12-2012

The Influence of Market Proximity on National Forest Hazardous Fuels Treatments

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Citation Details

Nielsen-Pincus, M., Charnley, S., & Moseley, C. (2013). The Influence of Market Proximity on National Forest Hazardous Fuels Treatments. Forest Science, 59(5), 566-577.

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Abstract: The US Department of Agriculture Forest Service's focus on hazardous fuels reduction has increased since the adoption of the National Fire Plan in 2001. However, appropriations for hazardous fuels reduction still lag behind wildfire suppression spending. Offsetting fuels treatment costs through biomass utilization or by using innovative administrative mechanisms such as stewardship contracting are two approaches to stretching appropriated dollars further across the landscape. We use fuels treatment data (n = 8,451 locations) to ask how wood-processing infrastructure influences where and how much hazardous fuels treatments, biomass utilization, and stewardship contracting occur on national forests in Oregon and Washington. We found that national forest ranger districts that are relatively close in proximity to sawmills or biomass facilities treated more overall ha and more wildland-urban interface ha and used stewardship contracting on more ha than ranger districts further away and that there was a threshold distance for these effects (40 minutes). We also found that proximity to sawmills and biomass facilities influenced the location and extent of hazardous fuels treatments that incorporated biomass utilization or were administered through a stewardship contract. Our analysis suggests that to be effective at offsetting some of the costs of hazardous fuels reduction and treat a greater extent of the landscape, policy strategies may need to focus on supporting a network of wood-processing facilities that is distributed across forest-based communities. FOR. SCI. 59(5):566–577.

Keywords: biomass utilization, fire hazard reduction, stewardship contracting, Pacific Northwest, spatial network analysis

OVER THE PAST DECADE, severe wildland fire has become a leading natural resource management problem for the US Department of Agriculture (USDA) Forest Service and the US Department of the Interior (USDOI). The increasing length of the fire season, expansion of the wildland-urban interface (WUI), the history of fire suppression, and climate change have all contributed to this trend (Theobald 2005, Running 2006, Westerling et al. 2006, Gude et al. 2008). US Forest Service expenditures on fire suppression have risen dramatically since the 1990s, averaging more than $1.5 billion per year since 2000 (Prestemon et al. 2008, Gebert and Black 2012). The use of land management strategies aimed to reduce the amount of hazardous fuels on the landscape is one approach for preempting the need to so dramatically prioritize wildfire suppression. Hazardous fuels reduction includes land management activities that are designed to alter fire behavior and cause wildland fires to burn with less intensity and severity, reducing the threat they pose to fire-adapted ecosystems, neighboring landowners, and homeowners living in the WUI while in many situations contributing to forest restoration (Pollet and Omi 2002, Gude et al. 2008, Martinson and Omi 2008).

Federal wildfire policy now includes a major focus on reducing hazardous fuels in the WUI and on federal lands (Western Governors' Association 2001, 2006). Hazardous fuels reduction has been a key issue for the Forest Service since the adoption of the first congressional appropriations associated with the National Fire Plan in 2001. With this focus, the Forest Service has developed performance measures to evaluate the agency's accomplishments and annual targets (USDA 2011). Yet, Forest Service appropriations for hazardous fuels reduction have averaged approximately $300 million per year between 2001 and 2010 (USDA 2010, 2011): for every dollar spent on wildfire suppression, only 20 cents is appropriated for hazardous fuels work. Nonetheless, from fiscal years 2001 to 2008 the major federal land management agencies reported treating hazardous fuels on more than 10 million ha of federally managed land (Wildland Fire Leadership Council 2010). The hectarage of hazardous fuels treated by the Forest Service has generally increased since 2000, and the agency spent an estimated $500 million on hazardous fuels reduction and related activities in fiscal year (FY) 2010 (approximately 24% of the Wildland Fire Management budget and 9% of the agency's total discretionary budget; USDA 2011). However, on many western national forests, fuels treatments cannot keep pace with need (Donovan and Brown 2007, Morgan et al. 2011, North 2012).

The cost of implementing hazardous fuels treatments

Manuscript received July 21, 2011; accepted October 1, 2012; published online December 6, 2012; http://dx.doi.org/10.5849/forsci.11-096.

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Acknowledgments: We are grateful for the assistance of several individuals who provided important contributions to this project. Robin Lily provided access to USDA Forest Service data on hazardous fuel treatments. Joe Gordon and Liz Podowski programmed the spatial network analysis and provided GIS support. Dorion Smith and Gary Lettman provided mill data for Oregon and Washington. We also thank Ellen Donoghue for helping frame the initial direction of the project, and three anonymous reviewers whose suggestions and critiques greatly improved the manuscript. This project was funded by the USDA Forest Service, Pacific Northwest Research Station agreement number PNW06JV11261975.

creates a significant challenge for changing fire behavior across large landscapes (Daugherty and Fried 2007). The small-diameter wood and brush that pose the greatest risk for catastrophic wildfire typically have limited commercial value. Consequently, there is relatively little ability to draw on traditional wood products markets to help offset the cost of treatments (Evans 2008, Aguilar and Garrett 2009, Sundstrom et al. 2012). The financial feasibility of transporting small-diameter trees over long distances in regions such as the western United States increases the challenge of finding markets to help offset the costs of hazardous fuels treatments with a revenue source (Daugherty and Fried 2007). In an era when congressional funding is increasingly scarce relative to the scope of the problem (Moseley and Reyes 2008) and traditional wood products markets are increasingly costly to reach, how can the federal government accomplish hazardous fuels reduction work in a cost-effective manner and reduce suppression costs, natural resource damage, and fire risk to local communities?

Adding value to the materials generated from hazardous fuels treatments continues to have the potential to improve the financial margins on hazardous fuels reduction work but requires market innovation, planning, and investment to create value where it did not exist in the past. Use of stewardship contracting is one way to undertake fuels reduction. Authorized by Congress in the early 2000s, stewardship contacting allows the Forest Service to sell goods (e.g., timber) and purchase services (e.g., removal of hazardous fuels) in a single contract, allowing for more comprehensive and cost-effective treatment. Stewardship contracting can also help increase social agreement among forest stakeholders to proceed with hazardous fuels reduction efforts that involve timber removal because the stewardship contracting process incorporates stakeholder collaboration (Moseley and Davis 2010, Becker et al. 2011a). In addition, stewardship contracting can potentially overcome the supply barrier to developing biomass utilization infrastructure in which federal lands are the main source of supply and unpredictable harvests have been a problem in the past (Hjerpe et al. 2009, Becker et al. 2011a). Stewardship contracts can be awarded for up to 10 years, increasing the certainty of supply.

In addition to stewardship contracting, policymakers, forest managers, community organizations, and businesses have been increasingly focused on biomass utilization. Biomass utilization is often achieved by allowing businesses to purchase the minimal value materials generated from hazardous fuels projects. The income from sale of the minimal value biomass can help to reduce the net costs of hazardous fuels reduction while creating renewable energy and economic development opportunities for rural communities (Aguilar and Garrett 2009, Sundstrom et al. 2012). Biomass may be used for thermal or electrical energy generation or for small-diameter wood products; biomass may bring new and emerging markets into forest management.

Both stewardship contracting and the increasing focus on biomass utilization are strategies for reducing the net costs of treating hazardous fuels that rely on the existence or development of sawmills and biomass facilities with the capacity to use biomass or small-diameter wood harvested within a cost-effective distance. However, it has not been empirically demonstrated whether and to what extent local markets for biomass affect hazardous fuels reduction, nor is it clear how close sawmills and biomass utilization facilities need to be to treatment locations to affect hazardous fuels reduction efforts. Transportation can be a significant component of the costs associated with biomass utilization (Young et al. 1988, Abbas et al. 2008, Becker et al. 2009, Wu et al. 2011) and is often cited as a barrier, suggesting that sawmills and biomass facilities located far from treatment locations may not create viable markets for low-value material (Becker et al. 2011a). Becker et al. (2009) suggested that decreasing the proximity of markets to harvest sites is the only strategy that will offset hazardous fuels reduction costs in a meaningful way. Although there have been numerous theoretical assessments of supply availability (e.g., Daugherty and Fried 2007, Barbour et al. 2008, Jones et al. 2010, Wu et al. 2011), actual empirical studies of market influences are limited (however, see Evans 2008).

The objective of this article is to understand the role of wood products markets in accomplishing hazardous fuels reduction on national forest lands. Specifically, we examine the hectarage of hazardous fuels treatments, the utilization of biomass, and the administration of stewardship contracts in relation to the location of sawmills and biomass facilities in Oregon and Washington, USA. We consider three main research questions:

1. Do forest managers on ranger districts that are located in closer proximity to sawmills and biomass facilities use biomass from more hectarage, administer stewardship contracts over greater areas, and treat more overall hectarage of hazardous fuels than those on ranger districts located further away?
2. Within a given ranger district, does the location of sawmills and biomass facilities influence where biomass utilization, stewardship contracting, and other hazardous fuels treatment activities occur?
3. Does a threshold exist beyond which the proximity to sawmills and biomass facilities ceases to influence the location and extent of biomass utilization, stewardship contracting, and hazardous fuels treatments?

Materials and Methods

Study Area

The Oregon and Washington administrative region of the Forest Service (Pacific Northwest Region, Region 6) includes 16 national forests and 66 ranger districts that encompass approximately 10 million ha of Oregon and Washington.[1] The buildup of wildland fuels is increasingly recognized as a problem in Pacific Northwest forests, especially on the drier, more fire-adapted East side of the Cascade Mountains and in southern Oregon where forests have increasingly departed from their historical fire regimes (Daugherty and Fried 2007). Management treatments to reduce the impact of fuels on wildfire hazard are common in these locations, as forest managers and the public have increasingly reached agreement on the need to mitigate wildfire hazard around communities and to restore fire-adapted ecosystems.

Oregon and Washington have a long history of forest management and wood products industry infrastructure, including sawmills and other facilities that convert wood to energy. Both states also have enacted policies to develop and support woody biomass-based energy capacity (Becker et al. 2011b). The region also has an extensive network of forest roads and highways and a workforce engaged in natural resource management. Although the number of sawmills has declined over the past several decades, the productive forests of western Oregon and Washington supported nearly 200 primary wood processing mills in 2005 (Prestemon et al. 2005, Spelter and Alderman 2005). Sawmill density is more sporadic east of the Cascade Mountains, but mills remain important there for forest management. Representative of many of the same challenges and opportunities faced throughout the western United States and nationally, the Pacific Northwest provides a microcosm of forest diversity, management strategies, and distribution of sawmills and biomass facilities.

Data Sources and Generation

To empirically test the relationship between the location of wood products markets and implementation of hazardous fuels treatments, we conducted an analysis based on three spatial data sets: hazardous fuels treatment records, sawmill and biomass facility locations, and a detailed road and highway network for Oregon and Washington (Figure 1).

Hazardous Fuels Treatment Records

In October 2010, we obtained hazardous fuels treatment records for Region 6 of the Forest Service for FY 2005–2010 from the National Fire Plan Operating and Reporting System (NFPORS) and the Forest Service Activity Reporting System (FACTS). Forest Service data in NFPORS are generated from the FACTS, the agency's performance tracking system. NFPORS was originally created by the Forest Service and Department of Interior to track National Fire Plan accomplishments. The data included 16,649 treatment records for the two-state study area. Each treatment record included attributes about the location, size and type of treatment, funding source, administrative mechanism used to accomplish the treatment, and time when the treatment was completed and information on whether the treatment occurred in the WUI and whether biomass from the treatment was used. We did not obtain data on volume of biomass utilization or removal. We used the latitude and longitude of the treatment locations to map the activities in a geographic information system (GIS). For quality control we excluded 25 treatment locations for which the latitude/longitude was missing, was clearly input incorrectly (e.g., 1N, −2W), or occurred outside of the boundaries of Oregon and Washington. We also followed the methodology of Schoennagel et al. (2009) and deleted treatment locations that were duplicated more than 10 times in a given year. Doing so eliminated 47 locations that were recorded as the treatment location for more than 1,200 treatment observations. The remaining treatment records included 99.2% of the original treatment locations, two-thirds of which included only one treatment per location per year. Last, because a number of administrative units reported relatively few hazardous fuels treatments, we focused our analysis on national forest ranger districts that reported more than 1,000 ha of hazardous fuels treatments over the 6-year study period. This final step removed an additional 431 treatment locations, leaving approximately 95% of the original treatment locations.

Primary Wood Processing and Utilization Facilities

We developed a GIS data set of sawmills and biomass utilization facilities as a proxy for wood products and wood fuels markets. We included only the 197 sawmills and 34 biomass facilities that were in operation during the 2005–2010 time period represented by the treatment data. To develop the facilities data set, we gathered data from a number of secondary public and private sources, and ground-truthed the data with assistance from the Oregon Department of Forestry, the Washington Department of Natural Resources, and key community and industry informants. For biomass facilities, we sourced facility locations from the Oregon Department of Energy's *Oregon Bioenergy Book* (Oregon Department of Energy 2009), US States Environmental Protection Agency's eGRID database (US Environmental Protection Agency 2010), and the Northwest Power and Conservation Council's biomass generation map (Northwest Power and Conservation Council 2011). A list of unique sawmills and wood energy facilities was created based on information gathered from all sources, and each facility was attributed with name, type, and location (latitude and longitude). Facilities were then imported into a GIS and mapped. Capacity data for the facilities were unavailable.

We included sawmills in our data set because many have been retooled to process small-diameter trees (down to 7 in. in some cases) and because wood products processing infrastructure and biomass energy facilities are often codependent (Becker et al. 2011a). We did not include other mill types (such as cedar and bark products, log furniture, and post and pole) because many of these facilities have low capacity and are geared toward smaller niche markets and are therefore not comparable to sawmills and biomass facilities in creating market demand for forest products.

Roads and Highways

We obtained detailed digital GIS road and highway coverages from the USDOI Bureau of Land Management Oregon and Washington regional office (US Department of the Interior 2011). The data include more than 1.8 million road segments for Oregon and Washington at the 1:24,000 scale and are derived from a variety of sources including Bureau of Land Management, Forest Service, US Geological Survey, digital line graphics, state departments of transportation, counties, and a variety of other state, federal, and local sources. We used the ArcGIS integrate tool to perform one major preprocessing step on the roads and highways layer (using a 0.00025-degree cluster tolerance) to ensure that all road and highway segments were spatially connected in the network. The integrate process simplified the network slightly by merging road and highway segments within about 15 m of each other. At this scale we could not account for road closures.

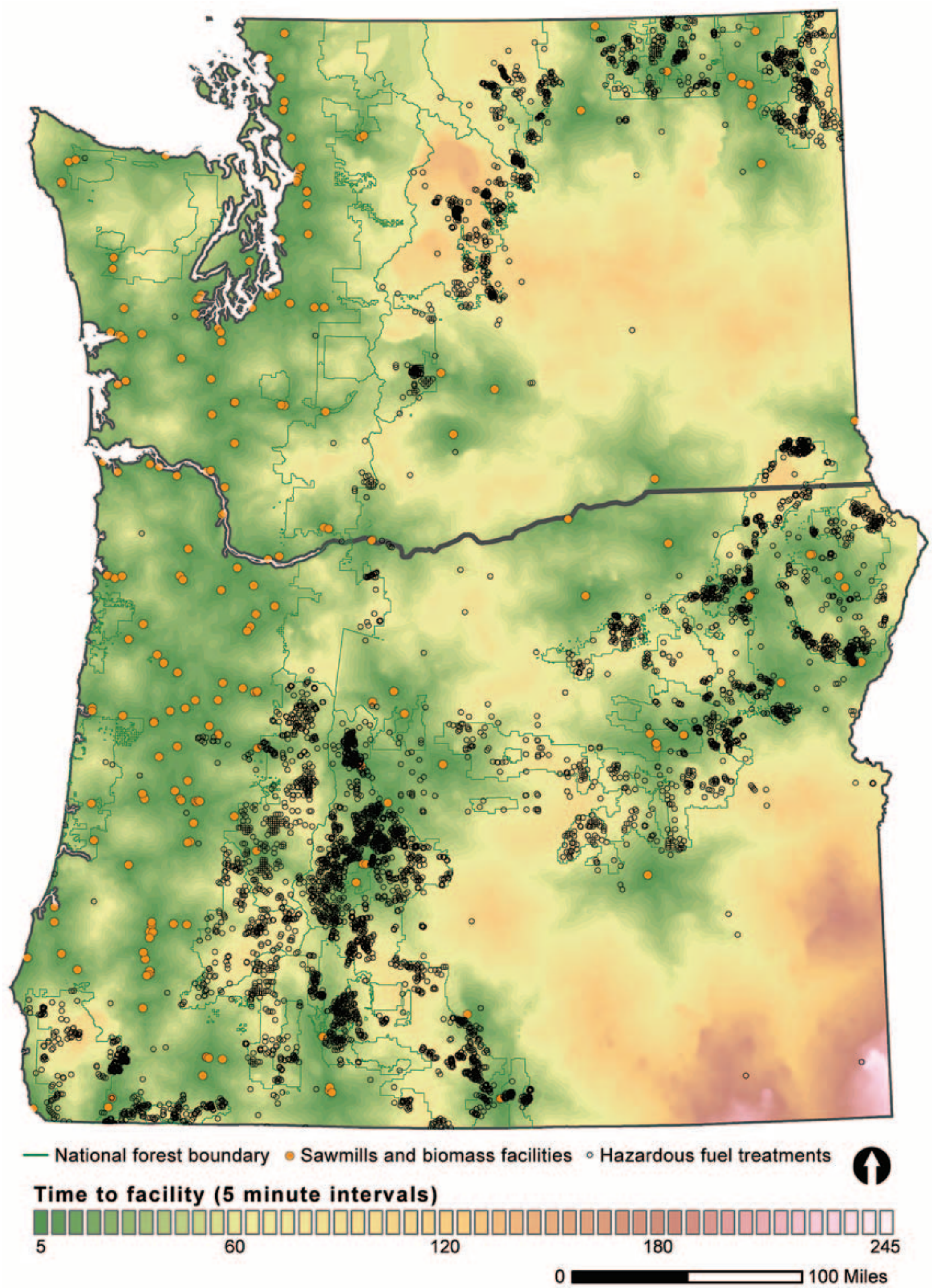

Figure 1. Travel time surface for hazardous fuel treatments (black circles) and sawmill and biomass facilities (orange circles) in Oregon and Washington. National forest boundaries are outlined in green.

Generating Proximity Between Treatment Locations and Facilities

We conducted a network analysis using ESRI's ArcGIS Network Analyst tool to generate travel distance and times from treatment locations to facilities. To run the network analysis, we first associated all treatment and facility locations with their closest point in the road network. Second, we programmed all state highways and interstates with an average travel speed of 80 km/h, and all other roads with an average travel speed of 40 km/h. We then selected the shortest travel time route between each treatment location and a sawmill or biomass facility. Although the choice of the two travel speeds greatly oversimplifies reality, we made this decision to increase the likelihood that the network analysis preferentially generated routes between treatments and facilities that used highways and interstates over other potentially shorter distances, but longer travel time and more expensive routes.

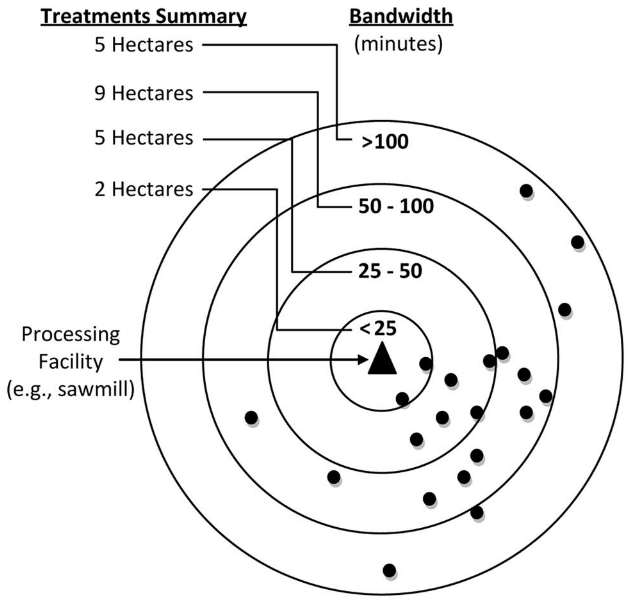

Figure 2. Conceptual diagram of hazardous fuels treatment proximity to wood-using markets. Each black dot represents 1 acre treated and the treatment summary represents the number of acres treated within each bandwidth of time from the wood-using sawmills and biomass facilities.

We use the term *proximity value* to refer to the travel time generated by the network analysis for each treatment location to indicate that these results are proximate rather than precise estimates of travel time. After the generation of proximity values for each treatment location, we aggregated the hectarage of hazardous fuels treated in 5-minute bands of proximity to sawmills and biomass facilities (i.e., the number of ha treated within 5 minutes, within 10 minutes, within 15 minutes, and so on) (Figure 2) for each ranger district. We do not infer or intend to imply that materials generated from hazardous fuels treatments actually travel these routes or even leave the treatment locations at all; rather, we used the ha treated within given bands of proximity to represent the general influence of industry infrastructure on hazardous fuels treatments.

Data Analysis

We begin by summarizing the hazardous fuels treatment data for Oregon and Washington according to the number of treatment locations, total ha of treatments, ha of treatments in the WUI, ha of treatments by type, ha from which biomass was used, use of administrative mechanisms for accomplishing treatments, and treatment proximity to facilities. For each field we summarize the treatment data by geography (i.e., Oregon versus Washington), fiscal year (i.e., 2005–2010), treatment type, administrative mechanism, and market proximity.

To answer our first research question about whether ranger districts that are closer to facilities conduct more hazardous fuels treatments, use biomass from more treatments, and use stewardship contracting for more treatments, we grouped ranger districts into two groups. The first group included those ranger districts in which the average proximity of treatments to sawmills and biomass facilities was at or below the median proximity for all ranger districts; all other ranger districts were grouped into the second group. We provide a treatment summary for both the near and far districts and test whether ranger districts with relatively close sawmills and biomass facilities report more hazardous fuels treatments, more biomass utilization, and more stewardship contracting than those farther away using a Student's *t*-test to determine whether the differences between the groups are significant.

To answer our second research question about whether treatment locations within ranger districts are influenced by the location of sawmills and biomass facilities, we examined the hazardous fuels treatment data compiled into 5-minute bands of proximity to sawmills and biomass facilities. Our analysis is hierarchical, with the treatment data nested within ranger districts. To account for the hierarchical nature of our data, we used the Mixed Linear Model (MIXED) procedure in SAS. The random intercept regression model allows the regression model to vary by ranger district and was specified as

$$y_{ij} = \beta_0 + \beta_1 x_{1ij} + \cdots + \beta_p x_{pij} + \gamma_j + \varepsilon_{ij}, \qquad (1)$$

where y_{ij} is the ha treated in proximity band i on ranger district j, β_0 is the average intercept across all ranger districts, $\beta_{1ij} \cdots \beta_{pij}$ is the set of p slope coefficients for fixed effects $x_{1ij} \cdots x_{pij}$, and γ_j are ε_{ij} are uncorrelated random error terms (with a mean of 0 and variance parameterized by the data). γ_j can also be interpreted as the random intercept coefficient that specifies for a given ranger district the deviation in ha treated for that ranger district from the average ranger district. In essence, the random intercept corrects for differences in the magnitude of ha treated by different ranger districts. We used this model specification to create three regressions, each with different dependent variables: total ha treated, ha treated from which biomass was used, and ha treated in which the treatment occurred using stewardship contracting.

Our primary independent variable of interest was the proximity bandwidth value. We first tested for the significance of the proximity coefficient, expecting that, if significant, the proximity coefficient would be negative, reflecting fewer treatments occurring in areas further from facilities. We also included the hectarage treated within the WUI as a covariate in each regression so that any significant effects from proximity could be attributed independently of forest manager WUI preference. The Healthy Forest Restoration Act directs forest managers to use no less than 50% of allocated hazardous fuels funding to treat WUI areas (16 USC § 6513 (d)(1)(A)), and US wildfire policy provides more general direction to give priority to treatments in WUI areas over other areas (Vaughn and Cortner 2005, Schoennagel et al. 2009). We also controlled for the size of the ranger district (in ha) to ensure that our results were not simply an artifact of larger ranger districts accomplishing more treatments. In both covariate cases, we tested for the significance of the variables in explaining the hectarage of hazardous fuels treatments at a given proximity to facilities, expecting that if significant the covariate coefficient signs would be positive, reflecting a positive relationship between the reported hectarage of hazardous fuels treatments and preference for WUI and ranger district size. We also expected the results of the random intercept model to affirm our first research question, such that positive intercept values (i.e., more treatment hectarage) would be associated with ranger districts with relatively nearby sawmills and biomass facilities, and negative intercept values (i.e., less treatment hectarage) would be associated with ranger districts that are relatively farther away.

To answer our third research question, we examined the concept of a threshold beyond which sawmills and biomass facilities had no influence on hazardous fuels treatments. First, to identify a potential threshold, we iteratively reran the random intercept regressions. In the first iteration, we included only those ranger districts for which the average proximity value was greater than 20 minutes. In the second iteration, we reran the random intercept regressions using only data from ranger districts for which the average proximity value was greater than 30 minutes, and so on in 10-minute increments through 60 minutes. We expected that at some threshold of proximity the effect of sawmill and biomass facility locations would cease to influence the hectarage of hazardous fuels treatments reported. Second, we examined the specific effects of proximity on individual ranger districts by reprogramming the random intercept regression to allow a full random effects model, incorporating both random slopes and intercepts by ranger district. We specified the new model similar to the random intercept model but with the addition of a slope coefficient estimated for each ranger district

$$y_{ij} = \beta_0 + \beta_1 X_{1ij} + \cdots + \beta_p X_{pij} + \gamma_{0j} + \gamma_{1j}\text{Proximity}_{ij} + \varepsilon_{ij}, \quad (2)$$

where γ_{0j} is a random intercept coefficient for ranger district j and γ_{1j} is the slope coefficient for the random effect of proximity for ranger district j. We present the number of random slope coefficients that were significant, the number of ranger districts that were within the distance threshold, a χ^2 test for association between the two, and the odds that random slope coefficients are significant for ranger districts within and outside the threshold.[2]

Results

Hazardous Fuels Treatments in Oregon and Washington

We excluded 20 ranger districts that reported fewer than 1,000 ha of hazardous fuels treatments over the 2005–2010 study period from the analysis. Excluded ranger districts reported an average of 460 ha treated per ranger district, ranging from 2 to about 1,000 ha 14 of these ranger districts were located west of the Cascade Mountains where wildfires are less common. Excluded districts did not exhibit bias in the average proximity to mills.

The remaining 46 ranger districts reported a total of 328,940 ha of hazardous fuels reduction at 8,451 treatment locations (Table 1), approximately 40% of which were reported to occur in a WUI area (Figure 3A). Over three-quarters of the reported hectarage treated occurred on forests in Oregon east of the Cascade Mountains (Figure 3B). The hectarage of reported hazardous fuels treatments increased from 12,576 ha in fiscal year 2005 to more than 80,000 ha reported in fiscal years 2009 and 2010 (Figure 3C). Administratively, the in-house workforce accomplished the most treatment hectarage; service contracts and timber sales were used to accomplish the second and third most hectarage, respectively. Stewardship contracts were used to accomplish only about 3% of all hectarage reported (Figure 3D). The majority of hectarage treated was accomplished mechanically[3] rather than with prescribed fire or other methods (Figure 3E). Nearly two-thirds of all reported hectarage treated occurred within approximately 50 minutes of sawmills and biomass facilities, yet some volume of biomass was used from only about 9% of the treated hectarage (Figure 3F).

Do Closer Ranger Districts Conduct Hazardous Fuels Treatments Differently than Those Farther Away?

The average proximity to sawmills and biomass facilities of the median ranger district was 43 minutes. Taken together, the 23 "closer" ranger districts reported nearly 75,000 more total ha treated, 60,000 more ha treated in a WUI, more hectarage from which biomass was used, and more hectarage administered with a stewardship contract than the 23 ranger districts for which the average treatment location was farther from a facility than the median proximity (Table 2). Closer ranger districts reported treating more than 8,500 ha on average; ranger districts farther than the median proximity reported treating only about 5,500 ha ($t = 1.74$; $P = 0.08$). These close ranger districts also reported nearly 2.9 times the number of ha treated in the WUI ($t = 2.35$; $P = 0.02$) and administered more than 4.5 times the ha treated using stewardship contracting ($t = 1.94$; $P = 0.05$) than their counterparts on ranger districts far from sawmills and biomass facilities. Although closer ranger districts also reported more biomass utilization, the average hectarage of treatment from which biomass was used did not significantly differ between the two groups of ranger districts ($t = 1.24$; $P = 0.22$).

Mixed-effects regression results also support the finding that ranger districts closer to sawmills and biomass facilities conduct more total treatments, use biomass from a greater number of their treated ha, and administer more ha of treatments through stewardship contracts, even after controlling for the number of ha treated in the WUI and the size of the ranger district. As expected, random intercept values varied from negative to positive, with closer ranger districts tending to have greater intercept values and farther ranger districts having smaller intercept values, indicating that ranger districts in closer proximity to markets tend to do more overall treatments, biomass utilization, and stewardship contracting.

Does Proximity to Facilities Influence Where Hazardous Fuels Treatments Occur within a Ranger District?

Travel times from treatment locations to the closest facility in our model ranged from less than 5 minutes to nearly 200 minutes and varied substantially by ranger district. Proximity to sawmills and biomass facilities did not significantly influence where on a ranger district the hectarage of all hazardous fuels treatments occurred. However, proximity did significantly influence where the hectarage treated occurred from which biomass was used and for which stewardship contracts were used (Table 3, Panel A). Proximity regression coefficients for both the biomass utilization

Table 1. Hazardous fuels treatment attributes for Oregon and Washington reported by USDA Forest Service Region 6 to the National Fire Plan Operating and Reporting System.

	Treatment locations	Total treatments	WUI treatments	Mechanical treatments	Market proximity <50 min	Market proximity ≥50 min
	(n)			(ha)		
Total	8,451	328,940	126,427	175,953	218,904	110,036
Oregon						
Eastside	5,210	213,851	64,422	116,091	152,986	60,865
Westside	1,139	43,519	15,521	25,558	31,174	12,345
Washington						
Eastside	1,887	68,023	46,259	32,628	31,341	36,682
Westside	220	3,547	225	1,675	3,404	144
Fiscal years						
2005	368	12,576	7,235	10,128	11,086	1,491
2006	484	21,830	6,485	11,416	12,593	9,237
2007	1,728	66,768	24,434	32,105	41,056	26,522
2008	1,619	58,591	22,921	28,895	35,544	23,048
2009	1,993	87,285	33,982	46,147	63,368	23,917
2010	2,259	81,889	31,370	47,261	55,259	26,630
Treatment types						
Prescribed fire	2,651	145,174	49,139		12,111	82,420
Mechanical thinning	4,780	103,602	42,687		76,172	27,430
Other mechanical	2,705	55,512	29,358		44,129	11,384
Forest harvest	666	16,839	2,310		12,111	4,728
Other treatments	146	7,814	2,932		4,073	3,741
Administrative mechanism						
In-house workforce	3,260	147,626	60,148	23,742	88,805	58,822
Service contracts	3,363	92,243	40,095	86,945	68,615	23,628
Timber sale	1,465	42,149	11,484	42,139	31,775	10,374
Stewardship contract	183	10,850	4,398	10,419	9,045	1,805
Grants and agreements	36	4,347	3,641	4,016	3,380	966
Other mechanisms	125	31,724	6,661	8,692	17,284	14,440
Market proximity						
<50 min	5,923	218,905	93,750	132,412	218,904	-
>50 min	2,528	110,036	32,676	43,541	-	110,036
Biomass utilized	1,218	31,007	11,129	29,760	22,504	8,504

Only ranger districts that treated more than 1,000 ha are included. The 20 ranger districts that treated fewer total acres averaged 459 ha treated over the 6-year study period; 14 of these 20 ranger districts were westside ranger districts.

and stewardship contracting regression were negative, indicating that within a given ranger district, fewer ha were treated using these mechanisms as the distance to facilities increased. The WUI was also a significant influence on each of the models, indicating that WUI treatment ha positively influence the total hectarage of treatments, biomass utilization, and stewardship contracting. However, in the biomass utilization and stewardship contracting models, the strength of the influence of WUI was substantially smaller than the influence of proximity, a further indication of the importance of nearby sawmills and biomass facilities for biomass utilization and stewardship contracting. Ranger district size did not significantly influence any of the three models.

Does a Threshold Exist Beyond which Proximity to Facilities Has No Influence on Hazardous Fuels Treatments?

The influence of proximity to sawmills and biomass facilities on biomass utilization and stewardship contracting was not consistently significant across all ranger districts. Proximity ceased to influence biomass utilization and stewardship contracting when we included only those ranger districts for which the average treatment was greater than 40 minutes from a facility (Table 3, Panel B). In each of these subset regressions, the results demonstrated patterns of overall model fit similar to the full regression, with a similar influence from the WUI treatments (remaining a relatively smaller effect than proximity), and no significant influences from ranger district size.

Reprogramming the regression model to allow the effect of proximity to vary by ranger district (i.e., random slope and random intercept models) helped to identify specific ranger districts for which the influence of proximity to sawmills and biomass facilities was a significant influence on the variables of interest in this study. Most of the ranger districts on which proximity influenced where hazardous fuels treatments were located were within the 40-minute threshold. We used a contingency table to cross-tabulate the count of significant random slope coefficients and the count of being within the 40-minute threshold to compare the odds of having a significant slope coefficient relative to being near to or far from market infrastructure (Table 4). Ranger districts within the 40-minute threshold exhibited 5.3 times greater odds of exhibiting a pattern of locating hazardous fuels treatments disproportionately closer to sawmills and biomass facilities ($\chi^2 = 4.03$, $P < 0.05$) than those ranger districts beyond the 40-minute threshold, which were more

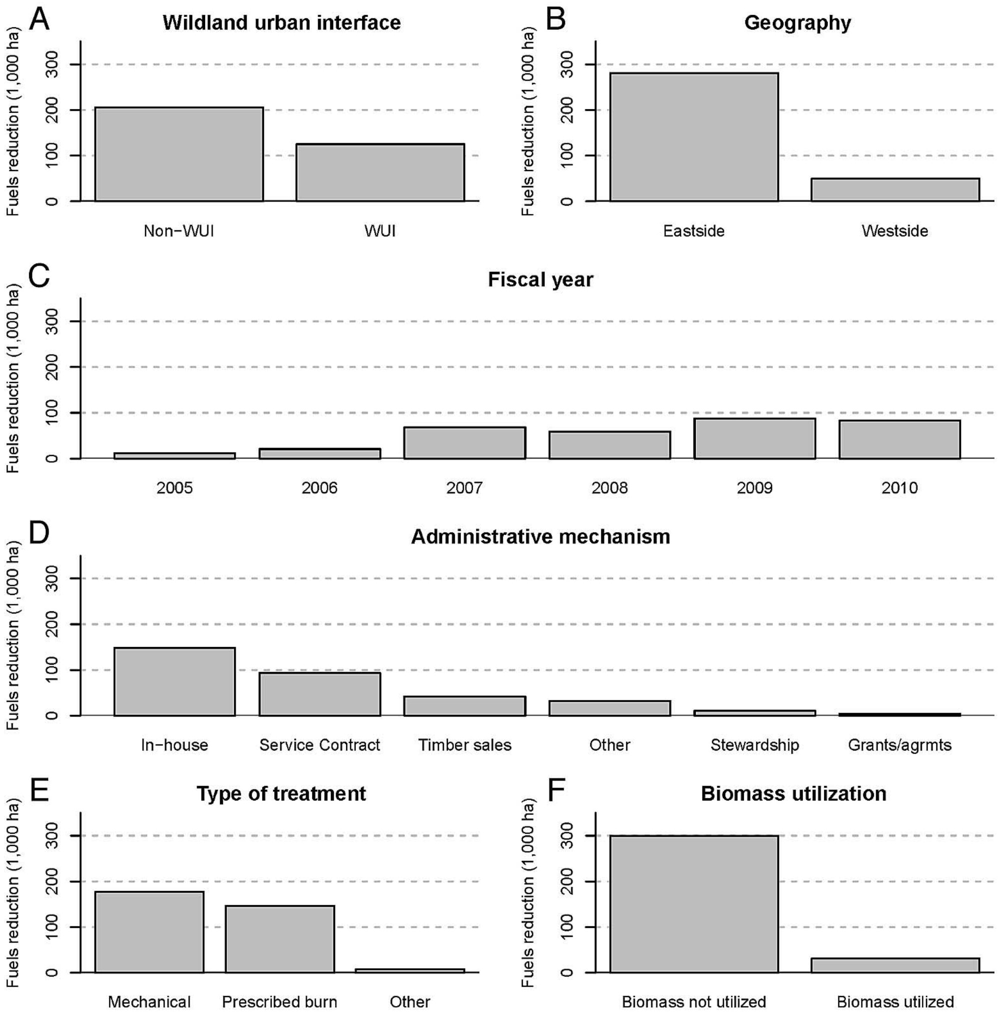

Figure 3. Summary of hazardous fuels treatment characteristics on national forests in Oregon and Washington between fiscal years 2005 and 2010.

likely to locate hazardous fuels treatments randomly with respect to the distance to market infrastructure.

Biomass utilization also exhibited a meaningful pattern. Of the ranger districts within the 40-minute threshold, 45% (9 of 20) exhibited a significant effect of proximity to sawmills or biomass facilities on biomass utilization, whereas only 15% (4 of 26) of ranger districts beyond the threshold exhibited this effect ($\chi^2 = 4.55$, $P = 0.03$). Finally, proximity to sawmills and biomass facilities strongly influenced the use of stewardship contracting. Every ranger district for which there was a significant relationship between proximity and the location of hazardous fuels treatments administered by stewardship contracting was within the 40-minute threshold ($\chi^2 = 10.36$, $P < 0.01$). These observed patterns indicate that proximity to market infrastructure can play an important role in hazardous fuels treatment decisions, especially for forest managers within reach of market infrastructure.

Discussion

The task of making hazardous fuels treatments more cost-effective to reduce wildfire risks to communities and forest resources rests heavily on adding value to the materials generated from hazardous fuels reduction. Markets can help offset the costs of hazardous fuels treatments through the utilization of woody biomass and other small-diameter materials generated from treatments (Becker and Viers 2007). We examined hazardous fuels reduction accomplishments on national forests in Oregon and Washington to investigate whether the location of sawmills and biomass facilities affected the number of ha treated, the location of treatments, and the types of treatments and mechanisms used to accomplish hazardous fuels reduction. We also examined how close sawmills and biomass facilities need to be to national forests to significantly influence hazardous fuels reduction accomplishments.

We found that although nearly two-thirds of hazardous fuels treatments were located within about 60 km (about 50 minutes) of sawmills and biomass facilities, biomass was used from only about 9% of the hectarage treated. Forest managers on ranger districts that were closer than the median ranger district to sawmills and biomass facilities reported significantly higher overall treatment hectarages, more treated ha in the WUI, and more use of stewardship contracting. In addition, although not statistically significant, these ranger districts also used biomass from 70% more total ha; the greater hectarage constituted a similar proportion of their total treatment area (Table 2).

Table 2. Summary of hazardous fuels treatment attributes grouped by those ranger districts that reported treatments closer to and further from market infrastructure than the median ranger district (43 minutes).

	Ranger districts close to facilities	Ranger districts far from facilities
No. of ranger districts	23	23
Median treatment proximity to market (minutes)	32	55
Total treatments (ha for all ranger districts)		
Treated	201,097 (100%)	127,843 (100%)
Treated in the WUI	93,769 (47%)	32,657 (26%)
Biomass utilization	19,446 (10%)	11,562 (9%)
Stewardship contracting	8,907 (4%)	1,944 (2%)
Average treatments (ha per ranger district)		
Treated*	8,743 (100%)	5,558 (100%)
Treated in the WUI†	4,077 (47%)	1,420 (26%)
Biomass utilization	859 (10%)	506 (9%)
Stewardship contracting†	387 (4%)	85 (2%)

Only ranger districts that treated more than 1,000 ha are included. The 20 ranger districts that treated fewer total acres averaged 459 ha treated over the 6-year study period; 14 of these 20 ranger districts were westside ranger districts.
* $P < 0.10$ (*t*-tests for differences in average acres treated between groups).
† $P < 0.05$.

Table 3. Mixed-effects regressions of proximity on respective dependent variables controlling for ha of treatments within the WUI and national forest size, with random intercept summary by national forest ranger district (Panel A) and subset regressions indicating that proximity for biomass utilization and stewardship contracting ceases to be significant on ranger districts where the average treatment is >40 minutes from a sawmill or biomass facility (Panel B).

Dependent variable	Total acres treated for hazardous fuels	Acres from which biomass was used	Acres administered by stewardship contracting
Panel A			
Parameters: coefficient			
Intercept (fixed)	272.73†	102.20	47.34
Proximity[a]	−0.71	−0.49*	−0.36†
WUI	1.20‡	0.08‡	0.02†
District size	<0.00	<−0.00	<0.00
Random intercept average (range)	0.00 (−375.20 to 431.99)	0.00 (−72.98 to 185.82)	0.00 (−27.88 to 117.07)
Model fit (χ^2)	39.31‡	55.80‡	58.45‡
R^2 (predicted versus observed)	0.63	0.32	0.29
Panel B: proximity coefficient[b]			
Average proximity (no. of ranger districts)			
>20 min ($n = 44$)		−0.50*	−0.36†
>30 min ($n = 35$)		−0.55*	−0.37*
>40 min ($n = 26$)		−0.08	0.03
>50 min ($n = 15$)		−0.08	−0.08
>60 min ($n = 11$)		−0.27	−0.03

[a] Proximity is the modeled travel time from treatment locations to sawmills or biomass facilities. Negative coefficients indicate that greater travel times result in fewer ha treated.
[b] Subset regressions were not conducted on total acres treated because proximity was not a significant influence in the overall regression.
* $P < 0.05$.
† $P < 0.01$.
‡ $P < 0.001$.

Mixed-effects regression also confirmed that ranger districts closer to infrastructure conduct more total treatments, do more treatments that use biomass, and do more treatments with stewardship contracts than those further away. The threshold for these effects was 40 minutes. Proximity influenced total ha treated on only 2 of 26 districts that were further than 40 minutes from a facility. Proximity did not influence the area of treatments from which biomass was used or for which stewardship contracting was used beyond 40-minutes travel time.

Proximity to sawmills and biomass facilities also influenced where treatments occurred within a ranger district, especially for biomass utilization and stewardship contracting and especially on ranger districts close to sawmills and biomass facilities. Hazardous fuels treatments on ranger districts within 40 minutes of sawmills and biomass facilities were more than 5 times as likely to exhibit a significant relationship between the hectarage of hazardous fuels treated and the proximity of those ha to sawmills and biomass facilities and 4 times as likely to exhibit a significant relationship between the hectarage from which biomass was used and the proximity of those ha to sawmills and biomass facilities. All ranger districts in which there was a significant relationship between the hectarage of stewardship contracting and the proximity of those ha to sawmills and biomass facilities were less than 40 minutes on average from sawmills and biomass facilities.

Table 4. Cross-tabulation results of the number of ranger districts within the 40-minute proximity threshold and the number for which the random proximity slope coefficient is significant.

Parameter	Total hazardous fuel treatments	Biomass utilization	Stewardship contracting
A. No. of ranger districts for which average treatment proximity is less than 40 min	20	20	20
B. No. of ranger districts for which proximity coefficient is significant	10	13	7
Number of ranger districts meeting both criteria A and B	8	9	7
χ^2 statistic	4.03*	4.55*	10.36†
Odds of significance for ranger districts <40 min (90% CI)	5.31 (1.23–22.84)	4.30 (1.34–13.74)	
Odds of non-significance for ranger districts >40 min (90% CI)	2.56 (0.91–7.14)	2.13 (1.04–4.36)	1.54 (1.17–2.01)

Odds ratios significantly greater than 1 indicate that ranger districts within the 40-minute threshold from market infrastructure have a greater likelihood of being responsive to the influence of the market. CI, confidence interval.
* $P < 0.05$ for Fisher's exact test of χ^2 probability.
† $P < 0.01$.

The 40-minute proximity threshold equates to an approximate 40-km distance threshold. The 40-minute threshold finding should not be taken as generalizable, however; the specific threshold of this distance is likely to vary across regions and time, depending on treatment and transportation costs (Evans 2008), as well as on road speed, product value, subsidies, and other factors. A distance of 40 km is shorter than what others have indicated could be economically viable. Wu et al. (2011) indicated that certain logging systems could generate economically viable biomass utilization even at haul distances of up to about 70 km, and Jones et al. (2010) found that economic viability in some cases could extend beyond 128 km. Our finding of a 40-minute proximity threshold is the result of our assumed road network speeds. Although our road network travel speed assumptions oversimplify reality, they serve to identify the most efficient transportation routes. Furthermore, we did not examine biomass utilization volumes, which could affect the travel distance and time that is financially feasible. The key finding is that there are thresholds beyond which distance to infrastructure ceases to affect hazardous fuels reduction activities, and these thresholds can be calculated for particular places and circumstances. Future efforts to estimate the effect of proximity on treatment locations may more directly identify thresholds through the use of nonlinear models that asymptote at the point where the distance to a facility ceases to make the treatment economically viable.

Our analysis also suggests that the markets represented by sawmills and biomass facilities have the most potential to impact hazardous fuels management and biomass utilization on the forests they are most close to and that any market influence on hazardous fuels treatments is limited at longer distances. Furthermore, although the use of stewardship contracting is relatively rare, stewardship contracting is most common when nearby markets exist, allowing the goods produced from stewardship contracting to obtain their highest value. Although mostly common sense, these results have important implications for areas far from existing market infrastructure, i.e., distance matters.

Furthermore, our analysis suggests that wood products and biomass energy facilities that are distributed across the landscape rather than centralized will make it easier for forest managers to harness powers of the market in addressing the high costs of hazardous fuels treatments. Policy strategies that rely on adding value to the materials generated from these treatments are most likely to be successful if sawmills and biomass facilities are in sufficiently close proximity to the materials they are expected to use. The current distribution of sawmills and biomass facilities leaves much of the east side of Oregon and Washington too far away from markets to efficiently offset costs and add value to biomass generated from hazardous fuels treatments (Figure 1). Yet the dry, fire-adapted forests of the Pacific Northwest region east of the Cascade Range is where hazardous fuels management will continue to be a dominant issue into the future. A centralized system of sawmills and electrical generation facilities is not likely to be an economically or ecologically feasible approach to solving this problem (Kumar et al. 2003, 2008). In contrast, a network of multiple processing facilities strategically distributed across forest-based communities could be more effective for offsetting some of the costs of hazardous fuels treatments and increasing the number of acres treated and the frequency of biomass utilization from hazardous fuels reduction on Forest Service lands. Such facilities would need to be of a size and type appropriate to the local resource base and community.

The economic and market development barriers to biomass utilization are commonly cited challenges to making biomass utilization relevant in a hazardous fuels context (Aguilar and Garrett 2009, Becker et al. 2011a, Sundstrom et al. 2012). Policy incentives and the development of biomass utilization infrastructure have been identified as high priorities among national forest managers and staff, state foresters, and others (Aguilar and Garrett 2009, Sundstrom et al. 2012). Our findings offer one interpretation of why adding value to biomass generated from hazardous fuels treatments is a challenge: markets for the materials may have relatively little reach and that reach will probably shrink to the extent that it is influenced by increasing transportation costs (Jones et al. 2010). However, from these results, we also find guidance for addressing the problem through facilities that may be more feasible to site, finance, and develop in a distributed network at an appropriate scale and of a type suitable to local needs, assets, and annual volume of biomass supply that is available within a feasible transportation distance. For example, small- and medium-scale electrical generation (less than 15 mW), pellet production, and thermal energy facilities may feasibly address existing energy demands (Zerbe 2006, Daugherty and Fried 2007, Neary and Zieroth 2007). Schools, hospitals, and industrial processes are common applications where replacement of existing petroleum-based heating systems provides opportunities to substitute imported fuel sources with local ones that have the cobenefits of offsetting the cost of hazardous fuels treatments and promoting local community economic development (Becker and Viers 2007).

We also recognize several limitations in our analysis. We only examined hazardous fuels treatment completed by the Forest Service. Incorporation of treatments completed on other federally managed lands and those completed on state and private lands would paint a more comprehensive picture of the extent of hazardous fuels treatment across the landscape and how industry infrastructure influences where those treatments occur. We also had no temporal data on mill operations. Although our mill data set was compiled for those facilities that were open during the period of the study, there was no guarantee that those mills operated at full capacity and without shutdowns during the study period. Understanding facility capacity and operations would allow for more precise estimates of the influences of those facilities on hazardous fuel treatments. Finally, we were only able to examine the area treated but not the volumes of material treated or used. We know of no readily available data that would link treatment locations, areas, and volumes. Collecting and maintaining volume-based data that are linked spatially to treatment records would greatly enhance our understanding of the market's ability to influence the location of treatments, offset treatment costs, and facilitate treatment of a greater extent of the landscape.

Conclusions

In sum, this study finds that proximity to sawmills and biomass facilities has a significant influence on the number of acres treated for hazardous fuels reduction on national forest lands and on the number of acres treated in the WUI. It also finds that proximity to infrastructure increases biomass utilization from fuels treatments and use of stewardship contracting to accomplish treatments. There are thresholds beyond which distance to infrastructure ceases to affect hazardous fuels reduction activities, however; the threshold in this study was 40 minutes or about 40 km. This threshold is likely to vary by place and circumstance. These results confirm that distance to infrastructure matters for hazardous fuels reduction, that transportation costs are important as an economic constraint in the production of forest-based products and energy (Abbas et al. 2008, Becker et al. 2011, Wu et al. 2011), and that transportation costs are a critical factor bearing on the ability to harness market forces in hazardous fuels reduction. Our data do not draw from beyond Oregon and Washington, making our findings most applicable to our study region. Nevertheless, we believe that the general pattern we found—that the influence of markets on hazardous fuels treatments diminishes with distance—is probably applicable elsewhere (Wu et al. 2011).

In Oregon and Washington, fuels reduction needs are greatest east of the Cascades; however, infrastructure is concentrated west of the Cascades, making it largely too far away to offset costs and add value to material generated from fuels treatments. If solving this problem by adding value to high-cost hazardous fuels treatments byproducts is an important policy goal, our results indicate that markets for wood products and biomass energy need to be developed in a distributed, rather than centralized, network across forest-based communities. Ideally, this network of facilities would be appropriately sited, scaled, and typed according to local environmental, social, and economic circumstances. Public policy that provides incentives for developing such a network of wood products and biomass utilization infrastructure could be an important contribution to an effective program of reducing wildfire risks across the western United States.

Endnotes

1. Ranger districts are territorial subdivisions of national forests that constitute the smallest administrative decision unit on the National Forest System.
2. Readers interested in the full random intercept, random slope model results should contact the lead author.
3. We aggregated treatment types into two main categories: mechanical and prescribed fire. All treatments that used fire were captured in the prescribed fire category, including broadcast burning, pile burning, fire use, and others. All treatment that used human labor and human-operated equipment were included in the mechanical category, including thinning, mastication, chipping, lop and scatter, machine piling, and others. Undefined treatments and livestock grazing treatments were aggregated into a third category: other.

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