Estimating Harvest Costs for Applying Fuel Treatments to FIA Plots

Initial Final Report

Prepared By:

Frederick Cubbage, Rodrigo Arriagada, and Gregory Frey
Professor and PhD Students
Department of Forestry and Environmental Resources
North Carolina State University
Raleigh, NC 27695-8008

Prepared For:

Karen Lee Abt
Station Representative
RWU-FS-SRS-4851
Economics of Forest Protection and Management
USDA Forest Service, Southern Research Station
Research Triangle Park, NC 27709

25 May 2006
Version #1

Estimating Harvest Costs for Applying Fuel Treatments to FIA Plots

Final Report

INTRODUCTION

As noted in our study plan, there has been substantial increase in wild forest fires in the 2000s, especially in the Western United States. Concerned with the rising damages and suppression costs associated with catastrophic wildfire, the United States General Accounting Office called for a cohesive strategy of fuel reduction treatments to control excessive losses to wildfires (U.S. GAO 1999). The federal Comprehensive Strategy and Implementation Plan were the two principal USDA Forest Service and Department of Interior responses[1]. In addition, the president and Congress have encouraged fuel treatments through the Healthy Forests Restoration Act, National Fire Plan and Healthy Forests Initiative[2]. All of these initiatives propose greatly increasing the amount of fuel reduction treatments, including prescribed fire and mechanical approaches. In some cases, mechanical fuel treatments involve the removal of marketable timber products.

Mechanical fuel treatments are different from typical harvests because they involve partial cutting, with small diameter materials requiring the most effort and larger diameter materials the least; in that sense, they are similar to thinning operations. Many of the proposed mechanical treatments may be on steep sites, so their expense per unit of material removed is likely to be different from typical silvicultural treatments. This will affect the net costs of these treatments. The removal of products will also result in impacts on the local and regional timber markets by potentially increasing the supply of some products to mills. This will influence the price of products at the mill, which will in turn affect the net returns to the landowner.

As part of a larger research project, the USDA Forest Service Southern Research Station is developing a model that will determine the optimal allocation of fuel treatments across fire prone regions of the United States. This model is estimating the appropriate mix of treatments across space and over time and the amount of subsidy that the government will need to provide to reduce forest fuel loads and their eventual wildfires. Determining

---

1 A Collaborative Approach for Reducing Wildland Fire Risks to Communities & the Environment: 10-Year Comprehensive Strategy (8/2001) http://www.fireplan.gov/reports/7-19-en.pdf
and Implementation Plan (5/2002) http://www.fireplan.gov/reports/11-23-en.pdf

2 Healthy Forests Restoration Act, HR 1904, December 3, 2003. http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=108_cong_bills&docid=f:h1904enr.txt.pdf

Healthy Forests Initiative http://www.fs.fed.us/projects/documents/HealthyForests_Pres_Policy%20A6_v2.pdf

National Fire Plan http://www.fireplan.gov harvest costs for these treatments for all regions and forest types of the U.S. is an integral part of this larger project.

In this project, we considered several harvest cost models in use for different regions of the country and different types of timber and harvesting techniques. These included mainly the Auburn Harvesting Analyzer (AHA) spreadsheet package (Tufts et al. 1985), a model developed in the U.S. South; STharvest (Hartsough et al. 2001) and Forest Reduction Cost Simulator (FRCS) (Fight et al. 2006) simulators, harvesting cost simulation packages developed in the West. These models simulate harvests using data for specific conditions on one site.

However, some situations require the development of harvesting costs for a large number of sites using more than one type of harvest. One approach for developing these harvest cost estimates is to run the harvest cost models on a sample of representative sites, similar to a procedure employed by Cubbage and Greene (1989). One can then estimate a regression equation using the Forest Inventory and Analysis data as predictors. This method will allow an estimate of harvesting costs to be made for several different harvesting systems using the available data and assumptions about other characteristics and conditions on the site. The regression equations could then be included in a larger model designed to determine the broad scale costs and benefits of fuel treatment programs.

Previous studies of products available from fuel treatments (Fried 2003, Chalmers et al. 2003) have focused on very specific locations (SW Oregon, Sierra Nevadas). These projects all used FIA data at the plot level combined with the use of the Forest Vegetation Simulator and either assumptions or the use of STHarvest to develop harvest costs for each plot and treatment type. Given the scope of the proposed work (all FIA plots in a region), this approach is not feasible. Thus, the objective of this project is to develop an average harvest cost, or a range of costs, for each selected forest fuel reduction treatment and each major broad forest type across the country, based on assumptions and available FIA data.

METHODS

For this research, we examined several available harvest cost models before using STharvest and FRCS. To represent forest stands, we used the FIA plot-level data. A data set was assembled by the USDA Forest Service Economics of Forest Protection and Management work unit at Research Triangle Park, NC. These data were used to: (a) to evaluate the accuracy and applicability of competing harvest cost models, and (b) to generate regression equation approaches to calculating harvest costs for the selected fuel reduction harvesting systems in the major Western U.S. forest types.

In a related component of this research project, a set of region-specific treatments were developed, which will be prescribed for fuel treatment harvests that we estimated. There were 3 to 8 treatments for each region that were based on appropriate silvicultural rules to minimize fire hazards – e.g., wide spacing, larger stems, and less brush so fires could not crown out. These prescriptions will be provided for use in this project, and their costs will be calculated using the available harvest cost models.

This project used the FRCS and STHarvest cost simulation models, adapting them to regions, forest types and treatments typical in the West. We used data on the Forest Inventory and Analysis (FIA) plots in the western states, and then used the harvesting cost packages with harvesting rules or guidelines set by the broader USDA Forest Service fuel treatment project. STHarvest was developed to address small diameter timber harvest costs on the Pacific Coast and interior West (Hartsough et al. 2001). The STHarvest model is highly specific in the development of its costs estimates. We used STHarvest for making a number of harvesting cost estimates from the beginning of this project in 2004 through 2005. It provided cost estimates for al the FIA plots in the West, and was the basis for a preliminary paper that we presented in March of 2005 (Arriagada et al. 2006).

In February, 2006 a new version of FRCS was released (Fight et al. 2006) designed to estimate costs for fuel reduction treatments involving removal of trees of mixed sizes in the form of whole trees, logs, or chips from a forest and to address the buildup of fuels in forests that contribute to risk of uncontrollable wildfire. We have re-analyzed all the harvesting cost estimates with it in 2006, since it seemed to provide more accurate estimates and more understandable results. At this stage of the project, STHarvest will be used to confirm consistency with our new FRCS results and to provide a means to validate our cost estimations.

This research investigated the effects of several factors, including tree size, tract volume and removal intensity on harvesting costs for applying fuel treatments to Forest Inventory and Analysis (FIA) plots in 12 states located in the Western United States. Ground and cable-based harvesting systems were included and their costs were estimated (Hartsough et al. 2001, Fight et al. 2006). Regression analysis was then used to develop cost equations to predict harvesting costs for each system and different combinations of covariates such as tree size, location, tract volume, tree density and removal intensity were used to explain variation in harvesting costs.

Both whole-tree (WT) and log-length systems were included in the empirical analysis of the harvesting costs for applying fuel treatments to FIA plots using ST Harvest and FRCS. The six harvesting systems included in this analysis are shown in Table 1 together with the conditions under which they customarily operate. In the whole-tree harvesting method, the tree is felled and delivered to the landing with limbs and tops attached to the stem. In the short-wood or log-length method, trees are processed at the stump. Figure 1 illustrates the steps and activities at each phase of harvesting for both systems.

ST Harvest and FRCS were used first to estimate production and costs of the six harvesting systems shown in Table 1. Both computer applications are public-domain software used to estimate costs for harvesting small-diameter stands or the small-diameter component of a mixed-sized stand (Fight et al. 2003, 2006). The programs can estimate costs of harvesting small trees in stands in the interior Northwest. They provide production functions for harvesting as part of the simulation package, and allow users to use the default costs or update those costs. Equipment prices in the model were updated with current prices from the Green Guide (2005). Table 2 shows the assumptions included in the models to estimate harvesting costs in this study.

Table 1. Ground-based or cable systems and condition to operate

	Manual Felling			**Mechanical felling**		
	Ground based		**Cable**	**Ground based**		**Cable**
Tree size and slope	**Whole tree length**	**Log length**	**Whole tree length**	**Whole tree length**	**Log length**	**Log length**
Maximum tree size (ft^3)	150	150	150	80	80	80
Minimum tree size (ft^3)	1	1	1	1	1	1
Maximum slope (%)	<40	<40	>40	<40	<30	>40

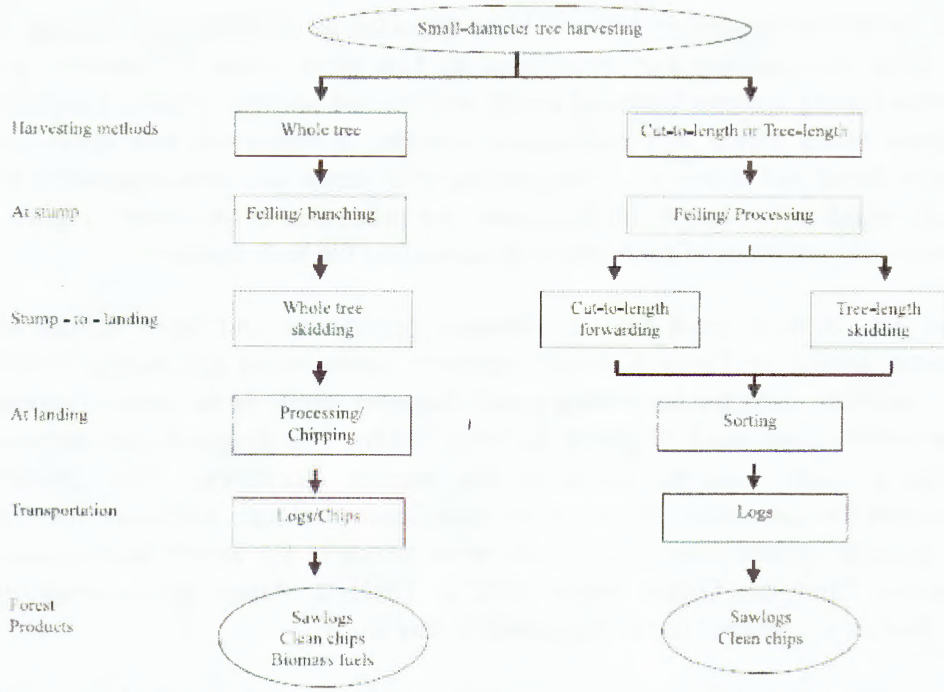

Figure 1. Flow chart of small wood harvesting in whole-tree and cut-to-length/tree-length operations (Han-Sup et al. 2004)

The FIA data plots represented typical forest conditions in the West. The harvesting scenarios for these plots were based on research by colleagues at the USDA Forest Service Southern Research Station and Pacific Northwest Research Station. The Forest Service researchers developed forest harvesting rules that would be appropriate for reducing the risk of forest fires, by limiting spread along the crown and crowning--the spread of fires from the ground to the crown of the trees. They then provided these harvesting rules and scenarios to us, along with sets of summarized FIA plot level data (Huggett 2005, personal comm.). We then used the spreadsheet simulators to estimate harvesting costs for these FIA plots based on tree density conditions, the amount of material to be harvested, and the harvesting systems that would be appropriate for the slope conditions of that FIA plot. We had about 10,000 FIA plots so needed automated methods to run all the harvest simulations. We were able to obtain a ST Harvest front-end simulator from Bruce Hartsough (personal comm. 2005; Chalmers et al. 2003), which was then used to be able to run the approximately 10,000 FIA plot harvest simulations swiftly. For FRCS, we were able to input the data directly into the program by using its batch mode.

Table 2. Assumptions used in ST Harvest and FRCS to estimate harvesting costs for applying fuel treatments to FIA plots

Variable	Unit	Value
Logging system	---	Whole-tree and log-length harvesting methods, ground based and cable yarder
Cut type	---	Partial cut
Yarding distance	Feet	800
Slope	%	Range from -1% to 85%
Move-in distance	Miles	50
Harvested area	Acres	50
Removal intensity	Cut trees/acre	Range from 0 to 4,682
Tree size	DBH class	d3 < 5" d6 = 5"-6.9" d8 = 7"-8.9" d10 = 9"-10.9" d12 = 11"-12.9" d14 = 13"-14.9" d15 = 15"+

The FIA plots provided a large sample of conditions in the West and an excellent means to estimate basic regression equations of timber harvesting costs by important variables. Once production rates and costs were estimated using the harvesting packages, a set of regression equations were estimated to develop an average of harvest costs for the 12 states included in this study. The western states included in the data frame were Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, South Dakota, Utah, Washington and Wyoming.

The method of least squares regression was used to fit a prediction equation of harvesting costs to the data. Selection of functional form for the timber harvesting cost equations was based on knowledge of timber harvesting operations, past studies, and statistical procedures. In general, timber harvesting is very expensive for small stands and small stems, since it takes many actions with expensive equipment and labor to harvest a small amount of volume. This characteristic has been estimated quantitatively in several studies, which have found that timber harvesting costs are much greater for small stems and for small tracts, and decline asymptotically to a minimum level at large stem size and tract size.

We initially estimated logging costs using complex log-log functions, with dummy variables for each state in the West and several independent variables, when we made our first cost calculations using the STharvest simulator (Arriagada et al. 2006).

The FRCS simulator seemed to provide better cost estimates, probably because it was designed specifically for fuel reduction harvest applications. Thus, based on our more recent analyses and regression runs, we estimated harvesting costs per diameter class using a much simpler functional form:

harvesting cost per acre = $\beta_0 + \beta_1$ (trees removed per acre small dbh class) + β_2 (trees removed per acre medium dbh class) + β_3 (tress removed per acre big dbh class) + β_4 (Slope) + ε

where harvesting cost is measured in $USD per acre, small dbh class includes trees with dbh less than 6.9 inches, medium dbh class includes trees with dbh between 7 and 12.9 inches, big dbh class includes tress with dbh higher than 12.9 inches and slope is measured in percentage. Table 3 and 4 shows the descriptive statistics of the variables included in this analysis which includes data on 9,466 plots for the case of ground-based harvesting systems and plots for the case of cable-based harvesting systems respectively.

This functional form allows one to use directly the results obtained from FRCS without transforming units given that this software gives estimates of harvesting costs in dollars per acre and FIA data come in values per acre. This simple linear functional form can easily satisfy the assumptions of the Classical Linear Model (CLM). Strictly positive variables (as is the case for harvesting costs) often have conditional distributions that are heteroskedastic or skewed; in the estimation of the regression equations robust standard error were calculated in order to make correct statements about statistical significance of the covariates.

Tables 3 and 4 show high coefficients of variation associated with number of trees removed per acre and slope which can be explained by the use of different fuel treatment scenarios and the different conditions of the FIA plots included in this study. This permitted us to estimate a robust and very representative harvesting cost function that can be applied to different treatment scenarios and locations.

Estimates of harvesting costs for the different harvesting systems were based only on plots that met the conditions to operate with each one of these following the criteria shown in Table 1.

Table 3. Statistics of covariates selected in cost analysis for ground based harvesting systems

Variable	Description	Mean*	Standard Deviation	Coefficient of Variation (%)
TRASM	Trees removed per acre in the small diameter class (0'-6.9' DBH)	219.74	230.48	104.8%
TRAMED	Trees removed per acre in the medium diameter class (7'-12.9')	32.14	44.23	137.6%
TRAB	Trees removed per acre in the large diameter class (>12.9')	4.79	14.12	294.9%
SLOPE	Slope of the plot (%)	14.33	13.56	94.66

* Including 9,466 plots located in twelve states in the West

Table 4. Statistics of covariates included in cost analysis for cable based harvesting systems

Variable	Description	Mean*	Standard Deviation	Coefficient of Variation (%)
TRASM	Trees removed per acre in the small diameter class (0'-6.9' DBH)	174.70	221.55	126.81%
TRAMED	Trees removed per acre in the medium diameter class (7'-12.9')	39.13	52.875	135.12%
TRAB	Trees removed per acre in the large diameter class (>12.9')	7.288	18.93	260.02%
SLOPE	Slope of the plot (%)	56.71	10.47	18.46%

* Including 2,573 plots located in twelve states in the West

For the case of the dependent variable, harvesting costs in dollars per acre were estimated for all the FIA plots included in this study, which included the six ground-based and cable harvesting systems used in this analysis. Table 5 shows the harvesting costs included in this study as the dependent variable, which were obtained using FRCS and then compared with estimates of ST Harvest to check consistency. Table 5 shows high coefficient of variations for all harvesting systems given that dbh classes go from small diameter trees to larger diameter trees which affects fuel treatment costs. The variation is also explained for the application of different harvesting systems under different conditions of tree density and with different harvesting intensities. And again, as was the case for the independent variables shown in Table 3 and Table 4, the high coefficient of variation of harvesting costs shown in Table 5 is also explained by different slope conditions and plot location.

Table 5. Statistics of harvesting costs per acre obtained with FRCS and included in cost analysis

Variable	Description	Mean	Standard deviation	Coefficient of variation (%)
MANWT	Cost of ground-based manual whole tree harvesting system ($/acre)	1,015(1)	806	79.4
MANLOG	Cost of ground-based manual log harvesting system ($/acre)	1,627 (1)	1,297	79.6
MECHWT	Cost of ground-based mechanical whole tree harvesting system ($/acre)	620(1)	471	75.9
CTL	Ground-based cut to length harvesting system ($/acre)	958(2)	673	70.2
CABLEMAN	Cost of cable manual log harvesting system ($/acre)	3,535(3)	2,108	59.6
CABLEMWT	Cost of cable manual whole tree system ($/acre)	2,794(3)	1,589	56.8

(1) Including 9,466 plots located in twelve states in the West

(2) Including 8,178 plots located in twelve states in the West

(3) Including 2,573 plots located in twelve states in the West

RESULTS

Using functional form presented above, and the information on harvesting costs obtained from FRCS and shown in Table 5, Table 6 shows the results of the parameter estimates of the harvesting cost function for fuel treatments of FIA plots for a ground-based manual whole-tree harvesting system. Similarly, Tables 7, 8, 9, and 10 show the results for the other harvesting systems.

Table 6. Estimation of the harvesting cost function for applying fuel treatments to FIA plots in twelve states in the West using a ground-based manual whole-tree harvesting system

Independent variables	Parameter	Estimated coefficient (OLS)	Robust Standard error	P-value
Constant	β_0	-107.669	10.545	0.000
TRASM	β_1	3.318	0.017	0.000
TRAMED	β_2	6.232	0.203	0.000
TRAB	β_3	16.810	0.809	0.000
SLOPE	β_4	7.856	0.161	0.000
N	9,466			
R^2	0.965			
F-value	65,477			0.000

Table 7. Estimation of the harvesting cost function for applying fuel treatments to FIA plots in twelve states in the West using a ground-based mechanical whole-tree harvesting system

Independent variables	Parameter	Estimated coefficient (OLS)	Robust Standard error	P-value
Constant	B_0	-50.792	9.554	0.000
TRASM	B_1	1.598	0.014	0.000
TRAMED	B_2	5.065	0.190	0.000
TRAB	B_3	14.069	0.798	0.000
SLOPE	B_4	6.271	0.147	0.000
N	9,466			
R^2	0.919			
F-value	26,868			0.000

Table 8. Estimation of the harvesting cost function for applying fuel treatments to FIA plots in twelve states in the West using a ground-based manual log harvesting system

Independent variables	Parameter	Estimated coefficient (OLS)	Robust Standard error	P-value
Constant	B_0	-161.941	12.846	0.000
TRASM	B_1	5.502	0.023	0.000
TRAMED	B_2	9.019	0.240	0.000
TRAB	B_3	20.437	0.882	0.000
SLOPE	B_4	13.425	0.220	0.000
N	9,466			
R^2	0.975			
F-value	90,441			0.000

Table 9. Estimation of the harvesting cost function for applying fuel treatments to FIA plots in twelve states in the West using a cable-based manual log harvesting system

Independent variables	**Parameter**	**Estimated coefficient (OLS)**	**Robust Standard error**	**P-value**
Constant	β_0	1199.051	225.2594	0.000
TRASM	β_1	6.640245	.2240821	0.000
TRAMED	β_2	23.16976	1.61496	0.000
TRAB	β_3	4.621073	11.26944	0.682
SLOPE	β_4	4.154159	1.79979	0.021
N	2,573			
R^2	0.783			
F-value	1,444			0.000

Table 10. Estimation of the harvesting cost function for applying fuel treatments to FIA plots in twelve states in the West using a cable-based manual whole tree harvesting system

Independent variables	**Parameter**	**Estimated coefficient (OLS)**	**Robust Standard error**	**P-value**
Constant	β_0	1417.599	220.9979	0.000
TRASM	β_1	3.464873	.2193248	0.000
TRAMED	β_2	19.99544	1.585212	0.000
TRAB	β_3	.5513315	11.05604	0.050
SLOPE	β_4	-.2607823	1.753207	0.882
N	2,573			
R^2	0.635			
F-value	504.81			0.000

Interpretation of the regressions shown in Tables 6, 7, 8, 9 and 10 is straightforward. Since none of the independent variables have been transformed, the regression parameter estimate for each independent variable is simply an estimate of the increase in harvesting costs (in dollars per acre) resulting from a one unit increase (either trees removed per acre or degrees of slope) in the independent variable.

For instance, when using the Manual Log harvesting system, for each additional tree removed per acre in the small diameter class, the cost of reducing the fuel load is increased by approximately \$5.50 per acre. Likewise, a tree removed in the medium diameter class increases cost by \$9.02 per acre, and removal of each large-diameter tree increases the cost by \$20.44 per acre. This is in line with intuitive reasoning that more harvesting leads to higher costs (thus the positive sign on the parameter estimates), and that larger trees are more costly to extract than smaller ones. Furthermore, for each additional degree of slope, cost is increased by \$13.43 per acre. The other harvesting systems' regressions have similar, intuitive results.

Using the regression equations, we predicted the harvesting costs of each plot under each harvesting system. Descriptive statistics for the predicted costs of each of the harvesting systems are given in Table 11. The mean of the predicted costs for each system is the same as mean of the simulated costs for each system obtained from FRCS, which is an artifact of using OLS regression ($\bar{\hat{y}} = \bar{y}$). On average, the cheapest system was the Mechanical Whole-Tree harvest system. This system had a mean predicted cost of $620 per acre with median predicted cost of $529 per acre. There was high variability in the costs per acre among plots for all the harvesting systems shown in Table 11, which coefficients of variation ranging from 72.84% to 78.66%. This is consistent with the high coefficient of variations shown in Tables 3 and 4 explained by the application of different fuel treatments and particular conditions associated with plots included in this study.

Table 11. Sample Fuel Harvesting Cost Calculations per Acre for FIA Plots for three Ground-Based Systems in the West, U.S. Dollars, 2005

System	Mean ($/acre)	Median ($/acre)	Standard Deviation	Coefficient of Variation (%)
Manual Whole-Tree	1,015	838	792	78.1%
Manual Log	1,627	1312	1279	78.7%
Mechanical Whole-Tree	620	529	452	72.8%

CONCLUSIONS

For our results from the from all the plots samples, the mean fuel harvesting costs based on our regression equation estimates had a wide range from $620 per acre to $3,535 per acre. These costs represent just the amount to cut and harvest the trees and bring them to the deck; subsequent processing or transport would be additional costs. This huge range was due mostly to the very expensive cases where cable yarding systems would be required, and some very expensive plots even with the ground based systems. The median costs were less expensive, at only $529 per acre for the mechanical whole tree systems. And thus half of the tracts would have costs less than $529 per acre where mechanical whole tree systems could be used.

Mechanical whole-tree harvesting operations were much cheaper on average than the other systems, followed by cut-to-length and manual-whole tree. Cable yarding systems were very expensive in most cases. Variations in the cost estimates are again partly explained by the different harvesting system applied, slope condition, plot location, tree density condition and removal intensity defined for every dbh class.

Several preliminary conclusions can be made as a result of this study. Slope was statistically significant no matter which harvesting system was selected, although its impact on costs varied. For ground based systems, slope added from about $6 to $14 per acre in costs for each 1% increase in slope, which was fairly substantial. Slope either added less, or even helped reduce cable yarder systems costs slightly. This actually does make sense, surprisingly, since steeper slopes up to a point are actually easier to log, since the yarders can get more lift and use less energy on a range of steeper slopes.

Harvesting costs also increased as more trees were harvested and as larger trees were harvested. For ground based systems, average costs increased from $2 to $5 per tree harvested per acre for the smallest dbh size class (0”-6.9”). They ranged from $14 to $16 per tree for the largest dbh size class (>12.9”). This increasing costs with increasing log size seems reasonable. We should note that while cost per tree were higher with large trees, there generally are many more small trees per acre. Thus a stand of many small trees still would cost more to harvest than a stand of much fewer large trees.

The costs per tree size class is not so clear with the cable yarder systems, where costs per tree increase the smallest amount with the larger tree sizes. We are not sure of the explanation for this yet, but it may be a function that yarders can deal with large logs easier than small logs, which is reflected in the production rates and lower costs per tree for large logs.

Overall, this research provides new information about timber harvesting costs for fuel reduction treatments. It developed a method to estimate timber harvest costs for fuel treatments in the West based on existing harvesting technologies, an existing western timber harvesting simulation package, and extensive FIA plot level data for 12 western states. Our results confirm that fuel harvesting costs are expensive. More importantly, they quantify the magnitude of these costs well, and provide an broad overview for all of the western states based on existing FIA data and fuel reduction harvesting guidelines provided by other researchers on this subject.

The results confirm that fuel reduction harvests take out a large share of small stems, using either expensive equipment or lots of manual labor, often on steep terrain. This is far less economically efficient than harvesting fewer large trees with much more volume, which is typical of normal sawtimber harvests in the West.

Providing these better estimates of these fuel reduction harvest costs can help managers plan how to allocate their budgets and forest and homeowners decide how to protect their property. We will continue these analyses and discuss their implications more as we summarize these results more and integrate them with the other joint fire science program economic study results.

REFERENCES

Arriagada, Rodrigo and Frederick Cubbage, North Carolina State University, and Karen Lee Abt. 2006. Estimating timber harvesting costs for fuel treatment in the West: preliminary results. In: Proceedings, Southern Forest Economics Workers Meeting (SOFEW); Baton Rouge, Louisiana, April 18-20. p. 241-251.

Carter, Douglas R. and Frederick W. Cubbage. 1994. Stochastic frontier estimation of technical efficiency in southern timber harvesting. Forest Science 41(3):576-593.

Carter, Douglas R. and Frederick W. Cubbage. 1994. Method-based technical efficiency and industry evolution in southern U.S. pulpwood harvesting. Canadian Journal of Forest Research 24(2):217-224

Carter, Douglas R.., Frederick W. Cubbage, Bryce J. Stokes, and Pamela J. Jakes. 1994. Southern pulpwood harvesting productivity and cost changes between 1979 and 1987. Research Paper NC-318. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. St. Paul, MN. 33 p.

Chalmers, S., B. Hartsough, and M. deLausaux. 2003. Development of a GIS-based Tool for Estimating Supply Curves for Forest Thinnings and Residues to Biomass Facilities in California. Final Report. Department of Biological & Agricultural Engineering, UC Davis, California.

Cubbage, Frederick W. 1983. Tract size and harvesting costs in southern pine. Journal of Forestry 81(7):430-433, 478.

Cubbage, Frederick W. 1983. Simulated effects of productivity rates, input costs, and stand volumes on harvesting costs. Forest Products Journal 33(2):50-56.

Cubbage, Frederick W., and Douglas R. Carter. 1994. Productivity and cost changes in southern pulpwood harvesting, 1979 and 1987. Southern Journal of Applied Forestry 18(2): 83-90.

Cubbage, Frederick W. and Douglas R. Carter. 1994. Southern pulpwood harvesting productivity and costs, 1979 to 1987. Southern Journal of Applied Forestry. 18(2):83-90.

Cubbage, Frederick W. and W. Dale Greene. 1990. Costs of conventional and biomass harvesting by forest tract size. Biomass 20(3&4):219-228.

Cubbage, Frederick W., W. Dale Greene, and John P. Lyon. 1989. Tree size and species, stand volume, and tract size: effects on southern harvesting costs. Southern Journal of Applied Forestry 13(3):145-152.

Cubbage, Frederick W. and James E. Granskog. 1982. Harvesting systems and costs for southern pine in the 1980s. Forest Products Journal 32(4):37-43.

Cubbage, Frederick W., Bryce J. Stokes, and James E. Granskog. 1988. Trends in southern forest harvesting equipment and logging costs. Forest Products Journal 38(2):6-10.

Cubbage, Frederick W., Paul A. Wojtkowski, and Steven H. Bullard. 1989. Cross-sectional estimation of empirical southern United States pulpwood harvesting cost functions. Canadian Journal of Forest Research 19:759-767.

Cubbage, Frederick W., Paul A. Wojtkowski, Thomas G. Harris, Jr., and G. H. Weaver. 1988. Regional analysis of factors affecting southern pulpwood harvesting costs. Forest Products Journal 38(11/12):25-31.

Fight, R., Zhang, X. and Hartsough, R. 2003. Users guide for STHARVEST: software to estimate the cost of harvesting small timber. Gen. Tech. Rep. PNW-GTR-582. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 12p.

Fight, Roger, et al. 2006. Fuel Reduction Cost Simulator. USDA Forest Service, Pacific Northwest Research Station. Portland, OR.

Fried, J.S., J. Barbour and R. Fight. 2003. FIA BioSum: Applying a multi-scale evaluation tool in Southwest Oregon. Journal of Forestry 101(2):8.

Green Guide. 2005. Green Guide Equipment Values. https://www.equipmentwatch.com/Marketing/GG_overview.jsp

Han-Sup, H., Lee, H. and Johnson, L. 2004. Economic feasibility of an integrated harvesting system for small-diameter trees in southwest Idaho. Forest Products Journal 54(2): 21-27.

Hartsough, B. Zhang, X. & Fight, R. 2001. Harvesting Cost For Small Trees in Natural Stands in the Interior Northwest. Forest Products Journal. 51(4):54-61

Hartsough, Bruce. 2005. ST Harvest block data input file program. University of California, Davis. Personal communication.

Huggett, Robert. 2005. Forest Inventory and Analysis (FIA) plot-level data summaries for 12 western states. USDA Forest Service, Southern Research Station. Personal communication.

Keegan III, C. et al. 2002. Harvest cost collection approaches and associated equations for restoration treatments on national forests. *Forest Products Journal* 52(7/8): 96-99.

Kluender, R., D. Lortz, W. McCoy, B. Stokes, and J. Klepac. 1998. Removal intensity and tree size effects on harvesting cost and profitability. Forest Products Journal 48(1):54-59.

Rummer, B.; Prestemon, J.P.; May, D.; Miles, P.; Vissage, J.S.; McRoberts, R.E.; Liknes, G.; Shepperd, W.D.; Ferguson, D.; Elliot, W.; Miller, S.; Reutebuch, S.E.; Barbour, J.; Fried, J.; Stokes, B.; Bilek, E.; Skog, K. and Hartsough, B. 2003. A strategic assessment of forest biomass and fuel reduction treatments in western states. http://www.fs.fed.us/research/pdf/Western_final.pdf

Stier, Jeffrey C. 1982. Changes in the technology of harvesting timber in the United States: some implications for labour. Agricultural Systems 9:255-266.

Stier, Jeffrey C. 1985. Implications of factor substitution, economies of scale, and technological change for the cost of production in the United States pulp and paper industry. Forest Science 31(4):803-812.

Stuart, W.B. 1981. Harvesting analysis technique: a computer simulation system for timber harvesting. Forest Products Journal 31(11):45-53.

Tufts, Robert A. et al. 1985. Auburn Harvesting Analyzer. The Compiler 3(2):14-15.

U.S. General Accounting Office. 1999. Western National Forests: A cohesive strategy is needed to address catastrophic wildfire threats. GAO/RCED 99-65. 60p.

Wang, Jingwan, W. Dale Greene, and Bryce J. Stokes. 1998. Stand, harvest, and equipment interactions in simulated harvesting prescriptions. Forest Products Journal. 48(9):81-86.