# ESTIMATING WOODY BIOMASS SUPPLY FROM THINNING TREATMENTS TO REDUCE FIRE HAZARD IN THE U.S. WEST

Kenneth E. Skog and R. James Barbour

## ABSTRACT

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

---

Ken Skog is project Leader USDA Forest Service, Forest Products Laboratory, PO Box 2398, Madison, WI 53726-2398. FAX: 608-231-9592, e-mail: kskog ( at ) fs.fed.us, and Jamie Barbour is Program Manager, USDA Forest Service, Pacific Northwest Research Station, PO Box 3890, Portland, OR 97208-3890. FAX: 503-808-2130

## INTRODUCTION

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

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

For 12 western states (Table 1), we selected timberland acres (land capable of producing 20 ft3 /acre/ year and not withdrawn from timber utilization) 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. For full results of our study see Skog and others (2006). Results are compared to those from a previous Forest Service assessment (Forest Service 2003).

The 12 western states have 127 million acres of timberland and 77 million acres of other forest land (Miles 2006). 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 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 timberland thinning treatments.

The terms “woody biomass” and “biomass” refer to all wood in all trees—in the main stem, tops, and branches of all sizes of trees. “Merchantable wood” refers to the main stem of all live trees with a diameter at breast height (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.

## METHODS

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

### Screens to Identify Area Eligible for Treatment

Of the 126.7 million acres of timberland in the 12 selected western states (Miles 2006a), 23.9 million acres passed an initial screen and were considered eligible for treatment. A second screen was applied when considering a specific silvicultural treatment and 23.9 million acres 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 1include: a) inventoried roadless areas, b) Counties west of Cascade Mountains in Oregon and Washington, where forests have a long fire return interval, c) Plots with lower fire hazard;

both crowning index (CI) and torching index (TI) > 25 mph or CI alone > 40 mph. For a map of inventoried roadless areas, see www.roadless.fs.fed.us/maps/usmap2.shtml

Plots *excluded from* Group 2 include: a) all plots outside wildland urban interface (WUI) areas, b) inventoried roadless areas, c) counties west of Cascade Mountains in Oregon and Washington, where forests have a long fire return interval, d) 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.

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.

Of the 126.7 million acres of timberland, 67.5 million acres (53%) have lower fire hazard by our criteria. Of the remaining 59.2 million acres, 21.6 (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 (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.

*Second Screen*

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

## Fire Hazard Reduction Objectives and Assumptions

*Selection of Plots for Treatment*

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

*Assumptions for Calculating Torching and Crowning Indexes*

Torching and crowning indices were calculated for each plot based on a) canopy fuel profile as computed from plot data, b) slope steepness, c) selected set of fuel moisture conditions corresponding to “summer drought” conditions (Rothermel 1991), and d) use of fire behavior fuel model 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. However, no plot data exist to characterize surface fuels. Assuming more extreme fire behavior such as fuel model 10 might lead to recommending thinning where none is really needed, while a fuel model 8 that results in very low intensity surface fires may not identify stands at risk of crowning. Fuel model 9 was as a compromise.

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.

*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.

*Limits on Removal of Basal Area*

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

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

*Long-Term Effect of Treatments on Fire Hazard*

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

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

## Silvicultural Treatment Objectives and Assumptions

The thinning treatments to reduce fire hazard have an objective to (1) move the stand toward an uneven-aged condition or (2) move the stand toward an even-aged condition. In addition, the objective of some treatments is to limit basal area removed to limit change in stand structure.

Although some authors (Graham and others 1999) have suggested that thinning uneven-aged stands does not generally reduce fire hazard, our uneven-aged treatments were specifically designed to reduce TI, CI, and the risk of crown fire.

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

*Treatments for forests with surface and mixed severity fire regimes*

Treatments 1A and 1B, uneven-aged, high structural diversity remove trees so the number of trees remaining in each dbh class after treatment is 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 SDI calculation method removes trees to reduce SDI evenly over all dbh classes to meet a fire hazard target. In Scenario 1A, removals are limited to 50% of initial basal area; in 1B, there is no limitation. This scenario results in forest structures that retain high structural diversity with intact understories of small trees.

When removals are restricted to < 50% of the original basal area, this ensures that some semblance of an uneven-aged forest structure is maintained. (Alexander and Edminster 1977, Burns 1983)

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

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

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

*Treatments for forests with high severity fire regimes*

Treatments 4A and 4 B, even-aged, thin from below (spruce–fir and lodgepole pine forest types) are similar to treatments 3A and 3B, except BA removals are restricted to 25% of existing stocking (treatment 4A ) or 50% of existing stocking (treatment 4B) and are only in WUI areas. 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).

## Harvest Costs and Product Revenue Estimation

The cost to provide biomass ready for transport at the roadside was estimated for each plot using the Fuel Reduction Cost Simulator (FRCS) from My Fuel Treatment Planner (Biesecker and Fight 2005, Fight and others 2006). Cost estimates are made for up to eight harvesting systems, based on the number and average volume of trees in various size categories and the slope of the site. Ground-based harvesting systems include: a) Manual-felling log-length system, b) Manual-felling whole-tree (WT) system, c) Mechanized-felling WT system, and d) Cut-to-length (CTL) system. Cable-yarding systems include: a) Manual-felling log-length system, b) Manual-felling WT system, c) Manual WT/log-length system, and d) CTL system.

The cost for the least expensive suitable system was assigned to each plot. We 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 might be reduced if small dbh trees are not removed from the site and treated by another method (e.g. pile and burn).

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

| | |
|---|---|
| Delivered sawlogs (vol. from main stem ≥ 7 in. dbh) | $290/10^3 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 Fuel Treatment Evaluator 3.0 (FTE), a web-based tool, available for general use, was used to select areas for treatment, apply treatments to FIA plot data, and generate removal information and maps (Miles 2006b).

## FINDINGS

### Area Treated and Biomass Removed

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

FRCC refers 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

Our treatments 3A and 4A together would treat 7.2 million acres and treatments 1B and 4B together would treat 18.0 million acres with 85% of acres in FRCCs 2 and 3.

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

Treatment 1B would thin the largest area—17.5 million acres or about 14% 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%).

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 million odt from treatment 3A and 4A and 640 million odt from treatments 1B and 4B. (Tables 1, 2).

The distribution of biomass removed by tree size differs greatly between the uneven-aged and even-aged treatments (Table 3). In addition, the distribution for the uneven-aged treatments differs substantially from the results of the uneven-aged treatment used in the 2003 Assessment. The 2003 Assessment showed the most biomass removed from the 10-in. dbh class. In contrast, our uneven-aged treatments provide most biomass in ≥21 in. dbh classes Our uneven-aged treatments remove more because residual SDI for our treated stands is <20% of maximum SDI, versus

30% of maximum in the 2003 Assessment. Thinning to an average 20% of maximum SDI is needed to thin to achieve CI>40 when we cannot attain TI>25. We could help attain TI>25 rather than having to reach CI>40 by pruning branches to raise canopy base height and by decreasing surface fuels.

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

## Fire Hazard Reduction Outcomes

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

1. Treatment is applied; both CI>25 and TI>25.
2. Treatment is applied; CI>40.
3. Treatment is applied; 50% 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 with the 50% BA removal limit (1A and 2A) treat 71% and 61% of eligible acres, respectively. These treatments reach the medium or high hazard reduction goal for 44% and 30% of eligible acres, respectively (Table 4). When the BA limit is removed (1B and 2B), a slightly greater percentage of acres is treated (72% and 62%), all reach a hazard reduction target, and biomass removal increases 14% (548 to 627 million odt) and 8%, respectively.

The even-aged treatment with the 50% BA removal limit (3A) treats 28% of all eligible acres but reaches the medium or high hazard reduction goal for only 7% of the eligible acres (Table 4). When the 50% limit is removed (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 the need to obtain a minimum level of merchantable wood to yield positive average net revenue *and* a restriction on BA removal, our results suggest that the even-aged treatment would more likely achieve one of the hazard reduction targets than would an uneven-aged treatment. – In our example - 44% or 30%, versus 7%.

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, provide positive net revenue from sale of products.

**Treatment Costs, Product Revenues, Net Revenues**

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

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

*Treatment Costs*

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

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

*Biomass Revenues*

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

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

*Net Revenue (Costs) From Treatments*

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

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

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

*Biomass removal maps*

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

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

Two sets of treatments were applied to the 14 million acres of federal timberland judged eligible for treatment. These are treatments 1A & 4A, and treatments 3A & 4A. Volumes and harvest costs from these treatments are used as inputs to the FTM-West market model described by Ince and Spelter, and Kramp in these proceedings. Unevenaged treatments 1A and 4A combined (SDI treatment) treat 10.9 million acres and provide 347 million tons (23.2 billion $ft^3$) at an average cost of $1531/ acre ($0.719 / $ft^3$ ). Even aged treatments 3A and 4A combined (TFB treatment) treat 5.6 million acres and provide 148 million tons (9.9 billion $ft^3$) at an average cost of $1420/ acre ($0.807/ $ft^3$).

## SUMMARY

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

Under our assumptions, uneven-aged treatments will be able to treat a higher proportion of acres with resulting positive net revenue than will even-aged treatments. Moreover, for treated acres, if 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.

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 ft3/acre of merchantable wood. But the 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.

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

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

## ACKNOWLEDGEMENTS

This paper is an outcome of the Wood Utilization Opportunity Areas (WUOA) Project that was funded in part by the National Fire Plan Research Program (Project 02.FPL.C.1). The project is a collaborative effort of USDA Forest Service researchers and managers including: Ken Skog, Forest Products Lab, and Jamie Barbour, Pacific Northwest Research Station – co-team-leaders; Roger Fight, research forest economist (retired), Pacific Northwest Research Station; Karen Abt and Bobby Hugget, research economists, Southern Research Station, Frank Burch, silviculturist, Washington, DC; Pat Miles, research forester, North Central Research Station; Elizabeth Reinhardt, project leader, Rocky Mountain Research Station; and Wayne Sheppard, research silviculturist, Rocky Mountain Research Station.

## REFERENCES

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Table 1**-Area treated by state and treatment scenario (million acres)

| State | Treatments for Forest types other than spruce-fir and lodgepole | | | | | | Treatments for spruce-fir and lodgepole | |
|---|---|---|---|---|---|---|---|---|
| | Uneven-aged treatments | | | | Even-aged treatments | | Even-aged in WUI area only | |
| | 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 |
| | 1A | 1B | 2A | 2B | 3A | 3B | 4A | 4B |
| AZ | 0.5 | 0.5 | 0.4 | 0.4 | 0.1 | 0.1 | 0.0 | 0.0 |
| CA | 4.4 | 4.4 | 3.8 | 3.8 | 1.5 | 1.5 | 0.0 | 0.0 |
| CO | 1.2 | 1.3 | 1.1 | 1.1 | 0.4 | 0.5 | 0.1 | 0.1 |
| ID | 2.4 | 2.5 | 2.2 | 2.2 | 1.1 | 1.1 | 0.4 | 0.4 |
| MT | 2.9 | 3.0 | 2.5 | 2.6 | 1.5 | 1.6 | 0.0 | 0.0 |
| NV | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| NM | 0.9 | 1.0 | 0.8 | 0.8 | 0.3 | 0.3 | 0.0 | 0.0 |
| OR | 2.2 | 2.2 | 1.8 | 1.8 | 0.9 | 0.9 | 0.0 | 0.0 |
| SD | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| UT | 0.4 | 0.4 | 0.4 | 0.4 | 0.2 | 0.2 | 0.0 | 0.0 |
| WA | 1.8 | 1.8 | 1.5 | 1.5 | 0.6 | 0.6 | 0.0 | 0.0 |
| WY | 0.3 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 | 0.0 | 0.0 |
| Total | 17.1 | 17.5 | 14.8 | 15.1 | 6.7 | 6.8 | 0.5 | 0.5 |

**Table 2**-Initial standing biomass and biomass removals from this assessment (million oven dry tons)

| State | Initial volume on treatable timberland (million acres) | Treatments for Forest types other than spruce-fir and lodgepole | | | | | | Treatments for spruce-fir and lodgepole | |
|---|---|---|---|---|---|---|---|---|---|
| | | Uneven-aged treatments | | | | Even-aged treatments | | Even-aged in WUI area only | |
| | | 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 |
| | | 1A | 1B | 2A | 2B | 3A | 3B | 4A | 4B |
| AZ | 29.5 | 11.0 | 13.1 | 8.9 | 9.9 | 2.3 | 2.6 | 0.1 | 0.1 |
| CA | 419.2 | 219.5 | 222.4 | 144.8 | 145.2 | 37.4 | 40.1 | 0.2 | 0.3 |
| CO | 49.3 | 20.6 | 28.4 | 17.4 | 21.8 | 6.0 | 7.5 | 0.8 | 1.4 |
| ID | 171.4 | 68.1 | 83.1 | 57.7 | 63.4 | 26.6 | 29.4 | 6.4 | 10.5 |
| MT | 166.7 | 66.8 | 84.4 | 58.9 | 69.2 | 36.5 | 41.9 | 0.1 | 0.2 |
| NV | 0.9 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 | 0.1 | 0.0 | 0.0 |
| NM | 41.9 | 18.3 | 24.1 | 15.0 | 18.4 | 5.5 | 6.3 | 0.0 | 0.0 |
| OR | 210.4 | 76.8 | 88.7 | 53.9 | 56.2 | 25.5 | 26.3 | 0.0 | 0.0 |
| SD | 3.9 | 1.3 | 1.4 | 1.1 | 1.1 | 0.3 | 0.3 | 0.0 | 0.0 |
| UT | 18.2 | 7.5 | 9.8 | 6.9 | 8.0 | 2.9 | 3.2 | 0.0 | 0.1 |
| WA | 128.7 | 50.0 | 60.9 | 38.8 | 42.4 | 14.9 | 15.4 | 0.0 | 0.0 |
| WY | 17.7 | 7.5 | 10.3 | 7.3 | 8.9 | 3.6 | 4.5 | 0.1 | 0.2 |
| Total | 1257.7 | 547.8 | 626.8 | 410.8 | 444.7 | 161.6 | 177.5 | 7.6 | 12.8 |

**Table 3** -- Biomass removal by treatment and tree dbh class (tons per acre)

| dbh class (inches) | Treatments for Forest types other than spruce-fir and lodgepole | | | | | | Treatments for spruce-fir and lodgepole | |
|---|---|---|---|---|---|---|---|---|
| | Uneven-aged treatments | | | | Even-aged treatments | | Even-aged in WUI area only | |
| | 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 |
| | 1A | 1B | 2A | 2B | 3A | 3B | 4A | 4B |
| 2.0 | 0.4 | 0.5 | 0.5 | 0.6 | 0.8 | 0.9 | 0.4 | 0.5 |
| 4.0 | 1.2 | 1.5 | 1.5 | 1.7 | 2.2 | 2.4 | 1.5 | 2.2 |
| 6.0 | 2.1 | 2.4 | 2.8 | 3.0 | 4.9 | 5.1 | 4.9 | 5.4 |
| 8.0 | 2.9 | 3.3 | 3.6 | 3.8 | 6.2 | 6.5 | 4.8 | 6.6 |
| 10.0 | 3.1 | 3.6 | 3.6 | 3.9 | 4.4 | 4.7 | 3.5 | 5.8 |
| 12.0 | 3.0 | 3.4 | 3.1 | 3.3 | 2.5 | 2.8 | 0.7 | 2.1 |
| 14.0 | 2.5 | 2.8 | 2.2 | 2.4 | 1.2 | 1.4 | 0.4 | 0.9 |
| 16.0 | 1.9 | 2.2 | 1.5 | 1.6 | 0.6 | 0.8 | 0.4 | 0.8 |
| 18.0 | 1.4 | 1.7 | 0.9 | 1.0 | 0.4 | 0.5 | 0.0 | 0.2 |
| 20.0 | 1.0 | 1.2 | 0.4 | 0.5 | 0.3 | 0.3 | 0.0 | 0.0 |
| 22+ | 12.5 | 13.2 | 7.6 | 7.7 | 0.7 | 0.6 | 0.0 | 0.0 |
| Total | 32.0 | 35.8 | 27.7 | 29.5 | 24.2 | 26.0 | 16.6 | 24.5 |

**Table 4**-Fire Hazard outcomes - Percent of treatable acres

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

**Table 5 -** Estimated treatment costs, and revenues[a] minus fuel treatment costs when larger diameter logs are sold for higher value products, or, alternately, for chips

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

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

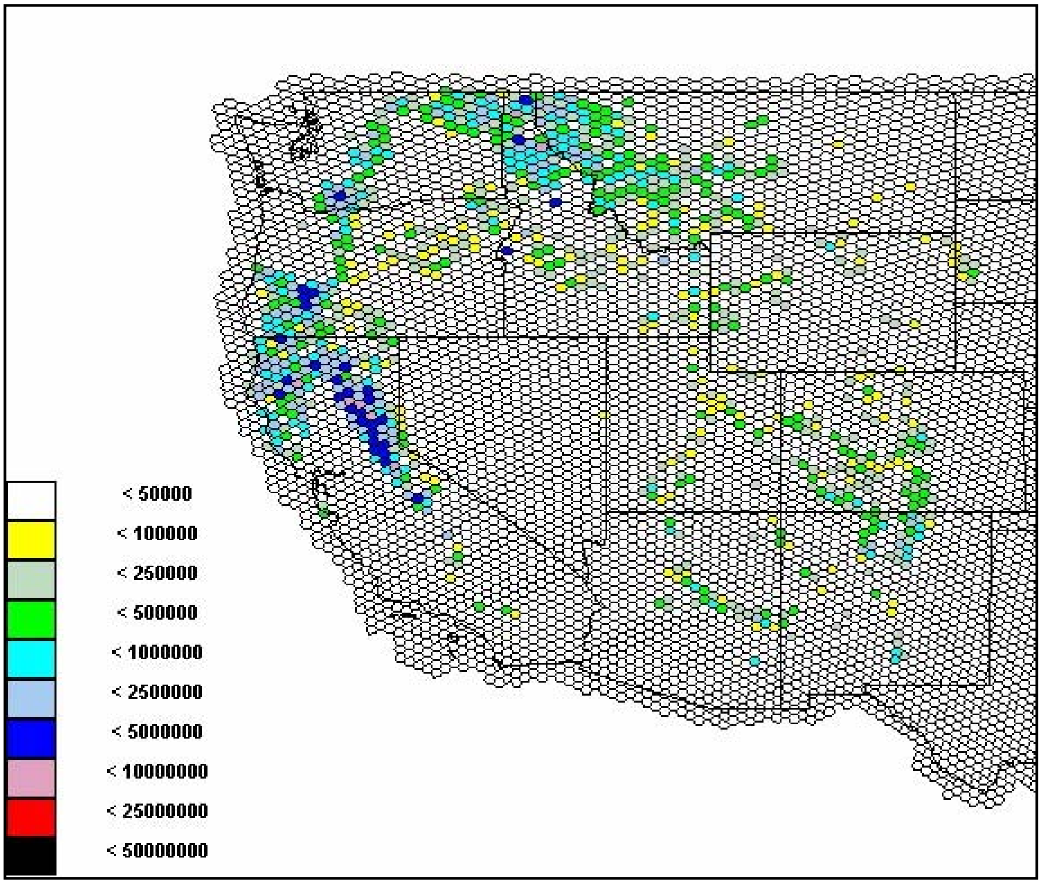


**Figure 1 –** Total biomass removed per 160,000 acre area for Uneven aged treatment 1A (tons)

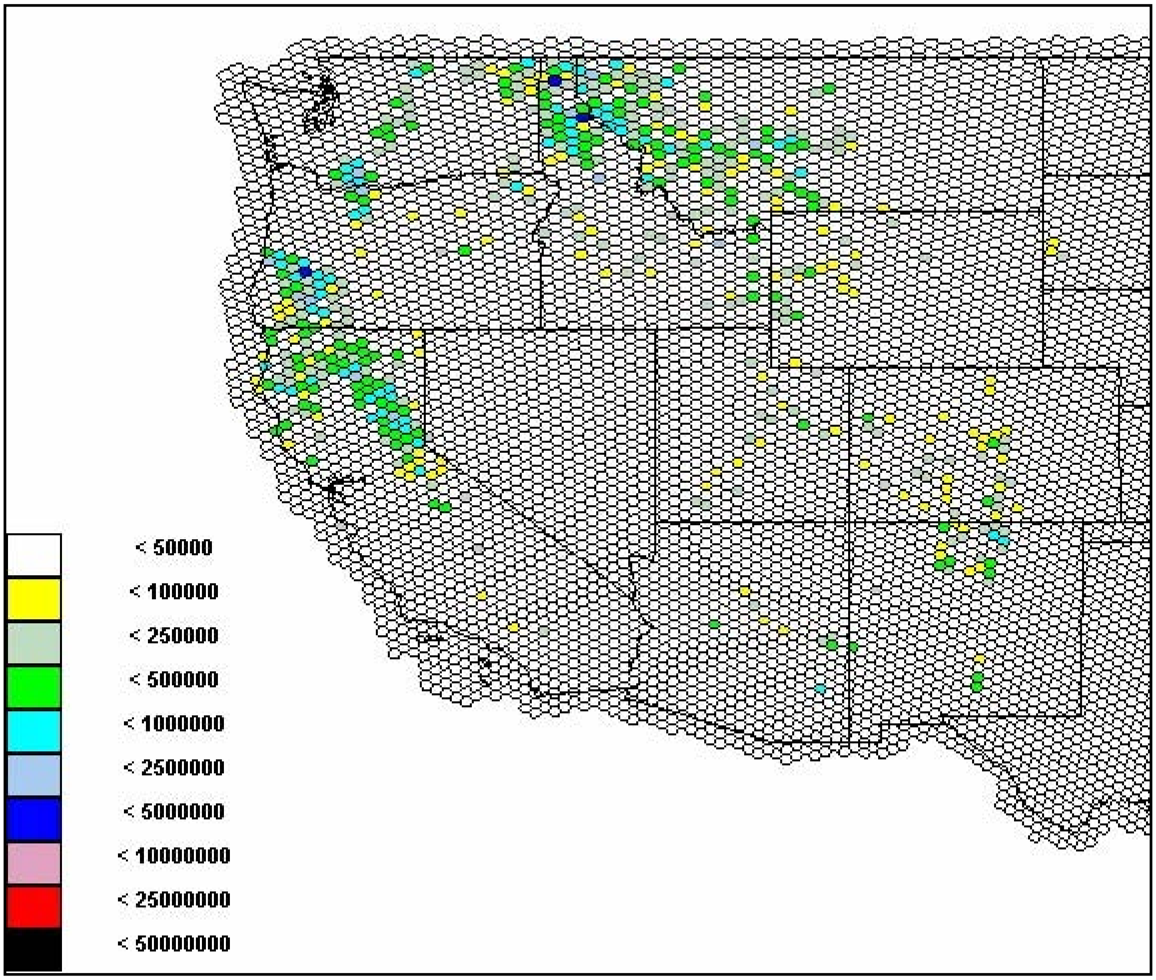


**Figure 2-**Total biomass removed per 160,000 acre area for Even aged treatment 3A (tons)