ	0.5	0.5	0.4	0.4	0.1	0.1	0	0
CA	4.4	4.4	3.8	3.8	1.5	1.5	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
NV	0	0	0	0	0	0	0	0
NM	0.9	1.0	0.8	0.8	0.3	0.3	0	0
OR	2.2	2.2	1.8	1.8	0.9	0.9	0	0
SD	0.1	0.1	0.1	0.1	0	0	0	0
UT	0.4	0.4	0.4	0.4	0.2	0.2	0	0
WA	1.8	1.8	1.5	1.5	0.6	0.6	0	0
WY	0.3	0.4	0.3	0.3	0.2	0.2	0	0
Total	17.1	17.5	14.8	15.1	6.7	6.8	0.5	0.5

Table 5—Treatable area by fire regime condition class (FRCC)

	Area (10^6 acres)					
	FRCC					
2003 Assessment treatment scenario	1	2	3	Other	Total	WUI only
Low and mixed severity[a]						
Total acres where TI or CI < 25	3.0	9.8	8.7	2.3	23.9	1.0
1A Uneven-aged high diversity, 50% limit	2.1	7.1	6.5	1.5	17.1	0.7
1B Uneven-aged high diversity, no limit	2.1	7.2	6.6	1.6	17.5	0.7
2A Uneven-aged limited diversity, 50% limit	1.9	6.1	5.5	1.4	14.8	0.6
2B Uneven-aged limited diversity, no limit	1.9	6.2	5.5	1.4	15.1	0.6
3A Even-aged thin from below, 50% limit	1.0	2.8	2.2	0.6	6.7	0.3
3B Even-aged thin from below, no limit	1.0	2.9	2.3	0.7	6.8	0.3
High severity WIU only						
4A Even-aged thin from below, 25% limit	0.0	0.4	0.0	0.0	0.5	0.5
4B Even-aged thin from below, 50% limit	0.0	0.4	0.1	0.0	0.5	0.5

Table 6—Treatable area and biomass removal by slope for treatments 2B and 3B in surface and mixed severity fire regimes

Treatment scenario	≤40% slope	>40% slope	Total
	Area (10^6 acres)		
Total acres TI or CI < 25	15.8	8.8	23.9
2B Uneven-aged limited diversity, no BA limit	9.7	5.3	15.1
3B Even-aged thin from below, no BA limit	3.9	2.9	6.8
	Biomass (10^6 odt)		
2B Uneven-aged limited diversity, no BA limit	279.1	165.6	444.7
3B Even-aged thin from below, no BA limit	99.0	78.5	177.5
	Average biomass removal (odt) per acre		
2B Uneven-aged limited diversity, no BA limit	28.7	31.1	29.5
3B Even-aged thin from below, no BA limit	25.1	27.2	26.0

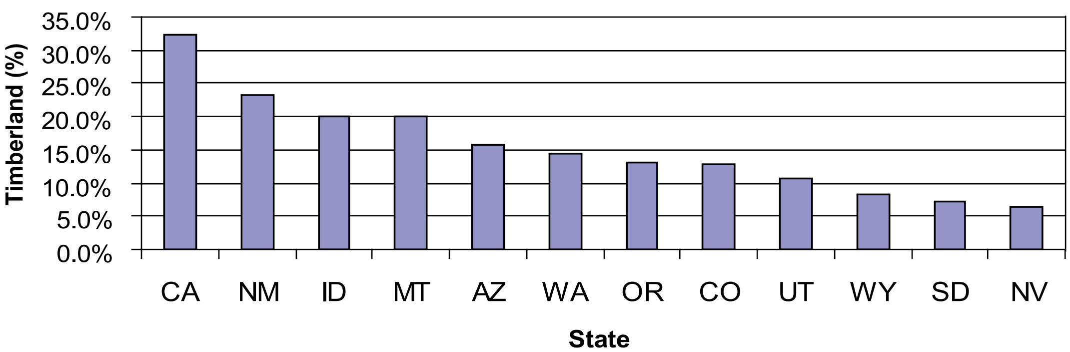

Figure 1—Proportion of timberland acres to be thinned by treatment 1A by state.

0.8 to 1.2 million acres (0.5 plus 0.3 or 0.7). Our treatments would suggest removals on 20% to 30% of the timberland WUI acres (0.8 to 1.2 million acres of 4.1 million acres). To the extent that communities decide to treat WUI areas larger than those defined by Stewart and others (2003), we would be underestimating the acres of severe fire regime forest types that may be treated with positive average net revenue.

One factor that influences the expense of thinning is the slope of the land to be treated. Treatments on steeper slopes tend to be more expensive. About 60% of the acres selected for treatments are on <40% slopes (Table 6). Treatment 1B would thin the largest area—17.5 million acres or about 14% of all timberland in the 12 western states. The highest percentage of timberland to be treated would be in California (33%), followed by New Mexico (24%), Idaho (21%), Montana (21%), and Arizona (16%) (Fig. 1).

Fire Hazard Reduction

Four possible fire hazard reduction outcomes were identified for the 23.9 million acres that are eligible for treatment (acres with CI<25 or TI<25 and meeting other initial screens):

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

Uneven-aged treatments (1A, 1B, 2A, 2B) are able to treat more than twice as many eligible acres as the even-aged treatments (3A, 3B); that is, 14.6 to 17.5 million acres vs. 6.7 to 6.8 million acres (Table 4). This is because of the requirement that removals include 300 ft^3 of merchantable wood and because uneven-aged treatments take a higher proportion of volume as larger (merchantable) trees.

Uneven-aged treatments with the 50% BA removal limit (treatments 1A and 2A) treat 71% and 61% of eligible acres, respectively. These treatments reach the medium or high hazard reduction goal for 34% and 38% of eligible acres, respectively (Table 7). When the BA limit for the uneven-aged treatments is removed (treatments 1B and 2B), a slightly greater percentage of acres is treated (72% and 62%), and all these treated acres reach the medium or high hazard reduction goal. Moving from treatment 1A to 1B and

Table 7—Fire hazard outcomes: Percentage of treatable acres[a]

Treatment scenario	Percentage of treatable acres by goal achieved						
	Low (50% BA limit reached)[b]	Medium CI>40 only	High CI>25, TI>25	Total achieving medium or high target	Total receiving some treatment	Not treated (<300 ft^3 merchantable wood/acre)	Total
1A Uneven-aged High diversity, 50% limit	28	21	22	44	71	29	100
2A Uneven-aged Limited diversity, 50% limit	31	18	12	30	61	39	100
3A Even-aged Thin from below, 50% limit	21	4	3	7	28	72	100
1B Uneven-aged High diversity, no limit	0	23	49	72	72	28	100
2B Uneven-aged Limited diversity, no limit	0	14	48	62	62	38	100
3B Even-aged Thin from below, no limit	0	6	22	28	28	72	100

[a]Total treatable area = 23.9 million acres.
[b]Treatment is done but BA limit is reached.

thereby reaching a hazard reduction target on each acre treated requires an increase in biomass removal of 25% (502 to 627 million odt). To move from treatment 2A to 2B requires a 16% increase in removals (Table 8), which includes the biomass from the additional 1% of acres treated.

Even-aged (thin from below) treatment with the 50% BA removal limit (treatment 3A) treats 28% of all eligible acres (Table 4) but reaches the medium or high hazard reduction goal for only 7% of the eligible acres (Table 7). When the 50% limit is removed (treatment 3B), 28% 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% increase in biomass removals, which includes the biomass from the additional 1% of acres treated.

In general terms, for forest area where there is both the need to obtain a minimum level of merchantable wood to help 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 (Table 7). For treatments 1A and 2A, a higher proportion of eligible area is treated and reaches a target (44% and 30%, respectively) compared with treatment 3A (7%).

Figures 2 to 13 show number of acres by CI and TI group before and after treatment. Uneven-aged treatments are effective in raising CI but not as effective in raising TI. Conversely, even-aged treatments are very effective in raising both TI and CI to >25 mph. Even-aged treatment 3B reached CI>25 and TI>25 on 95% of all acres treated. Only 5% of acres met the CI>40 target alone. In comparison, uneven-aged treatment 2B reached CI>25 and TI>25 on 62% of acres, with 24% reaching CI>40.

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

Biomass Removed

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% of FRCC-3 acres are treated, 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 to 640 million odt (Table 8). Treatments 3A and 4A would provide 169 million odt total and treatments 1B and 4B, 640 million tons total. The uneven-aged treatments (1A to 2B) generate more than twice as much biomass as the even-aged treatments (3A and 3B), because more than twice as many acres would be treated and more biomass would be removed per acre (Tables 4 and 8).

The distribution of biomass removed by tree size differs greatly between the uneven-aged and even-aged treatments. 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-in. dbh class, with progressively less biomass taken from larger dbh classes (Forest Service 2003, Fig. 6). In contrast, our uneven-aged treatments provide most biomass in ≥21 in. dbh classes (Table 9, Figs. 14 and 15).

Table 8—Initial standing biomass and biomass removals

State	Initial vol. biomass on treatable land (10^6 odt)	Biomass removed (10^6 odt) by various treatment scenarios per State							
		Treatments for forest types other than spruce–fir and lodgepole pine						Treatments for spruce–fir and lodgepole pine; even–aged treatments in WUI area only	
		Uneven-aged treatments				Even–aged treatments			
		High structural diversity		Limited structural diversity					
		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
AZ	29.5	11.0	13.1	8.9	9.9	2.3	2.6	0.1	0.1
CA	411.7	172.3	222.4	117.4	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
NM	41.9	18.3	24.1	15.0	18.4	5.5	6.3	0	0
OR	214.5	78.3	88.7	55.1	56.2	25.5	26.3	0	0
SD	3.9	1.3	1.4	1.1	1.1	0.3	0.3	0	0
UT	18.2	7.5	9.8	6.9	8.0	2.9	3.2	0	0.1
WA	128.7	50.0	60.9	38.8	42.4	14.9	15.4	0	0.0
WY	17.7	7.5	10.3	7.3	8.9	3.6	4.5	0.1	0.2
Total	1254.4	502.0	626.8	384.6	444.7	161.6	177.5	7.6	12.8

Table 9—Biomass removed by treatment scenario and tree dbh class

Tree dbh class (in.)	Biomass removed (odt/acre) by various treatment scenarios per dbh class							
	Treatments for forest types other than spruce–fir and lodgepole pine						Treatments for spruce–fir and lodgepole pine; even–aged treatments in WUI area only	
	Uneven-aged treatments				Even–aged treatments			
	High structural diversity		Limited structural diversity					
	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
2	0.3	0.5	0.5	0.6	0.8	0.9	0.4	0.5
4	1.1	1.5	1.5	1.7	2.2	2.4	1.5	2.2
6	2.0	2.4	2.7	3.0	4.9	5.1	4.9	5.4
8	2.7	3.3	3.5	3.8	6.2	6.5	4.8	6.6
10	3.0	3.6	3.5	3.9	4.4	4.7	3.5	5.8
12	2.8	3.4	3.0	3.3	2.5	2.8	0.7	2.1
14	2.3	2.8	2.1	2.4	1.2	1.4	0.4	0.9
16	1.7	2.2	1.4	1.6	0.6	0.8	0.4	0.8
18	1.3	1.7	0.8	1.0	0.4	0.5	0	0.2
20	0.8	1.2	0.4	0.5	0.3	0.3	0	0
22+	11.4	13.2	7.0	7.7	0.7	0.6	0	0
Total	29.4	35.8	26.4	29.5	24.2	26.0	16.6	24.5

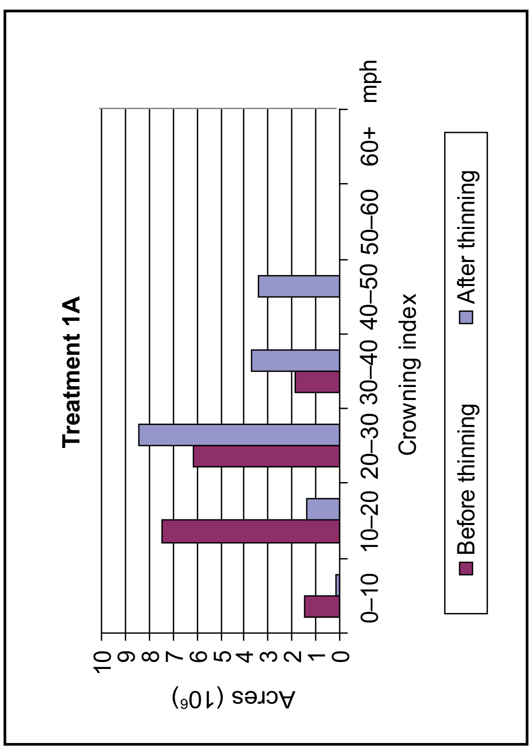

Figure 2—Acres of timberland by crowning index before and after treatment 1A.

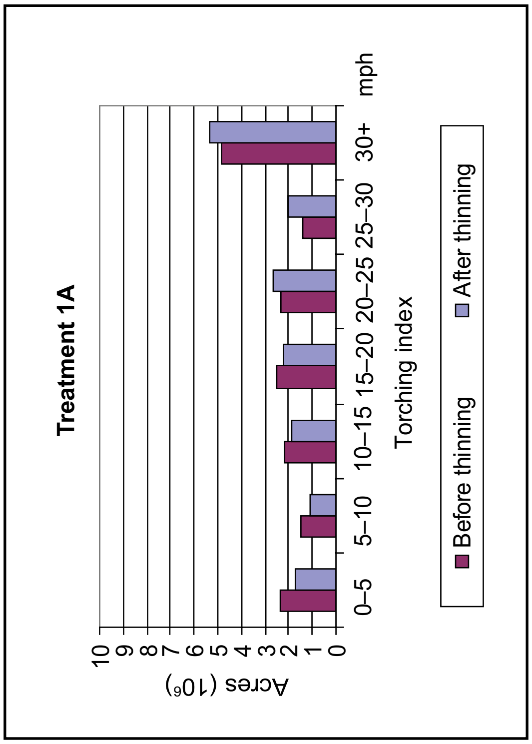

Figure 3—Acres of timberland by torching index before and after treatment 1A.

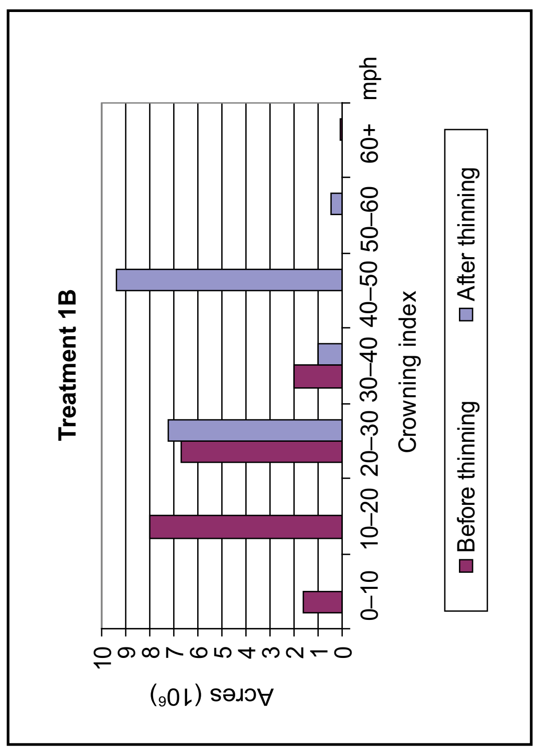

Figure 4—Acres of timberland by crowning index before and after treatment 1B.

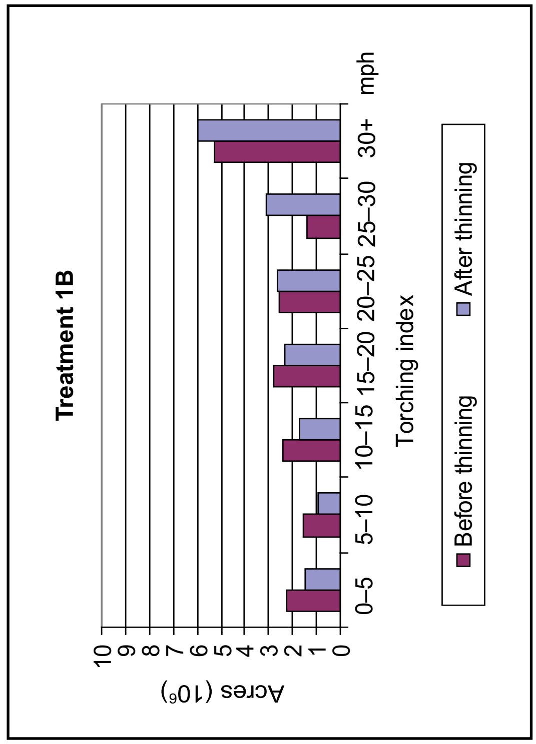

Figure 5—Acres of timberland by torching index before and after treatment 1B.

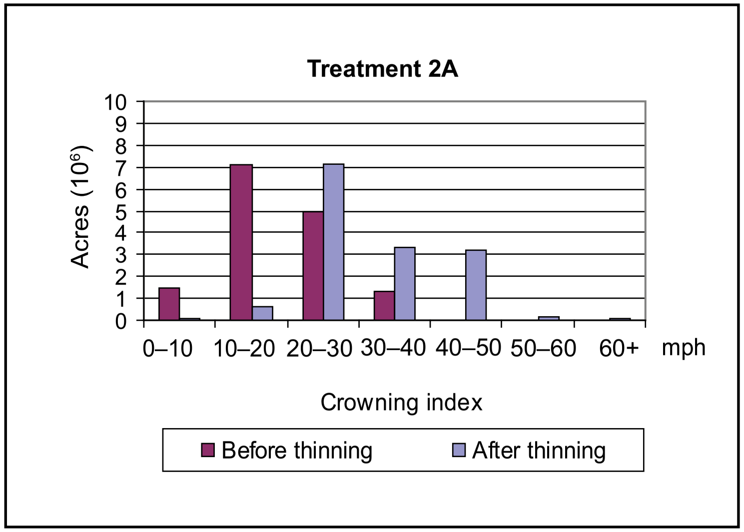

Figure 6—Acres of timberland by crowning index before and after treatment 2A.

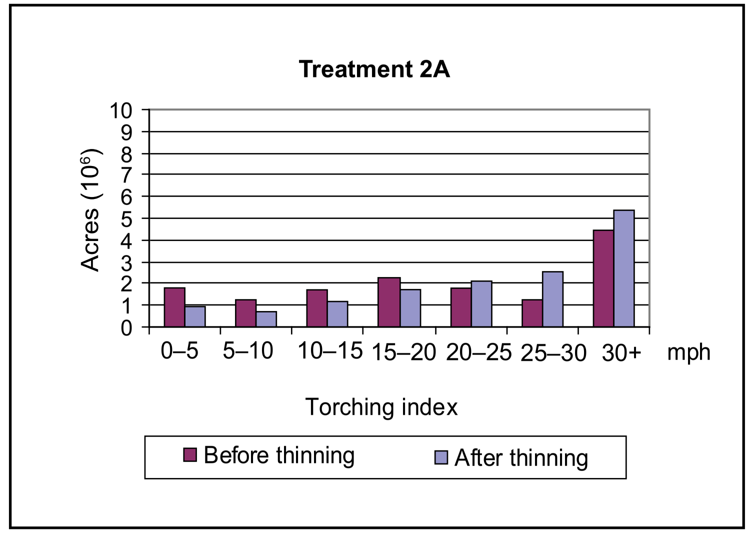

Figure 7—Acres of timberland by torching index before and after treatment 2A.

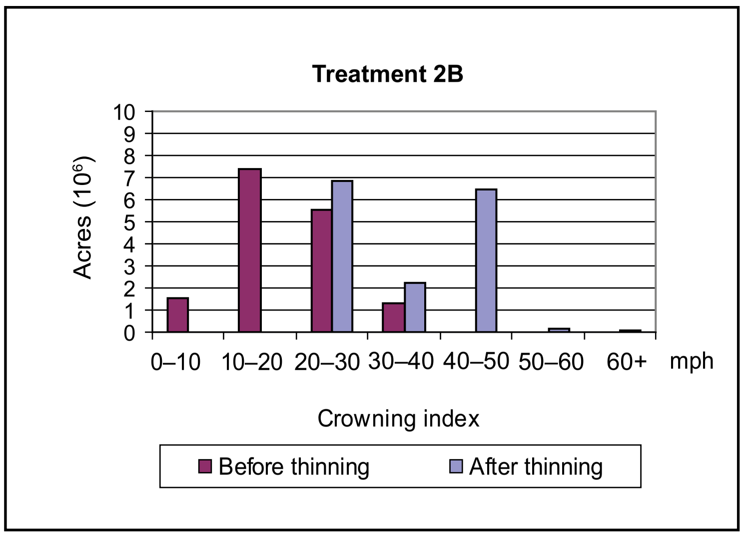

Figure 8—Acres of timberland by crowning index before and after treatment 2B.

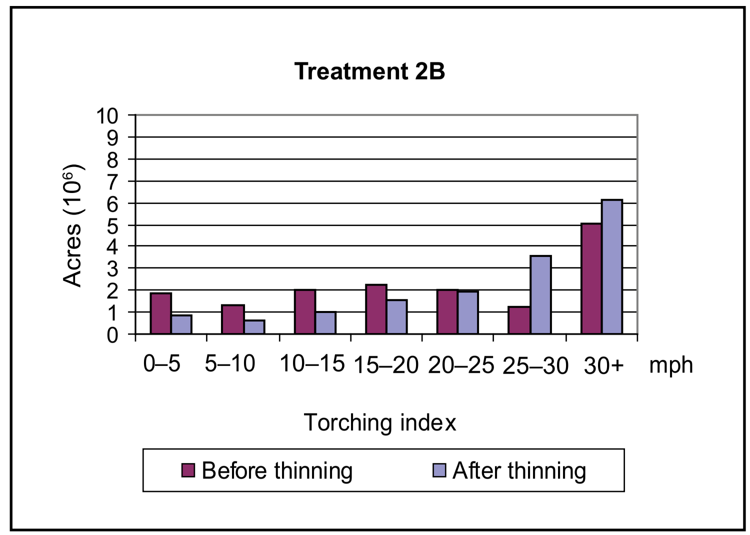

Figure 9—Acres of timberland by torching index before and after treatment 2B.

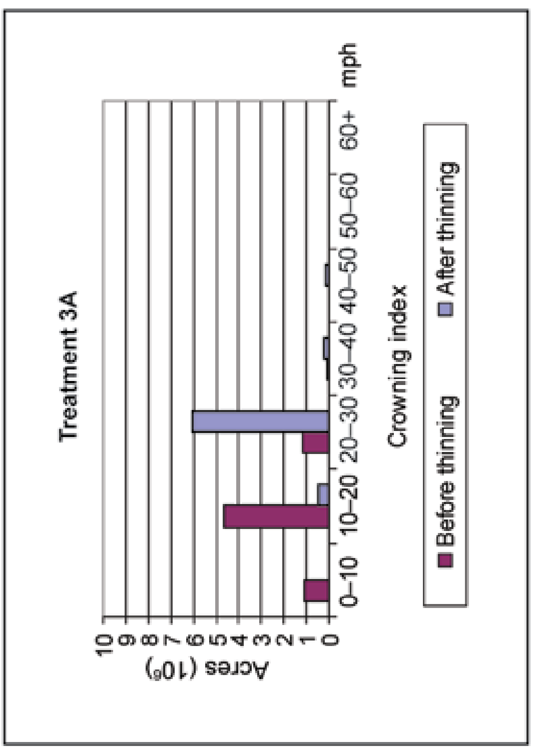

Figure 10—Acres of timberland by crowning index before and after treatment 3A.

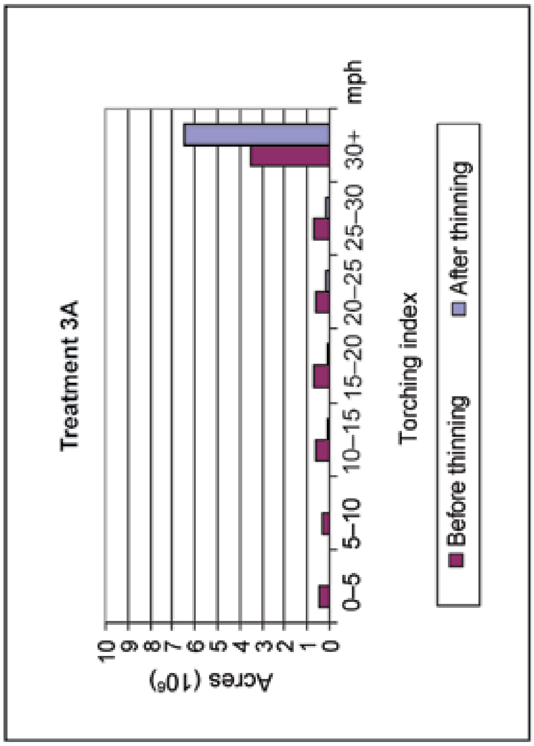

Figure 11—Acres of timberland by torching index before and after treatment 3A.

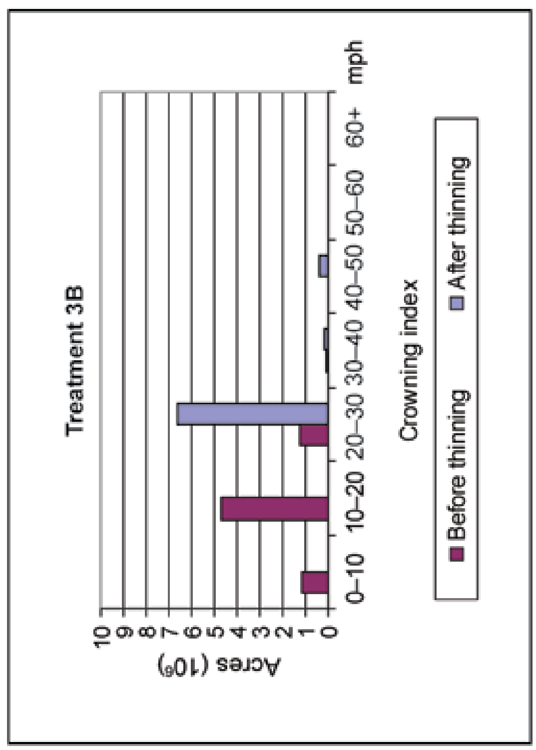

Figure 12—Acres of timberland by crowning index before and after treatment 3B.

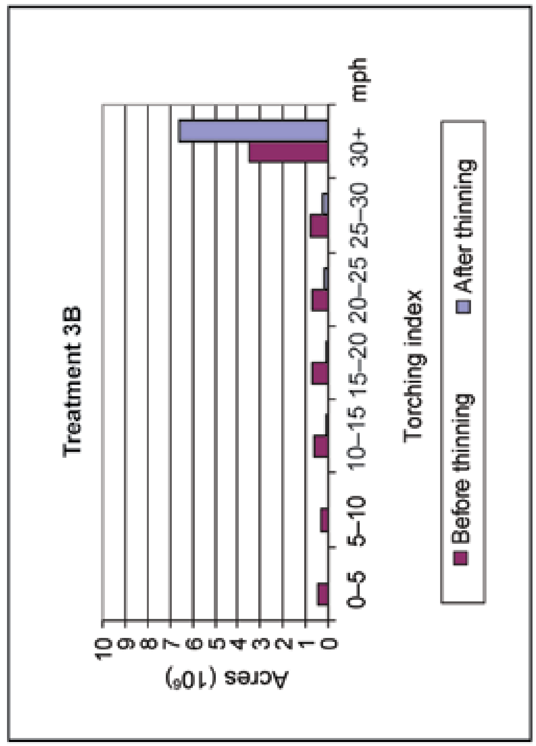

Figure 13—Acres of timberland by torching index before and after treatment 3B.

Why do our uneven-aged treatments remove so much more volume from the large-diameter trees in comparison to the 2003 Assessment? Since both studies used the stand density index (SDI) to specify uneven-aged treatment removals,[9] the difference in biomass removal distribution must be due to differences in (1) the plots selected for treatment and/or (2) the amount of removals required to reach the TI and CI targets. There were no explicit fire hazard reduction targets in the 2003 Assessment. Our focus on plots with CI<25 or TI<25 and plots that provide at least 300 ft^3/acre may or may not select plots with a higher density of larger trees. However, our uneven-aged treatments definitely remove a higher proportion of biomass on plots to achieve the hazard reduction targets. The residual SDI for our treated stands averages ≤20% of maximum SDI, versus 30% of maximum SDI for acres treated in the 2003 Assessment.

One reason that stands were thinned to an average of 20% of maximum SDI is the need to thin some stands enough to achieve CI>40 when we cannot attain TI>25. We found that the primary reason that plots did not attain TI>25 was low canopy base height; on many trees, the branches reached the ground.

Given concerns about harvesting large trees, there are at least two ways we could reduce harvest of large trees and reach CI>25 and TI>25. Essentially, we want to attain TI>25 so we do not have to thin enough to reach CI>40. We can help attain TI>25 by pruning branches to raise canopy base height and by decreasing surface fuels. Further study is needed to determine the effect of such changes on acres that would be treated and net revenues.

Even though our uneven-aged treatments (1A–2B) provide more than 25% of biomass from trees ≥22 in. dbh, they still provide 20% to 31% of biomass from trees <9 in. dbh. This is similar to the results of the 2003 Assessment, where 28% for biomass was derived from trees <9 in. dbh (Table 9). Our even-aged treatments provide 57% to 58% of biomass from trees <9 in. dbh, with most biomass coming from the 8-in. dbh class (7.0–8.9 in.) (Table 9, Figs. 16 and 17).

The proportion of all acres treated and biomass removed that comes from National Forest land is about 55% for both even-aged and uneven-aged treatments (Tables 10 and 11). These proportions increase to about 60% for all Federal land. The state of Washington has the highest proportion of biomass removals from private land (65%–70%).

Composite Treatment With Thinning Over an Extended Period

The estimated total biomass removal would be performed over a number of years. To prepare a single estimate of possible removals per year over time, we constructed a composite scenario that combines treatments 1A, 3A, and 4A. Since we do not know to what degree even-aged or uneven-aged thinning treatments will be used, a composite scenario was formed in which half the area needing treatment (low TI or CI) (12 million acres) was considered for uneven-aged treatment 1A and the remainder considered for even-aged treatment 3A. For any geographic area, we computed biomass yield under this combination of treatments as the simple average of their yields. The composite also includes biomass removal from uneven-aged treatment 4A—treatment of spruce–fir and lodgepole pine forest types in WUI areas.

This assumption about the application of alternate treatments is for illustration only. The selection of the silvicultural treatment method is ultimately a stand-level decision based on the unique characteristics of each site and specific management objectives.

Our composite scenario would treat 12.4 of the 23.9 million acres identified with CI<25 or TI<25; more than half the eligible area does not meet the 300-ft^3/acre criterion. The 12.4 million acres would provide 339 million odt of biomass. If 0.5 million acres were treated per year, then 13.7 million odt of total biomass would be provided per year over a period of 25 years. One-half million acres is chosen as a tentative annual treatment area to represent a plausible estimate, assuming current budgets and program emphasis continue for wood fiber and biomass production. Current annual harvest of roundwood in western states is 3.3 billion ft^3 or about 50 million odt/year (Smith and others 2004). This mix of thinning treatments over 25 years would increase annual biomass use by an additional 13.7 million odt/year compared to 50 million odt/year, or about 27% over the current level.

If 50% of the biomass were used for higher value products, then the remaining 50%, or 6.8 million odt/year, would be available for fuel. After 25 years, more area will have moved into the higher fire hazard class, and continued thinning would likely be required on at least 0.5 million acres/year. About half the area would be on National Forest land in the 12 selected western states.

The total number of acres treated and the total amount of biomass removed could be increased by lowering the 300-ft^3/acre merchantable wood requirement, removing the limitation to harvest no more than 50% of basal area, treating more area with the uneven-aged treatment, treating areas with less stand replacement fire hazard (higher CI and TI), protecting against fire hazard for “severe summer drought” conditions (vs. “drought summer” conditions), or requiring hazard to be reduced by more than indicated by the current CI and TI targets. For example, if the requirement to provide at least 300 ft^3/acre were eliminated, then 23.9 million acres of timberland would be thinned (vs. 12.4 million acres) and 388 million odt would be removed in the 12 western states (vs. 339 million odt).

[9]The stand density index (SDI) method specifies how many trees will remain after treatment in each dbh class by specifying the fraction of total SDI that each dbh class will contribute.

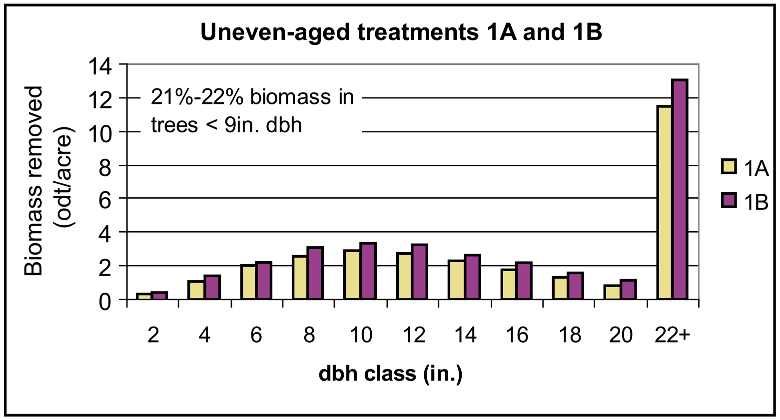

Figure 14—Biomass removal for uneven-aged treatments 1A and 1B by dbh class.

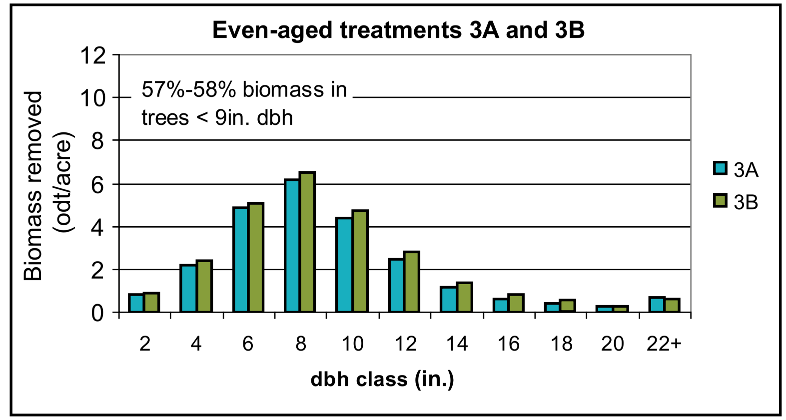

Figure 15—Biomass removal for uneven-aged treatments 3A and 3B by dbh class.

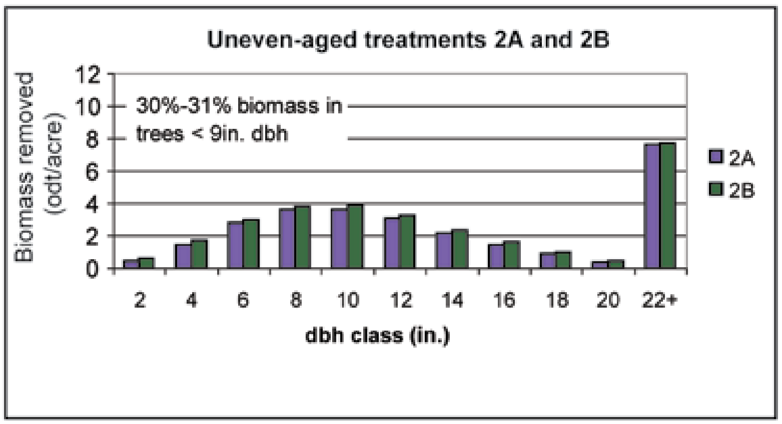

Figure 16—Biomass removal for even-aged treatments 2A and 2B by dbh class.

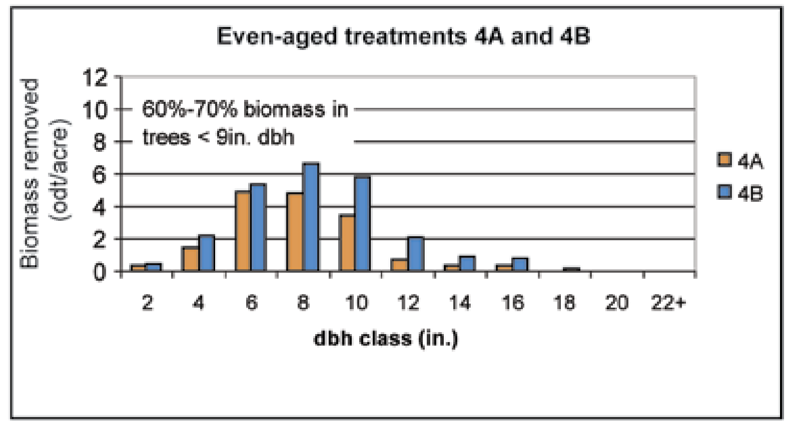

Figure 17—Biomass removal for even-aged treatments 4A and 4B by dbh class.

Table 10—Acres to be treated and biomass removal by State and timberland ownership for treatment 2A: Uneven-aged with limited structural diversity and 50% BA removal limit.

		Acres treated					Biomass to be removed (odt)				
State	Acres eligible for treatment	Total	National Forest	Other Federal	State and local gov.	Private	Total	National Forest	Other Federal	State and local gov.	Private
AZ	844,451	413,222	316,982	0	0	96,240	8,901,267	6,867,401	0	0	2,033,866
CA	5,467,486	3,478,730	1,766,799	20,323	16,269	1,675,339	117,381,106	65,070,309	588,359	1,737,615	49,984,823
CO	1,945,105	1,054,944	482,649	157,398	12,542	402,355	17,398,116	8,943,541	2,351,401	211,267	5,891,907
ID	3,004,862	2,182,848	1,343,161	135,434	202,480	501,773	57,689,068	35,658,467	3,539,846	5,327,192	13,163,563
MT	4,440,812	2,540,589	1,505,048	149,000	138,483	748,058	58,892,268	38,243,579	3,243,330	2,636,406	14,768,953
NV	25,232	9,304	1,092	0	0	8,212	192,926	20,144	0	0	172,782
NM	1,404,418	787,752	512,827	0	54,071	220,854	14,997,999	10,664,842	0	1,051,653	3,281,504
OR	3,112,455	1,789,192	806,719	284,183	52,430	645,860	55,089,353	28,254,642	8,399,877	2,137,529	16,297,305
SD	223,963	80,251	80,251	0	0	0	1,062,287	1,062,287	0	0	0
UT	523,600	353,186	200,433	30,689	39,798	82,266	6,934,122	3,906,055	321,374	1,133,697	1,572,996
WA	2,264,744	1,534,488	686,527	36,119	216,675	595,167	38,766,200	18,400,940	1,095,845	6,430,970	12,838,445
WY	621,160	338,519	113,335	94,639	9,121	121,424	7,280,875	3,066,847	1,809,850	147,305	2,256,873
Total	23,878,288	14,563,025	7,815,823	907,785	741,869	5,097,548	384,585,587	220,159,054	21,349,882	20,813,634	122,263,017

Table 11—Acres to be treated and biomass removal by State and timberland ownership for treatment 3A: Even-aged with 50% BA removal limit

		Acres treated					Biomass to be removed (odt)				
State	Acres eligible for treatment	Total	National Forest	Other Federal	State and local gov.	Private	Total	National Forest	Other Federal	State and local gov.	Private
AZ	844,451	70,231	53,333	0	0	16,898	2,300,432	1,882,860	0	0	417,572
CA	5,467,486	1,455,312	803,633	2,247	15,575	633,857	37,423,559	19,151,946	47,758	1,149,565	17,074,290
CO	1,945,105	429,960	217,922	67,048	8,171	136,819	5,956,266	2,818,756	1,048,046	105,005	1,984,459
ID	3,004,862	1,105,848	642,028	90,900	110,619	262,301	26,649,934	14,295,157	2,224,638	2,664,724	7,465,415
MT	4,440,812	1,536,571	999,233	77,359	67,275	392,704	36,497,740	25,363,725	1,803,451	1,278,766	8,051,798
NV	25,232	9,304	1,092	0	0	8,212	142,687	14,990	0	0	127,697
NM	1,404,418	293,242	188,486	0	22,511	82,245	5,466,340	3,553,175	0	573,497	1,339,668
OR	2,137,653	857,370	275,806	148,508	44,611	388,445	25,486,043	8,467,099	3,399,133	1,773,572	11,846,239
SD	223,963	21,271	21,271	0	0	0	272,654	272,654	0	0	0
UT	523,600	167,257	84,645	16,043	9,087	57,482	2,868,301	1,473,863	200,898	214,992	978,548
WA	2,287,432	569,146	278,986	5,649	118,078	166,433	14,913,636	7,262,337	121,295	3,578,001	3,952,003
WY	621,160	162,644	85,293	44,401	0	32,950	3,612,843	2,180,780	902,466	0	529,597
Total	22,926,174	6,678,156	3,651,728	452,155	395,927	2,178,346	161,590,435	86,737,342	9,747,685	11,338,122	53,767,286

Treatment Costs and Biomass Revenues

Average treatment costs per acre for even-aged treatments are about the same as that for uneven-aged treatments for the acres selected for each treatment (Tables 12 and 13), though fewer acres are selected for even-aged treatments, because fewer acres are able to provide the needed 300 ft^3/acre with the even-aged treatment.

Average per acre biomass gross revenues are significantly higher from the uneven-aged treatments, primarily because uneven-aged treatments average 67% of volume in the form of higher value sawlogs compared with 50% for even-aged treatments (Table 14). In either case, it is interesting that effective treatments tend to remove some commercial timber, and this could become a major bone of contention with environmental groups who recognize the need for fire hazard reduction treatments but do not advocate commercial timber harvest (Brown 2002). 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 13). When average revenues exceed average treatment costs across the selected treatment area, this means that positive net revenues on some acres would more than cover net costs on other acres. With a $20/green ton subsidy for chips, average net revenues per acre are also positive for uneven-aged treatments 2A and 2B 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. The positive average net revenues for all treatments on gentle slopes indicate we could relax the 300-ft^3 merchantable wood requirement (and still have positive average net revenue over all acres) and treat more acres with gentle slopes.

Treatment Costs

The estimated cost to harvest and move biomass to the roadside is less than $1,000/acre for about 50% of acres treated for all treatments except treatment 4A. For selected forest types in WUI areas, treatment 4A limits removal to no more than 25% of basal area and at the same time requires removal of 300 ft^3/acre. This combination appears to select timberland area with relatively low harvest costs per acre (Table 14). Acres on gentle slopes (≤40%) tend to cost less than $1,000/acre and acres on steep slopes (>40%) more than $1,000/acre (Figs. 18 and 19). The average cost for treatments on gentle slopes is $692 to $986/acre, while costs on steep slopes average $1,811 to $1,975/acre (Table 13).

Even though the even-aged treatments call for more trees to be harvested per acre on average (Table 12), their harvesting cost per acre is lower than or about the same as the cost 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; it is possible that when trees are smaller, a more automated (less expensive) harvesting system may be selected on average than when there are several large trees to be harvested. Costs for even-aged treatments would also be kept low by the requirement to provide a certain volume in larger trees to provide at least 300 ft^3/acre, thus limiting the proportion of small trees.

Biomass Revenues

Using biomass values from the 2003 Assessment, we estimate that the 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. dbh goes to higher value products and the remainder is delivered as fuel chips (Table 14). If all volume goes for chips, the delivered value varies from $430 to $640/acre.

For uneven-aged treatments 1A and 1B, about 67% of biomass is merchantable wood from trees ≥7 in. dbh. For even-aged treatments 3A and 3B, about 50% of biomass is merchantable wood. Also, the tonnage of biomass removed per acre is somewhat greater for treatments 1A and 1B compared with 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 the 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 13).

Net Revenue (Costs) From Treatments

Average net revenue from uneven-aged treatments (1A, 1B, 2A, 2B) is positive for gentle slopes ($278 to $690/acre) and negative for steep slopes (−$9 to −$490/acre). Average net revenue for even-aged treatments (3A, 3B) is $400 to $700 less than that for uneven-aged treatments in the same slope category (Table 13). 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) are estimated to 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—only plots with higher hazard and resulting in less removal per acre to meet target, and/or higher harvest costs per acre.

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 13). If merchantable wood is sold as chips rather than sawlogs, then all treatments, on both gentle and steep slopes, incur a net cost (Table 13).

For the product values and haul costs assumed, we could relax the requirement for 300 ft^3/acre for uneven-aged treatment for sites with gentle slope (resulting in more acres treated) and still have average positive net revenue per acre.

Table 12—Cumulative percentage of acres treated by harvest cost per acre for each treatment scenario

Treatment scenario[a]	Total acres (10^6)	Cumulative percentage of acres treated by harvest cost per acre												
		$0 to 199	$200 to 399	$400 to 599	$600 to 799	$800 to 999	$1,000 to 1,199	$1,200 to 1,399	$1,400 to 1,599	$1,600 to 1,799	$1,800 to 1,999	$2,000 to 2,199	$2,200 to 2,399	$2,400 to 2,399
1A Uneven-aged	17.1	1	10	25	37	47	55	61	66	73	82	89	96	100
2A Uneven-aged pine	14.8	0	9	25	39	48	56	62	66	74	84	91	98	100
3A Even-aged	6.7	0	4	21	33	42	48	52	55	66	79	89	100	100
4A Even-aged pine, SF, WUI	0.5	0	13	36	58	72	76	80	82	90	95	98	100	100
1B Uneven-aged	17.5	1	10	23	34	43	50	56	62	69	77	84	91	100
2B Uneven-aged pine	15.1	0	9	24	38	47	55	60	65	72	81	88	94	100
3B Even-aged	6.8	0	4	20	31	39	46	50	54	64	77	86	96	100
4B Even-aged pine, SF, WUI	0.5	0	9	27	40	55	62	71	77	82	84	90	96	100

[a]Pine is lodgepole pine; SF, spruce–fir.

Table 13—Estimated gross operational costs to cut and move wood biomass to roadside

Treatment	Biomass removed		Average treatment cost ($/acre)	
	trees/acre	odt/acre	Slope ≤40%	Slope >40%
1A	223	29	847	1,759
2A	300	26	819	1,825
3A	446	24	854	1,966
4A	285	17	692	1,811
1B	301	36	986	1,839
2B	348	30	882	1,864
3B	477	26	902	1,975
4B	381	25	952	1,822

Table 14—Estimated revenues minus fuel treatment costs and transport costs[a,b]

Treatment	Total merchantable wood from main stem of trees ≥7 in. dbh: mbf/acre		Total merchantable wood from main stem of trees ≥7 in. dbh: odt/acre		Other biomass: trees <7 in. dbh; tree tops + branches ≥7 in. dbh (odt/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 for higher value products and chips ($/acre) given $20/green ton subsidy		Gross revenue with merchantable wood for higher value products ($/acre)		Gross revenue with merchantable wood for chips ($/acre)	
	≤40% slope	>40% slope	≤40% slope	>40% slope	≤40% slope	>40% slope	≤40% slope	>40% slope	≤40% slope	>40% slope	≤40% slope	>40% slope	≤40% slope	>40% slope	≤40% slope	>40% slope
1A	7.3	7.6	19.5	20.3	9.5	9.9	$533	($319)	($992)	($1,910)	$912	$79	$2,393	$2,500	$503	$526
2A	6.0	6.5	16.0	17.5	9.8	10.1	278	(490)	(971)	(1,862)	669	(87)	2,022	2,200	472	498
3A	4.1	5.0	11.0	13.4	12.6	11.6	(112)	(833)	(973)	(1,882)	391	(368)	1,568	1,800	501	499
4A	3.0	3.9	7.9	10.5	8.7	6.2	(144)	(726)	(766)	(1,550)	202	(478)	1,120	1,325	349	304
1B	8.8	9.1	23.6	24.4	11.8	12.2	686	(9)	(1,161)	(1,917)	1,159	479	2,910	3,006	619	639
2B	6.6	8.5	17.6	22.9	11.0	5.8	356	(120)	(1,023)	(1,909)	798	114	2,240	2,650	528	431
3B	4.5	5.4	12.0	14.4	13.2	12.7	(86)	(762)	(1,024)	(1,892)	441	(255)	1,692	1,944	530	542
4B	5.0	6.4	13.5	17.3	11.0	7.5	(18)	(266)	(1,073)	(1,615)	421	36	1,789	2,093	480	420

[a]Assumptions: Delivered sawlog value = $290/mbf; delivered chip value = $30/odt; transport cost = $0.35/odt; haul distance = 100 miles.
[b]Merchantable wood: Main tree stem ≥7 in. dbh.

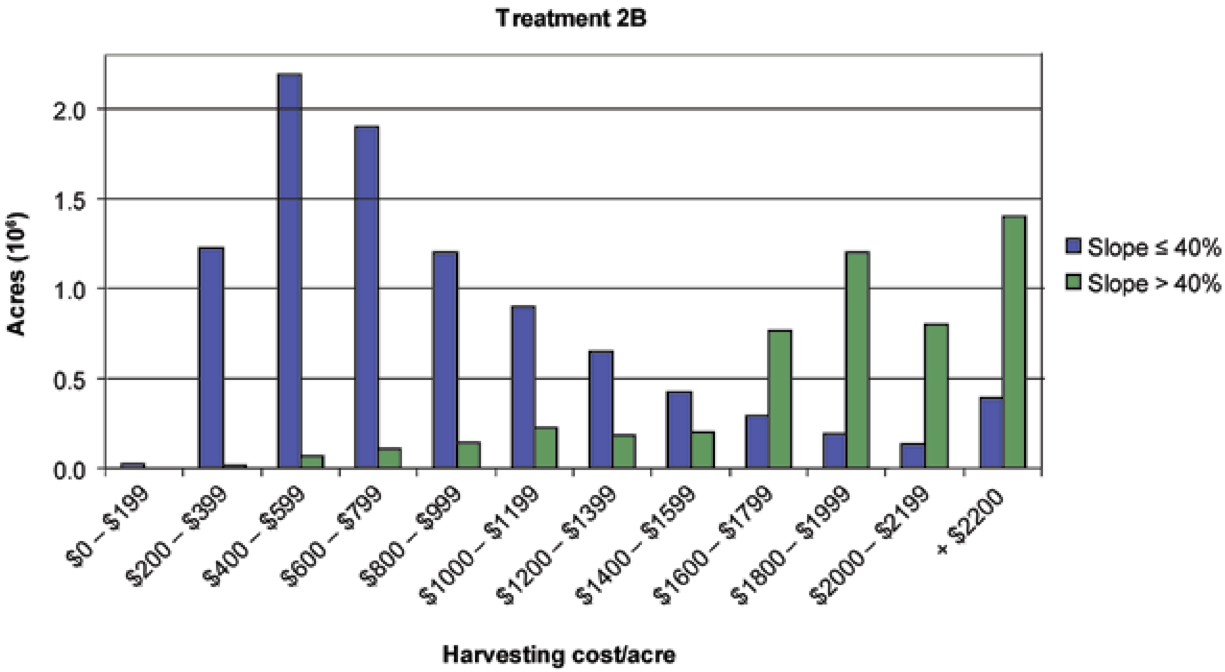

Figure 18—Timberland treated by treatment 2B by harvest cost category and slope.

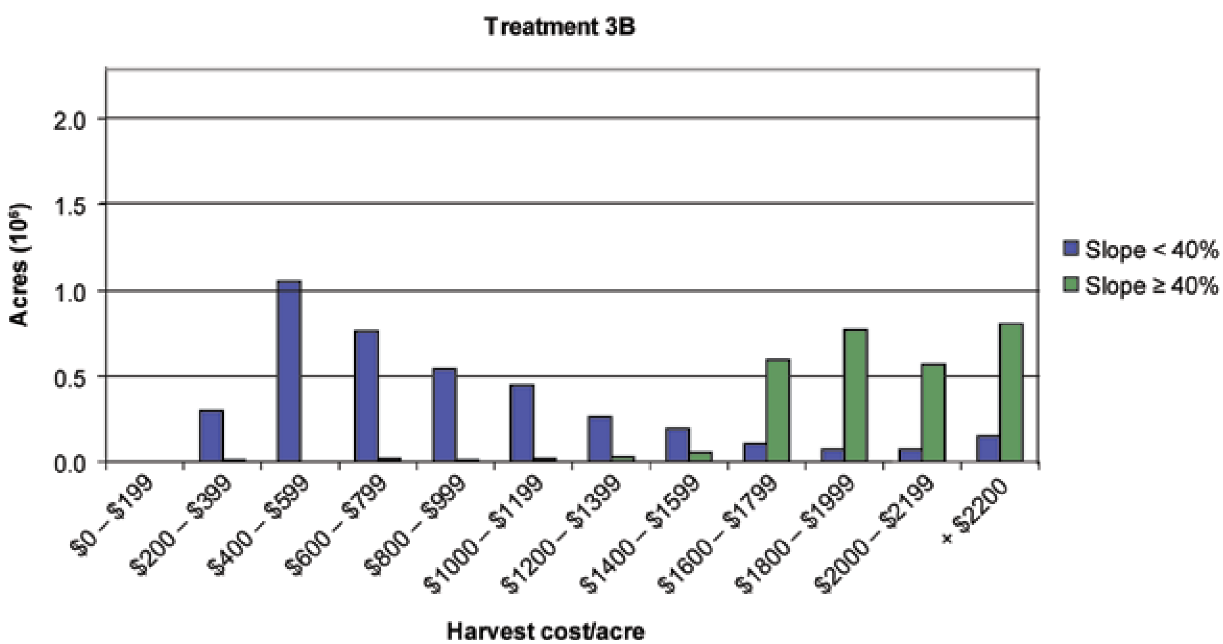

Figure 19—Timberland treated by treatment 3B by harvest cost category and slope.

But for treatments 3A and 3B on gentle slopes and for all treatments on steep slopes, we would need to require more than 300 ft^3 of merchantable wood per acre to attain positive average net revenue per acre.

Biomass Removal Maps

Figures 20 to 25 indicate locations where biomass removal from thinning on timberland are most likely to provide net revenues per acre for large areas needing treatment to reduce fire hazard based on the CI and TI criteria used here. These areas 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 that needs treatment and would provide at least 300 ft^3 per acre is found primarily in northern California, northern Idaho, western Montana, western Washington, and central Colorado (Fig. 24).

The maps do not imply that these are the only places where fire hazard is high. That was not the intent of our analysis. Our intent was to find the places where fire hazard is high and treatments to reduce it would provide a substantial and sustainable supply of wood that could offset treatment costs.

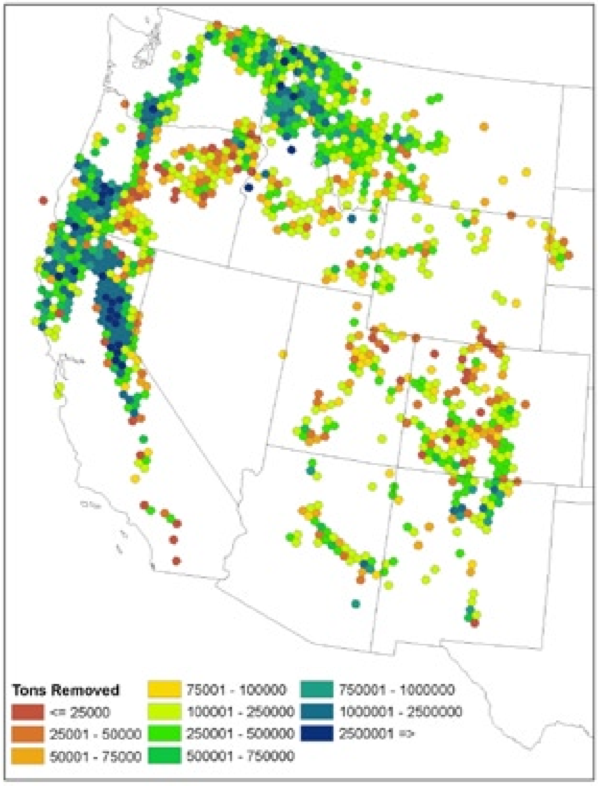

Figure 20—Total biomass removed per 160,000-acre area for uneven-aged treatment 1A.

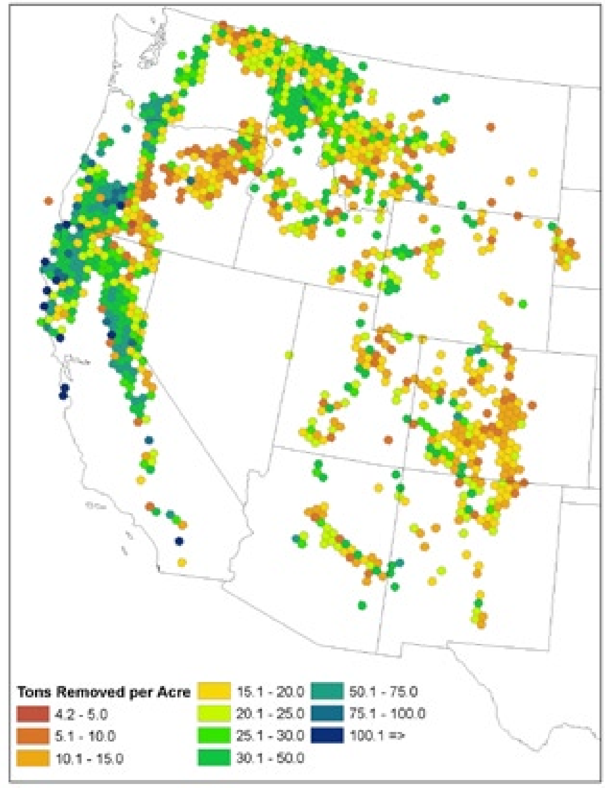

Figure 21—Average biomass removed per acre for uneven-aged treatment 1A.

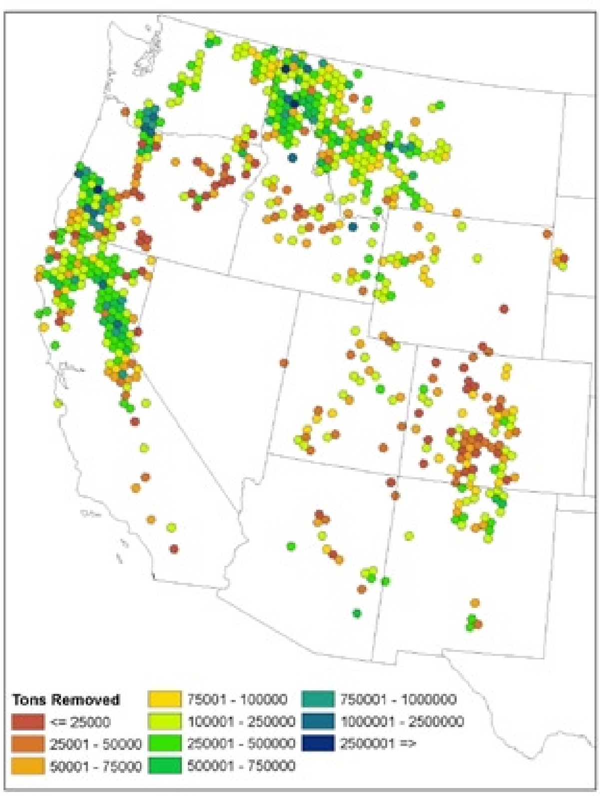

Figure 22—Total biomass removed per 160,000-acre area for even-aged treatment 3A.

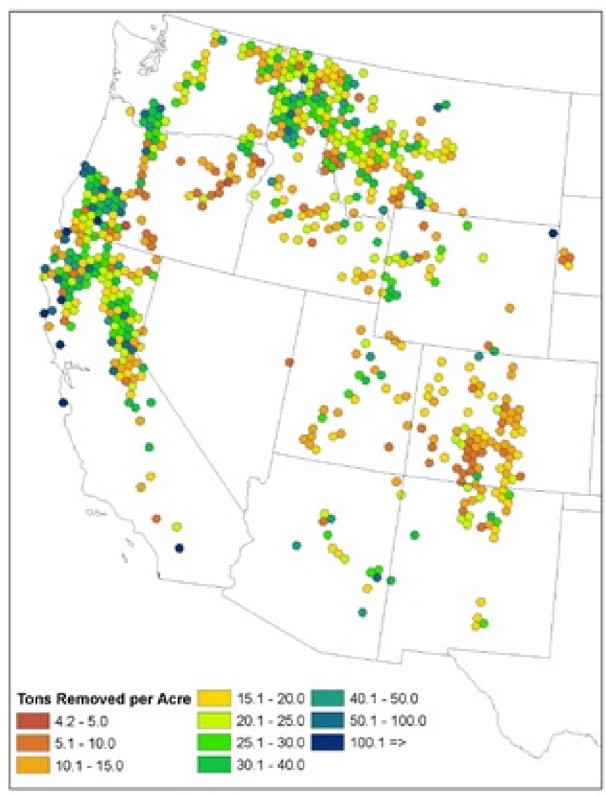

Figure 23—Average biomass removed per acre for even-aged treatment 3A.

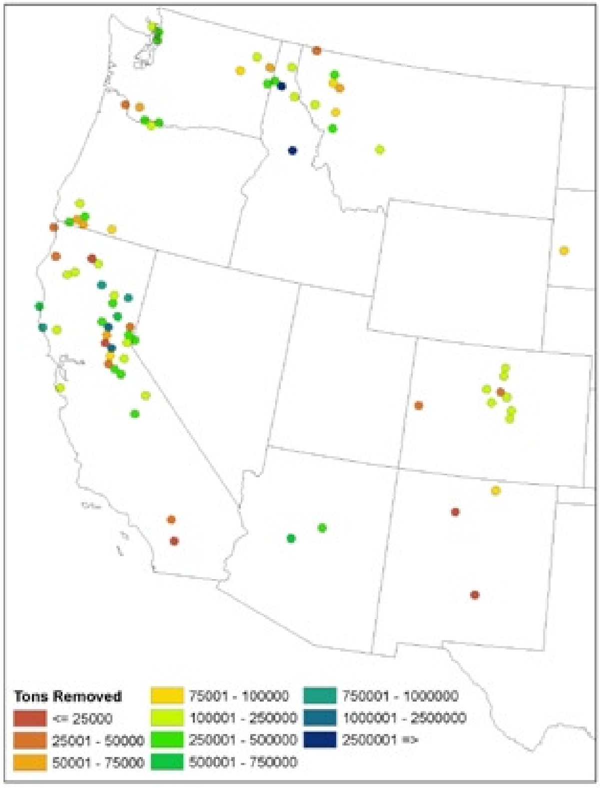

Figure 24—Total biomass removed per 160,000-acre area for uneven-aged treatment 1B in WUI areas only.

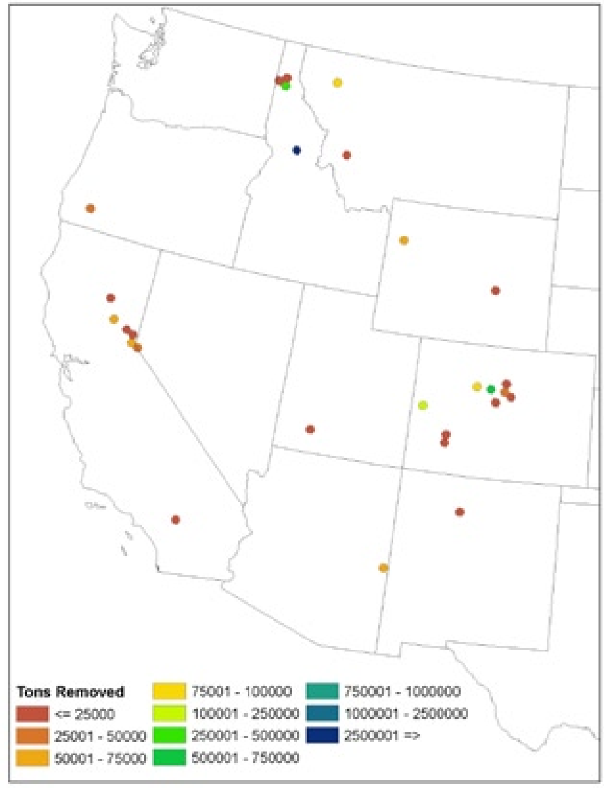

Figure 25—Total biomass removed per 160,000-acre area for even-aged treatment 4A (spruce–fir and lodgepole pine) in WUI areas.

The importance of a commercial timber component in financing fire hazard reduction treatments has been shown in several previous analyses (Barbour and others 2004, Fight and others 2004, Fried and others 2004).

As also shown here, without this commercial component, the treatments are frequently not effective and would not pay for themselves.

Our analysis suggests that the easiest places to implement large-scale operations that meet objective criteria (CI and TI thresholds) for fire hazard reduction and have a chance of paying for themselves are northern California, northern and central Idaho, western Montana, central and northern Oregon, and Washington. Our analysis does not suggest that these are the only places where fire hazard reduction opportunities exist or even where selected stand-level operations could pay for themselves. On the contrary, we found that only 10 %to 30 % of the area that meets our criteria for high fire hazard appears in the areas identified on these maps. In addition, the current analysis does not address the other two components of our analytical framework; i.e., the places where there is a reasonable business opportunity and the places where such large-scale operations would be socially acceptable. Consideration of those two components will be covered in future analyses.

The important point to take away from these maps is that the areas where the most wood could become available from fire hazard reduction treatments is concentrated in the northern half of the West. This is not really a surprising result because that is the most heavily forested part of the West. It is also where most of the remaining forest products industry is concentrated. An existing industry will undoubtedly make it easier to implement treatments where many small trees with little commercial value need to be processed. The manufacturing facilities needed to process this currently non-merchantable material are easier to establish near existing wood products facilities, because the critical mass of other mill residues and human expertise needed to support activities such as wood-fired electrical generation or other manufacturing processes that could use this material are already available. The presence of an existing wood residue stream will be important in creating confidence that sufficient raw materials will be available over the long run. In general, manufacturing processes that use these materials, e.g., electrical generation from wood residues, wood composites, pulp and paper, mulching, etc., are not stand-alone operations but are integrated with more traditional solid wood product operations.

Results From Thinning Treatments Given Alternate Assumptions

Treatments 2B and 3B were applied under the following alternate assumptions:

1. Only treat Oregon and Washington counties previously excluded from analysis.
2. Only treat plots that provide <300 ft^3 of merchantable wood per acre.
3. Assume delivered sawlog value as $175/mbf and delivered chip value as $15/odt.

Results for the treatment 2B and 3B base cases, where no assumptions were changed, are shown in Table 15. Results under alternate assumptions show (1) there is substantial acreage in Oregon and Washington that, if treated, may provide positive average net revenue, (2) acres that provide <300 ft^3 of merchantable wood per acre yield small tonnage per acre, on average, with higher costs per acre, and (3) with lower product prices, average net revenue could be negative for all treatments on both gentle and steep slopes.

Thinning treatments 2B and 3B for previously excluded Oregon and Washington counties would treat 4.9 and 3.7 million acres, respectively, for a respective increase of 34% and 54% over acres treated in the respective base cases. The average amount of biomass removed per acre would be notably higher than the averages for the base cases: 45 vs. 30 odt/acre for treatment 2B, and 39 vs. 26 odt/acre for treatment 3B. The net revenues would be $650 to $750 odt/acre more than those for the base case, where merchantable wood is used for higher value products.

The average amount of biomass removed for acres providing <300 ft^3 is 4.3 and 3.5 tons/acre for treatments 2B and 3B, respectively, or 13% to 15% of the average removal per acre for the respective base cases. It would cost an average $120 to $1350 more per acre in net cost (depending on treatment and slope) to treat these acres than to treat the acres providing ≥ 300 ft^3/acre (Table 15).

With hypothetical lower sawlog and chip values, thinning treatments 2B and 3B provide negative average net revenue for both gentle and steep slope sites (−$566 to −$1573/acre), which is lower than base case net revenues by $700 to $1,100/acre.

Concluding Remarks

Of a total timberland area of 127 million acres, this study identified 59.2 million acres of timberland in 12 western states with a high risk for stand replacement fire (CI or TI < 25 mph). After excluding roadless areas, selected counties in Oregon and Washington, and high severity fire regime forest types in non-wildland–urban interface (WUI) areas, we identified 23.9 million acres eligible for treatment.

The proportion of 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. The proportion of treated acres that will attain a given hazard reduction will also depend on whether removals are limited or not limited to taking 50% of initial basal area.

Under our assumptions, uneven-aged treatments 1A, 2A, 1B, and 2B will be able to treat a higher proportion of acres with resulting positive net revenue than will even-aged treatments 3A and 3B. Moreover, for treated acres, if there is a 50% limit on basal area removed, 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.

If sawlogs are sold for higher value products and if smaller trees, tops, and branches are sold for chips, then we estimate the following net revenues for uneven- and even-aged treatments 1B and 3B.

- Uneven-aged treatment 1B is able to treat the greatest number of eligible acres (72% or 17.2 million acres), meet the hazard reduction target on those acres, and provide average net revenues (costs) of $686 and −$9/acre on gentle and steep slopes, respectively. Given these positive net revenues, the proportion of acres that could be treated could be higher than 72% and still result in positive average net revenue; that is, lower the 300 ft^3/acre merchantable wood requirement.
- Even-aged treatment 3B is able to treat 28% or 6.7 million eligible acres, meet the hazard reduction target on those acres, and provide average net revenues of −$86 and −$762, on gentle and steep slopes, respectively. The proportion of steep slope acres treated would need to be reduced to attain positive average net revenue; that is, raise the 300 ft^3/acre merchantable wood requirement.

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 are 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. However, net revenue for the even-aged treatments remains negative for steep slopes.

The eligible acres and treated acres are predominately in California, Idaho, and Montana, which include 65% to 70% 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% of this timberland—treatments 1A through 3B would cover 0.3 to 0.7 million acres and

Table 15—Results under alternate thinning treatment assumptions[a]

Assumption[b]	Treatment	Area treated (10^6 acres)	Biomass removed (10^6 odt)	Biomass removed per acre (odt)	Average net revenue ($/acre) ≤40% slope	>40% slope
Base case (no change)	2B	15.1	444.7	29.5	356	(120)
Include only Oregon and Washington[c]	2B	4.9	223.1	45.1	1,108	642
Include only plots providing <300 ft^3 merchantable wood per acre	2B	8.8	38.1	4.3	(151)	(1,231)
Lower product prices	2B	15.1	444.7	29.5	(566)	(1,189)
Base case (no change)	3B	6.8	177.5	26.0	(86)	(762)
Include only Oregon and Washington[c]	3B	3.7	145.3	38.7	562	(100)
Include only plots providing <300 ft^3 merchantable wood per acre	3B	16.8	59.5	3.5	(208)	(1,496)
Lower product prices	3B	15.1	444.7	29.5	(798)	(1,573)

[a]Lower product price assumptions: Delivered sawlog value =$175/mbf; delivered chip value = $15/odt; transport cost = $0.35odt.
[b]Other assumptions for treatment case remain the same.
[c]Previously excluded.

treatments 4A and 4B, an additional 0.5 million acres. Harvest costs may be higher in WUI areas, so our net revenue estimates may be too high (as found in the Lake Tahoe Basin and Jackson Hole/Yellowstone regions). The WUI average net revenue is highest for treatment 4B on gentle slopes (−$18/acre).

Given the concern about removing large trees by uneven-aged thinning, it may be possible to reduce large tree harvest with supplementary treatments to increase torching index rather than thinning to reach a high crowning index. Supplementary treatments could include pruning and reducing surface fuels. These changes to the uneven-aged thinning would decrease biomass yield, number of acres providing 300 ft^3/acre, and gross revenue per acre. They are also likely to increase harvest costs and decrease net revenue per acre. Further study is needed to evaluate these possible changes.

Our estimates of acreage to be treated, biomass yield, and net revenues are sensitive to a range assumptions. In particular, if timberland in the western counties of Oregon and Washington were treated, biomass removal could increase up to 50% from our base case treatments. Also, the net revenue per acre from treatment will vary by location and over time with changing market conditions, and it could be lower or higher than our estimated average amounts.

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