The Effect of the Wildland-Urban Interface on Prescribed Burning Costs in the Pacific Northwestern United States

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ABSTRACT

The fire suppression policy on public lands during the last century in the United States has resulted in increased fuel loadings, necessitating the use of prescribed fire and mechanical treatments to decrease hazardous fuels and risks of catastrophic wildfire. While these practices are widespread, there is great variability in project costs, making planning difficult. Although previous studies have examined the factors that influence management costs, they have grappled with the lack of consistent and reliable data. We used the FASTRACS (Fuel Analysis, Smoke Tracking, and Report Access Computer System) database from the Pacific Northwest Region of the USDA Forest Service to identify important influences on fuels management costs. Projects conducted in the wildland-urban interface consistently exhibited higher treatment costs for both prescribed fire and mechanical fuels treatments.

Keywords: fuels reduction; prescribed burning; wildland-urban interface; economics

In recent years, wildland fire has come to the forefront of public interest. Decades of successful wildfire suppression during the 20th Century have elevated levels of burnable wildland fuels that if ignited could lead to catastrophic wildland fire (Arno and Brown 1991). Fuels reduction is of added importance in the wildland-urban interface (WUI), where changing demographics are making fuels management more complex (Snyder 1999). In populated areas, esthetics, air quality, structure protection, and risk add cost and complexity to management projects; however, there is little information available that defines the relationship between costs of management projects in the WUI and the factors that influence those costs.

Cost studies have typically focused on managerial, operational, or physical factors, yet rarely combine all three. Similarly, studies are often focused on either mechanical fuels treatments or prescribed burning. Finally, research across agencies has been difficult given the lack of consistent data. Notwithstanding, Cleaves et al. (1999) analyzed trends and influences on prescribed burning costs in the National Forest system during the period from 1985 to 1994. Similarly, Rideout and Omi (1995) looked at economic data for fuels management at a national level, using National Park Service data that included project information, physical site characteristics, and administrative factors. Using a constant elasticity model of declining cost with increases in scale, they found that the costs of fuels treatment varied with respect to the goals of the management efforts.

With respect to fuels treatments in the WUI, research is becoming more prevalent albeit complicated. In recent years, there has been increased migration into the rural fringe (Synder 1999, Davis 1990), giving rise to controversy regarding who is responsible for structure protection (Bakken 1995). While several studies concerning the WUI have focused on public attitudes and expectations, there are few that examine the effect of the WUI on costs. Furthermore, while it is apparent that fuels management costs can be highly variable, it has been difficult to identify sources of variation, frequently due to the lack of available data; records are often nonexistent or incomplete.

The Federal Wildland Policy of 1995 directs federal managers to implement fuels management plans with regard to both ecological and economic principles (USDI/USDA 1995). As funding is allocated, land managers will look toward economic analyses for answers to fuels management questions. In this study, we look at regionwide fuels management costs for the USDA Forest Service (FS) and USDI Bureau of Land Management (BLM). We develop two regression equations to study the factors that affect costs for prescribed burning and for mechanical fuels treatments. It is necessary to derive two equations given the difference in variables collected for each management project. We begin by discussing our methodology and assumptions and regression results and conclude with a discussion of our findings.

Methodology

The Pacific Northwest Region of the FS and the BLM in Oregon and Washington has been tracking fuels management projects for almost a decade as part of the Fuel Analysis, Smoke Tracking, Report Access Computer System (FASTRACS). This system enables managers to record fuels management project information including costs, physical site characteristics, and managerial factors. At the time of our analysis, in its fullest, unedited form the database contained 18,600 observations with 196 data categories representing years 1993 through 2002, with the bulk of the information from 1999 to 2001. Most of the data are from FS Ranger Districts and BLM Resource Areas.

For both mechanical and fire analyses, we focused only on the years after the National Fire Plan came into effect, beginning in the fall of 2000. Based on previous studies, data availability, and completeness, we selected variables that have been instrumental in explaining treatment costs. Data include physical site information, managerial and administrative factors, and operational information.

Factors were selected via backward elimination based on an extra sums of squares F-test. The elimination criterion was $P > 0.100$. For categorical variables such as activity type and season for example, reference levels were tested to assess significance. Levels of categorical variables were either retained or eliminated as a group. To assess the role of the WUI, a WUI indicator variable was included in analyses of both fire and mechanical treatments. We first fit a rich model with as many independent variables as possible and then worked through the backward elimination process. The resulting equations for mechanical fuels treatments and prescribed burning are depicted by Equations 1 and 2:

In both equations, the dependent variable is the natural log transformation of cost. Costs were also adjusted for inflation using the GDP deflator to year 2000. The independent variables are WUI, designated protection area (DPA), the natural log of acres (lnAcres), Cascade slope indicator,

$$\ln CPA = \beta_0 + \beta_1 WUI + \beta_2 DPA + \beta_3 \ln Acres + \beta_4 Slope + \beta_5 Winter + \beta_6 Summer + \beta_7 Fall + \beta_8 Handpile + \beta_9 MachinePile + \beta_{10} MachineLeave + \beta_{11} Ladder + \beta_{12} Thinning + \beta_{13} PCT + \beta_{14} FRI + \beta_{15} FRIII + \beta_{16} FRIV + \beta_{17} NaturalFuels + \beta_{18} NFPproject \quad (1)$$

$$\ln CPA = \beta_0 + \beta_1 WUI + \beta_2 DPA + \beta_3 \ln Acres + \beta_4 Slope + \beta_5 Elevation + \beta_6 Cascade + \beta_7 Broadcast + \beta_8 MachinePile + \beta_9 HandPile + \beta_{10} LandingPile + \beta_{11} Defensible + \beta_{12} WUI + \beta_{13} EcoSys + \beta_{14} 4{\times}4 + \beta_{15} 6{\times}6 + \beta_{16} 8{\times}8 + \beta_{17} HarvOther + \beta_{18} WholeTree + \beta_{19} BrushGrass + \beta_{20} DougFir + \beta_{21} Lodge + \beta_{22} Mixed + \beta_{23} FRII + \beta_{24} FRIII + \beta_{25} FRIV \quad (2)$$

slope and elevation, season, activity method, fire regime, natural fuels indicator, national fire plan project (NFP), objectives, and fuels types.

Results

Mechanical fuels treatments. The results are significant with an adjusted R^2 value of 0.578 based on 526 observations. The extra sums of squares F-test indicated the regression variables were strongly significant ($P < 0.02$) with the exception of lnAcres ($P = 0.2889$) (Table 1).

The variable lnAcres was retained for practical purposes for cost estimation. The estimated effect of the number of acres after anti-log transformations of both dependent and independent variables indicates that as the number of acres doubles, the cost increases by a factor of 0.927 (95% confidence interval (0.851–1.0069)). If the number of acres increases 10-fold, the cost increases by a factor of 0.778 (95% confidence interval (0.586–1.030)). These economies of scale are also supported in the literature (Rideout and Omi 1995, Jackson et al. 1982).

There was very strong evidence (t-test $P < 0.001$) that the WUI indicator variable had an effect on per-acre costs. After anti-log transformation, the estimate of the coefficient for the WUI indicator is 3.56 (95% confidence interval (2.52–5.05)), indicating costs are almost four times greater

Table 1. Coefficients, t-tests, and 95% confidence intervals for independent variables in the regression model for mechanical treatments from the year 2001.

Variable	Coefficient	*P*-value
Constant	0.219	0.686
WUI	1.271	0.000
DPA	0.469	0.011
lnAcres	–0.109	0.081
Slope	0.03203	0.000
Winter	0.988	0.011
Summer	0.943	0.000
Fall	1.293	0.000
Hand pile	1.447	0.001
Machine pile	1.375	0.004
Machine leave	–0.125	0.780
Ladder	0.774	0.093
Thinning	–0.694	0.151
PCT	1.391	0.023
FR I	1.693	0.000
FR III	1.925	0.000
FR IV	2.061	0.000
Natural fuels	0.967	0.000
NFP	–0.607	0.009

Dependent variable: lnCPA
R^2 0.593
Adjusted R^2 0.578
N = 526

in WUI areas. There was also strong evidence (*t*-test P = 0.011) that designated protection area had an effect on cost per acre. The effect of DPA was 1.60 (95% confidence interval (1.11–2.29)), indicating that mechanical activities in protected areas are associated with per acre costs 60% higher than those in non-protected areas.

Slope had a small but significant positive effect, signifying that increases in slope are associated with slight increases in per-acre costs. The natural fuels indicator also had a positive effect, suggesting that higher costs are associated with natural fuels as opposed to activity fuels or "undetermined." There was a negative effect from the NFP project indicator, which shows that NFP projects tend to have lower costs than non-NFP projects for mechanical treatments.

Three multilevel categorical variables (season, activity type, and fire regime) were included in the final regression equation. Reference levels for these variables were spring, "hand leave," and fire regime II, respectively, and were not therefore shown in the regression. The coefficients indicate that mechanical activity costs were estimated to be significantly higher in all seasons when compared to spring activities (*t*-test $P < 0.02$). Furthermore, fire regime II was associated with lower per-acre costs than fire regimes I, III, and IV (*t*-test $P < 0.001$).

Prescribed burning. Factors included in the final regression equation were WUI indicator, designated protection area indicator, lnAcres, average slope, midpoint elevation, Cascade slope indicator, activity type, management objectives, harvest specifications, fuels species, and fire regime. Coefficients, t-tests, and 95% confidence intervals for each variable are listed in Table 2.

The remaining variables were retained given strong statistical significance (extra sums of squares *F*-test $P < 0.04$). Factors that were eliminated from the fire equation include season, year, county population, state, natural fuels indicator, pile calculation method, pile tons, pile indicator (y/n), NFP project indicator, load calculation method, agency, work agent, multiple ignition indicator, and ignition method. The final regression equation had an adjusted R^2 of 0.610, based on 837 observations.

The WUI indicator was again strongly significant (*t*-test $P < 0.001$) with an estimated coefficient after transformation of 1.430 (95% confidence interval (1.246–1.642)), indicating that the per-acre costs for WUI fire treatments are about 43% more than the per-acre costs of non-WUI fire treatments. Additionally, there was strong evidence (*t*-test $P < 0.001$) to include the designated protection dummy variable in the regression model for fire treatments. After antilog transformation, the estimated coefficient for DPA was 1.349, indicating that per-acre costs of fire activities in designated protection areas are approximately 35% higher than those in non-protected areas.

There was strong evidence (extra sums of squares *F*-test $P = 0.039$) to include lnAcres in the regression model, and again the sign of the coefficient indicated economies of scale. Midpoint elevation and average slope both had a small but significant (*t*-test $P < 0.10$) effect on costs. Estimated effects were such that steeper slopes were associated with slight increases in cost, and higher elevations were associated with slight decreases in cost. The estimated effect of the Cascade slope variable suggested that per-acre costs of fire treatments are higher on the west side of the Cascade ridge.

Table 2. Coefficients, t-tests, and 95% confidence intervals for independent variables in the regression model for fire treatments from the years 2001 and 2002.

Variable	Coefficient	*P*-value
Constant	5.205	0.000
WUI	0.358	0.000
DPA	0.300	0.000
lnAcres	−0.178	0.000
Slope	3.28E−03	0.092
Elevation	−1.55E−04	0.000
Cascade slope	0.517	0.000
Broadcast burn	−0.258	0.197
Machine pile burn	−1.503	0.000
Hand pile burn	−1.259	0.000
Landing pile burn	−1.652	0.000
Obj: defensible space	−0.351	0.002
Obj: forest health	−0.303	0.000
Obj: WUI	0.205	0.024
Obj: ecosystem restoration	−0.300	0.012
Harvest 4×4	−0.317	0.005
Harvest 6×6	−0.120	0.203
Harvest 8×8	0.251	0.133
Harvest other	0.391	0.000
Harvest whole tree	−0.566	0.000
Brush/grass	−0.173	0.321
Doug-fir/hemlock/cedar	0.306	0.027
Lodgpole	0.618	0.000
Mixed conifer	0.427	0.000
FR II	0.467	0.000
FR III	0.268	0.007
FR IV	0.335	0.004

Dependent variable: lnCPA
R^2 0.622
Adjusted R^2 0.612
N = 837

Multilevel categorical variables (and reference levels) in the fire regression included activity type (underburn), primary project objective (fuel reduction), harvest specifications (not applicable), fuels species (ponderosa pine), and fire regime (fire regime I). Burning activities in all fire regimes were associated with higher per-acre costs when compared to fire regime I. Where primary project objectives are concerned, activities with the objectives defensible space, forest health, and ecosystem restoration were estimated to have significantly lower costs than those with the objective of fuel reduction (*t*-test $P < 0.02$). In contrast, activities with the objective WUI were associated with significantly higher costs than those with fuel reduction objectives (*t*-test $P = 0.024$). All of the burn activity types were estimated to have lower costs than underburning. However, there was only very weak evidence (*t*-test $P = 0.197$) supporting a difference of costs between broadcast burning and underburning. All of the fuels species were associated with significantly higher costs than ponderosa pine (*t*-test $P < 0.03$), with the exception of brush/grass, for which there was no evidence of a difference (*t*-test $P = 0.321$).

Discussion

Despite the large amount of information available in FASTRACS and extensive records, the R^2 values were somewhat lower than have been observed in previous studies (Rideout and Omi 1995, Jackson et al. 1982). Lower observed R^2 values may be due to the lack of information regarding key factors. For example, Rideout and Omi (1995) used information on escapes as a variable and ranking scores on values including ignition complexity, natural resources, historic importance, and wildlife habitat. Additionally, previous studies have focused more specifically on only one or two management objectives, resulting in less cost variability.

It is notable that WUI was a significant factor in both mechanical and fire treatments. Analysis of the FASTRACS data clearly indicates that costs are higher for WUI activities. For mechanical treatments, WUI activity costs were estimated to be more than three times as much as for non-WUI activity costs. For fire treatments, WUI per-acre activity costs were estimated to be 43% higher than those of non-WUI activities. The discrepancy in the size of the effect of WUI on costs between fire and mechanical treatment is somewhat unexpected. It is possible that when WUI fuels treatments are associated with relatively high risk or high cost, they are more likely to be treated via mechanical activities than via fire activities. Additionally, managers noted that burning costs can be prohibitively high in the WUI, so it may be the case that the data are skewed to include a greater relative number of low-cost WUI fire treatments.

DPA was also a significant factor in both the fire and the mechanical analyses, indicating that proximity to population centers or areas of smoke management concern can be associated with elevated fuels treatment costs. These results quantify the role of the WUI in fuels management costs and suggest that it may be worthwhile to formally consider WUI and DPA when estimating activity costs.

Activity type and unit size are generally considered to be two important factors influencing treatment costs (Cleaves and Brodie 1990, Cleaves et al. 1999). Activity types were found to be significant for both fire and mechanical treatments. Because this is a primary factor considered in budgeting, it is not surprising that different activities were associated with different costs. The variable lnAcres was included in both regression equations and results support the findings of previous studies (Rideout and Omi 1995, Jackson et al. 1982) that per-acre costs generally decrease as the number of acres treated increases. For fire treatments, this observation was strongly significant, but this was not the case for mechanical treatments. Because the number of acres treated does not greatly affect the per-acre costs of mechanical treatments, this analysis indicates that other factors are more important for estimating costs. With respect to the number of acres treated, mechanical treatments are more likely to have higher fixed costs and lower variable costs than fire treatments. Therefore, mechanical treatment per-acre costs will be less sensitive to overall treatment scale.

Primary project objectives were significant in the analysis of the fire data, supporting the findings of previous research (Cleaves and Brodie 1990). Furthermore, burning activities with WUI objectives were associated with higher costs than those with fuel reduction objectives. All other primary project objectives were associated with lower costs than those of activities with fuel reduction objectives. This result strengthens the argument that costs associated with WUI fire treatments are higher than those associated with non-WUI treatments. Primary project objectives were not found to be significant in the analysis of the mechanical data. It is possible that the significance of this factor was masked by other significant factors in the mechanical analysis.

Conclusion

The results of this analysis clearly indicate that per-acre costs of fuels treatments are higher in WUI areas for both mechanical fuels reduction and prescribed burning methods. Additionally, per-acre costs were found to be higher in areas of concern for smoke management or near population centers. Currently, WUI and DPA are not specifically factored into budgeting for fuels management activities in the Pacific Northwest. However, this analysis indicates that considering WUI and DPA could produce more accurate cost estimates. DPA is only a factor in Oregon where the smoke management plan delineates these areas. It would be possible, however, to develop similar classifications in other states based on smoke management concerns and population densities.

The FASTRACS database has great potential for future studies. It may become a more central part of the management system of the Pacific Northwest region. As more managers use FASTRACS, it will become a more complete record of management activities across the region. Additionally, perhaps it can serve as a model for a nationwide data management system. For accurate economic analysis of the FASTRACS database, however, it will be necessary to more precisely define what activity costs are composed of, as well as to define actual versus planned costs. This will ensure that costs may be compared across districts, forests, and regions. Additionally, for future studies of WUI issues, it will be necessary to develop a working definition of this term.

For statistical analysis purposes, more complete records are needed in the FASTRACS database. For example, many observations in this study were incomplete in the potentially important fields of weather, fuel moisture, condition class, threatened and endangered species, predominant aspect, and position on slope. Furthermore, it would be useful to record information on factors like unit shape, access, distance traveled to worksite, crew composition, hours of labor, days of mop-up, and occurrences of escapes. This would enable more comprehensive analyses, and the ability to predict a greater portion of cost variability.

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