Assessing the Potential for Log Sort Yards to Improve Financial Viability of Forest Restoration Treatments

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Abstract: Forest restoration and fuel reduction treatments have been widely applied in the western United States with the purpose of reducing the size and intensity of wildfires. However, the low value of small-diameter trees produced from such treatments has partly constrained the ability to treat all the areas identified as being in need of treatments. The objective of this study was to analyze the potential for log sort yards to increase the residual value of forest restoration treatments relative to a standard sort at landing in Ravalli County, Montana. We simulated log handing and transportation under two log sorting scenarios in Ravalli County: sort at landing resulting in two log products and sort at sort yard resulting in seven potential log products. Costs and value recovery in each scenario were estimated, and the residual values were compared. We found that establishment of a log sort yard in Ravalli County could increase the residual value of forest restoration treatments by 5%. However, the benefit of the sort yard varies substantially by the forest type from which logs are harvested and the available volume of and markets for high value products, such as house logs. FOR. SCI. 58(6):641–651.

Keywords: log sort yard, financial analysis, forest restoration treatment, spatial analysis, residual value

Forest health restoration and fuel reduction treatments have been widely used to limit the size and intensity of wildfires in the western United States (Healthy Forests Restoration Act 2003). These treatments designed for the reduction of hazardous fuels and restoration of historical fire regimes[1] may include mechanical thinning, prescribed fire, mastication of understory shrubs and small trees, mulching, application of herbicide, or a combination of these. Although the importance of such treatments is recognized, log-value recovery is critical to the extent and distribution of treatments (Fried et al. 2008, Keegan et al. 2004). The ability to treat the sizeable acreage identified as "in need" has been constrained by a combination of low-value logs harvested in forest restoration and fuel reduction treatments and land management agency budget constraints. In addition, log landings are often too narrow to provide space for extensive log sorting that may improve log-value recovery. Even when more extensive sorting is possible at the landing, extra handling of logs and transportation to various markets may not be justifiable if only low log volumes per product are available at the individual landings. Consequently, unsorted logs are often misdirected and either consumed for lower-value products or redirected through trades between mills, resulting in extra handling and transport costs at the mill.

Although some studies in various countries reported a favorable increase in log value due to the sorting operation at log sort yards (Kerrush 1984, Peterson 1986), others indicated that costs for running a log sort yard might outweigh the revenue generated by sorting and preprocessing logs (Sedney 1992, Sessions et al. 2005). It is commonly reported in the literature that log sort yards are not warranted in every case. Dramm and Jackson (2002) pointed out that a successful log sort yard requires a good business plan, a steady supply of raw material, product diversity, and well-established markets.

In the western United States, interest in commercial sort yards has increased because of declining timber resource quality and volume, increasing diversification of log and fiber markets, and the need to recover more value from the available resource (Dramm et al. 2002). The USDA Forest Service has interest in assuring that all material associated with a timber sale is directed to its highest value use. This has, in some instances, led to stipulations in timber offerings that require winning bidders to use logs down to a specified size. Cases in which the costs of removing these small logs exceed the value the logger receives for them can result in the US Forest Service losing revenue through reduced bids or can deter potential buyers from bidding on timber sales. A sort yard could mitigate or even eliminate this problem by providing a one-stop sale yard for loggers, which reduces the burden on loggers having to find markets for small volumes of small or otherwise less-valuable logs. This approach may lessen the need for sales administrators to stringently enforce log utilization standards, freeing up US

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This article uses metric units; the applicable conversion factors are: millimeters (mm): 1 mm = 0.039 in.; centimeters (cm): 1 cm = 0.39 in.; meters (m): 1 m = 3.3 ft.; square meters (m^2): 1 m^2 = 10.8 ft^2; cubic meters (m^3): 1 m^3 = 35.3 ft^3; hectares (ha): 1 ha = 2.47 ac.; kilometers (km): 1 kg = 0.6 mi.

Forest Service resources for use elsewhere, and encourage more competitive bidding by loggers at sales.

The objective of this study was to assess whether a log sort yard can increase the residual value of forest health restoration treatments to landowners relative to a traditional sort at landing. We simulated log handling and transportation under two log sorting scenarios in Ravalli County, Montana, USA: sort at landing scenario resulting in two log products (i.e., sawlogs and pulp logs) and sort yard scenario resulting in seven potential log products (standing dead house logs, green house logs, peeler logs, sawlogs, posts and poles, stud logs, and pulp logs). Costs and value recovery in each scenario were estimated, and the residual values were compared. The detailed methods and results are described below.

Methods

Study Area

Ravalli County, Montana, has a number of issues relevant to many other wildland-urban interface communities throughout the inland west and northwest of the United States (Figure 1). Ravalli County has an abundance of forestland—approximately 0.5 million ha of forestland (Loeffler et al. 2006). Much of this land is lower elevation, moderately to severely departed

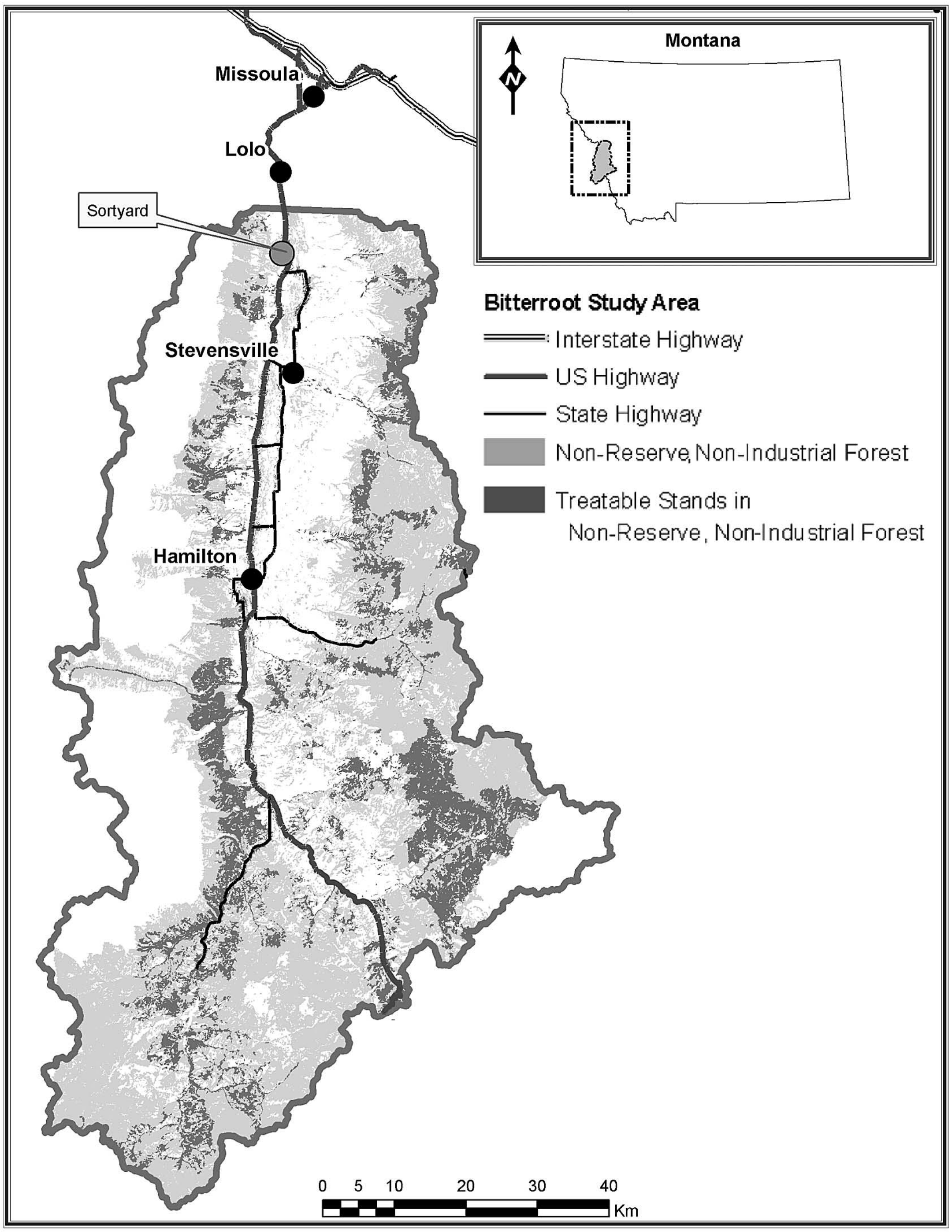

Figure 1. Map of Ravalli County, Montana, including location of treatable areas and the potential sort yard location.

from historical fire regimes (Hardy et al. 2001, Schmidt et al. 2002), and in need of restoration treatments (Fiedler et al. 2003, 2004). Within Ravalli County, there are approximately 208,008 ha of nonreserved federal and nonindustrial private forest lands. Among these, a total of 77,602 ha accessible from the existing roads with ground-based harvesting systems were considered in this study as treatable areas that could produce timber products.

The wood-processing facilities near the study area constitute a diverse range of log buyers including lumber mills, stud and plywood mills, a pulp mill, log home manufacturers, and a post and pole producer. Virtually all logs harvested in Ravalli County are processed in five western Montana counties (Flathead, Lake, Powell, Missoula, and Ravalli) that are within 320 km of Ravalli County forests (Spoelma et al. 2008). According to the Montana Manufacturers Information System (Montana Business Connections and Bureau of Business and Economic Research 2009), there were 108 primary wood processing facilities located within these five counties in 2009, ranging from large-scale operations with annual processing capacities greater than 0.2 million m^3 to small-scale family businesses. Log home manufacturers account for 45 of these facilities.

Most logging operations in Ravalli County are thinning operations that generate small volumes of low-value materials at typically small and narrow landings. Consequently, extensive log sorting at a landing is often limited, and some logs are misdirected and either consumed for low-value products or redirected through trades between mills, leading to extra handling and transport costs at the mill. According to data collected by the Bureau of Business and Economic Research at The University of Montana (T.A. Morgan, pers. comm., Nov. 6, 2007), approximately 1.5% of total timber harvest volume in Ravalli County was actually redirected from one mill to another in 2004. However, this volume does not include timber that was misdirected from the landing but not redirected due to handling and transport costs that may exceed potential timber value increase.

Silvicultural Modeling and Analysis

We classified various forest stands in the study area into five broad forest types by analyzing US Forest Service Northern Region Vegetation Mapping Project (R1-VMP) spatial forest vegetation coverage (Brewer et al. 2004) using a geographic information system (GIS). Restoration thinning prescriptions specific to each forest type were then developed based on the historical stand structure of each of the five forest types (C.E. Fiedler, University of Montana, pers. comm., May 8, 2007). Each prescription specifies a basal area and a species preference order for the residual trees (Table 1).

To estimate the quantity of timber harvested in each forest type, we simulated each prescription using the Forest Vegetation Simulator (FVS) (Dixon 2003) and US Forest Service Forest Inventory and Analysis (FIA) plot data acquired from the FIA Mapmaker database (Forest Inventory and Analysis 2011). We selected the FIA plots that were located on either nonreserved US Forest Service or nonindustrial private ownership land within the following four contiguous counties in western Montana that have similar forest types and stand structures: Ravalli, Lake, Mineral, and Missoula. These plot data were entered into FVS to summarize stand conditions and provide a tree list for each plot. This tree list was then used in the R1-VMP Stand Classifier program (Berglund et al. 2008) to classify each plot into one of the five forest types defined for this study. FVS was then used to simulate each prescription and generate a cut tree list for each plot.

Qualitative assessments of logs harvested from each forest type were also necessary in this study, because log quality affects determination of the highest value products that can be derived from the log. Plot-level qualitative variables of tree bole defects that affect log merchantability, including crook and sweep, and tree damage from weather, insects, disease and fire, were acquired independently from the Interior West Forest Inventory and Analysis headquarters in Ogden, Utah, and joined to the FVS tree list data. All cut trees coded as having disease or lightning or frost crack defects were classified as unmerchantable. These trees could still be cut to achieve desired stand conditions, but no merchantable product could be derived from the tree. Because of strict log quality requirements of log home manufacturers, cut trees that met house log specifications but were coded with any defect were downgraded to the log type of next highest value for which log specifications were satisfied.

Identifying Treatment Locations

Treatable areas in Ravalli County were determined via GIS analysis of the R1-VMP stand polygons. First, all nonreserved US Forest Service and nonindustrial privately owned areas in Ravalli County that are located within 600 m of existing roads with a median ground slope of 40% or less were selected. Then, all nonforested areas and areas burned with high and medium fire severity during the 2000 wildfire

Table 1. Target residual basal areas and preference orders of leave trees as restoration thinning prescriptions developed for five forest type groups.

Forest type	Target residual basal area (m^2/ha)	Leave species preference order*
Ponderosa pine	11	PP > WL > LP > DF > WP > WC > ES > AO
Dry mixed conifer	11	PP > WL > LP > DF > WP > WC > ES > AO
Douglas-fir	15	WL > PP > LP > DF > WP > WC > ES > AO
Lodgepole pine	18	WL > DF > LP > PP > WP > WC > ES > AO
Engelmann spruce-subalpine fir	21	WL > DF > LP > ES > AO

Species codes: PP, ponderosa pine (*Pinus ponderosa*); WL, western larch (*Larix occidentalis*); LP, lodgepole pine (*Pinus contorta*); DF, Douglas-fir (*Pseudotsuga menziesii*); WP, white pine (*Pinus monticola*); WC, western red cedar (*Thuja plicata*); ES, Engelmann spruce (*Picea engelmannii*); AO, all other species.

season were removed to identify treatable hectares in the study area (Figure 1). From the total treatable hectares, a subset of the R1-VMP stand polygons with the average size of 2 ha were selected by the following procedures to spatially represent a realistic amount of annually treated hectares across the study area.

1. The average number of hectares treated annually between 2003 and 2006 on both US Forest Service and nonindustrial privately owned lands in Ravalli County were computed (USDA Forest Service 2007, D. Rogers, Montana Department of Natural Resources and Conservation, pers. comm., Nov. 17, 2007): 418 ha in Bitterroot National Forest and 2,068 ha in nonindustrial privately owned lands.
2. The proportion of hectares within each forest type to the total area of all forest types was computed.
3. A random sample of treatment polygons was selected from each forest type such that the sum of hectares across the sampled polygons approximated the proportional hectares for each forest type (Table 2). These polygons were intended to represent a typical annual harvest on the five forest types.

Harvest Cost Modeling

We estimated harvest costs for each FIA plot identified in the silvicultural modeling analysis using the tractor skidding cost equation developed by Keegan et al. (2002). Harvest costs per green ton were estimated using average dbh, volume per hectare removed, and average skidding distance. dbh and volume removed were obtained from the FVS output, and the average skidding distance was assumed to be 240 m. The estimated mean harvest costs for the sampled areas are shown in Table 2.

Haul Cost Modeling

A GIS road network data layer covering the study area previously developed (USDA Forest Service Rocky Mountain Research Station, unpublished report, Nov. 10, 2008) was used for haul cost modeling. This road layer contains road segments classified as either paved or unpaved. The Forest Residue Trucking Simulator (USDA Forest Service Southern Research Station 2009) was used to estimate haul costs on paved and unpaved roads for log trucks with a diesel fuel cost of $1/L. It was assumed that the average speeds on paved and unpaved roads were 80 and 24 km/hour, respectively. Round trip haul costs were estimated to be $2.27/km for paved road segments and $4.88/km for unpaved road segments. Delay time including loading and unloading was ignored in the haul cost calculation.

These GIS road data, average per kilometer haul costs, and average harvest volumes for each of the forest types were entered into MAGIS (Forestry Sciences Lab 2006), a spatial decision support system for scheduling vegetation treatments and routing through road networks (Zuuring et al. 1995, Chung et al. 2005). MAGIS was used to simulate applying the treatments designated for each of the forest types, loading the logs created by the treatments onto the road network in the vicinity of the randomly selected polygons, and routing the loaded log trucks through the road network over the most cost-effective paths. The following specific methods were used to estimate haul costs for each log sorting scenario.

Sort at Landing Scenario

1. Pulp logs were routed directly to the paper mill from the randomly selected polygons of each forest type. The average haul cost from the randomly selected polygons for each forest type was adopted as the pulp log haul cost.
2. Sawlogs were routed to a common point several miles north of the study area from the randomly selected polygons of each forest type. Logs hauled to each of the candidate sawmills must travel through this common point, and the average haul cost from the randomly selected polygons for each forest type to this common point was estimated.
3. The additional costs to haul logs from the common point to each of the candidate sawmills were estimated.
4. Total haul costs for sawlogs from each forest type were estimated as the sum of 2 and 3, where 3 was the haul cost to the candidate sawmill that generated the highest residual value.

Sort Yard Scenario

1. Pulp logs were routed directly from the landings to the paper mill, and the average haul cost was estimated as described in the sort at landing scenario.
2. All other logs from the randomly selected polygons of each forest type were routed to the designated sort yard location, indicated in Figure 1. The average haul cost from the randomly selected polygons for each forest type to this point was estimated. In this study area, most timber markets are north of the harvested

Table 2. Summary information of randomly selected treatment polygons in each forest type.

Forest type	Area represented (ha)	No. of selected polygons	Mean harvest cost ($/ha)	SD of harvest cost ($)
Douglas-fir	970	513	1,661	1,149
Engelmann spruce-subalpine fir	234	92	1,231	1,060
Lodgepole pine	348	169	1,888	1,297
Dry mixed conifer	323	153	2,523	1,557
Ponderosa pine	572	347	1,127	892
Total	2,447	1,274		

polygons. Therefore, little rerouting of timber is required to direct timber to the sort yard.

3. The additional costs to haul logs from the sort yard to each of the processing mills were estimated.
4. Total haul costs from each forest type to each processing mill were estimated as the sum of 2 and 3, where 3 was the haul cost to the processing mill that generated the highest residual value.

End-User Log Specifications and Delivered Prices

In autumn 2007, telephone and personal interviews were conducted with 12 purchasers of logs from Ravalli County to acquire their log specifications and delivered log prices (Table 3). The 12 purchasers included one pulp mill, three log home manufacturers, one posts and poles manufacturer, one plywood manufacturer, four sawmills, and two stud mills. The range in delivered price for a log type reflects the variation in the willingness of mills to pay for different species and different willingness to pay among mills. The reported log specifications are the extreme values (i.e., largest maximum and smallest minimum) among the purchasers of that log type. In the analysis, the specific prices paid and log specifications applied at each mill were used in determining the routing of logs under the sort at landing and sort yard scenarios.

Log Bucking Simulation

To simulate bucking logs, FVS cut tree lists for each forest type, including individual tree height and dbh data, were entered into a spreadsheet. Tree volume and taper equations available from the National Volume Estimator Library housed at the US Forest Service Forest Management Service Center (USDA Forest Service 2006) were used to facilitate estimation of log diameters at various tree heights and volume per log segment in cut trees. Log bucking rules consistent with the log specifications for each of the 12 end users analyzed were developed with a series of "if-then-else" statements in the spreadsheet to simulate the process of cutting a felled tree into logs based on species, log length, and large and small end diameters. Specific bucking rules developed for each log sorting scenario are described below.

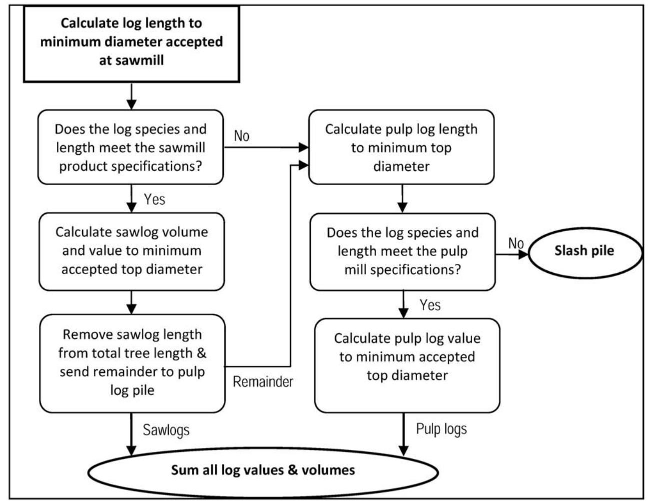

Figure 2. Log bucking procedures developed for the sort at landing scenario.

Sort at Landing Scenario

In this scenario, there is room for only two log piles at the landing: sawlog and pulp log. The logic for bucking logs into these piles is illustrated in Figure 2. All pulp logs are directed to the one pulp mill in the study area. However, there are four potential destinations for the sawlogs, and it is assumed that all sawlogs at any particular landing will be directed to only one of these mills. The bucking at the landing logic was applied to the cut tree list from each forest type using the log specifications for each of the four sawmills. The residual value for each sawmill and pulp mill combination was then determined for each forest type, where the residual value was estimated as the mill-delivered value of logs, less all costs associated with delivering the logs to the sawmill and pulp mill (i.e., harvest and haul). The sawmill and pulp mill combination that yielded the highest residual value for logs from a particular forest type determined which sawmill received all sawlogs from that forest type. The annual residual value of logs by forest type in the sort at landing scenario was estimated as follows:

$$LRV_{ft} = N_{ft} * (RevSM_{sm,ft} + RevP_{ft} - HarvCst_{ft} - HaulCstSM_{ft} - HaulCstP_{ft}) \quad (1)$$

where LRV_{ft} is residual value of logs harvested from forest

Table 3. Log specifications and delivered prices by product type.

Log type	Species accepted	Log specifications: Maximum large end diameter	Minimum small end diameter	Maximum length	Minimum length	Delivered price ($/m^3)
		(cm)	(cm)	(mm)	(mm)	
House logs	Standing dead DF,ES, LP	–	20	–	4	$96–$298
Green house logs	Dried DF, ES, LP	–	20	–	4	$123–$175
Peeler logs	DF, WL	76	19	11	5	$93
Sawlogs	All coniferous species	–	13	13	5	$48–$86
Posts and poles	LP	20	8	6	5	$84
Stud logs	LP, DF, ES, AF,WL, PP	76	11	11	3	$66–$77
Pulp logs	All coniferous species	71	6	14	4	$42

Species codes: PP, ponderosa pine (*Pinus ponderosa*); WL, western larch (*Larix occidentalis*); LP, lodgepole pine (*Pinus contorta*); DF, Douglas-fir (*Pseudotsuga menziesii*); WC, western red cedar (*Thuja plicata*).

type, ft, when sorted at the landing, N_{ft} is number of hectares treated annually by forest type, ft, $RevSM_{sm,\,ft}$ is revenue per hectare from sawmill, sm, for logs from forest type, ft, which is calculated as the delivered price of logs (\$/m^3) multiplied by volume of sawlogs per hectare, $RevP_{ft}$ is revenue per hectare from the paper mill for logs from forest type, ft, calculated as the delivered price of logs (\$/m^3) multiplied by volume of pulp logs per hectare, $HarvCst_{ft}$ is the mean harvest cost per hectare for forest type, ft, $HaulCstSM_{sm,\,ft}$ is the mean haul cost per hectare for sawlogs from forest type, ft, to the sawmill, sm, and $HaulCstP_{ft}$ is the mean haul cost per hectare to the paper mill from forest type, ft.

Sort Yard Scenario

In the sort yard scenario, it is again assumed there is only room at the landing for two log piles: pulp logs and logs destined for the sort yard. Small trees that can only make pulp logs are sent directly from the landing to the paper mill, whereas all other logs meeting the minimum specifications among all mills are sent to a sort yard. At the sort yard, the logs are bucked and sorted into the following product categories, listed in descending order of value per m^3: standing dead house logs, green house logs, peeler logs, sawlogs, posts and poles, stud logs, and pulp logs. These product categories accounted for 99% of volume harvested in Ravalli County in 2004 (T.A. Morgan, University of Montana Bureau of Business and Economic Research, pers. comm., Aug. 29, 2007).

Anecdotal evidence suggests that the existing supply of green house logs routed to log home manufacturers in the study area is small relative to the total volume processed. According to representatives of log home manufacturers, this is because of the limited local supply of green house logs, the inconvenience of having to carefully stack and air-dry the house logs for a year before use, and the ready availability of standing dead logs from Canada. In the sort yard analysis, it is assumed that green house logs can be stacked and dried for a year before sale. The specifications for house logs are stringent, and there are some types of defects not accounted for in the FIA data sets, such as spiral grain, which make logs unsuitable for this product category. In addition, there are applications for which standing dead trees are preferred for house logs. In the absence of better information, it is assumed that only half of the green house log volume predicted to be available from treatments can be marketed as house logs. The remaining green house log volume is sorted into the next highest value product categories, principally peeler logs, posts and poles, and sawlogs.

Sorting logic similar to the sort at landing scenario was used in this scenario. However, instead of the two potential product categories and five potential end users described in the sort at landing scenario, logs in the sort yard scenario were bucked according to log specifications for seven potential product categories and 12 potential end users. It is important to note that a "bucking rule of thumb," not optimal bucking, was simulated in a spreadsheet for the sort yard scenario. That is, the highest residual value product that could be bucked from the large end of the log was cut first. Then, starting from the large end of what remained of the log, the highest residual value product was cut and so on until no further product could be cut from the log. The residual value of logs from each forest type in the sort yard scenario was estimated as follows:

$$SYRV_{ft} = N_{ft} * \Big(\sum_{m=1}^{M} RevM_{m,ft} + RevPM_{ft} - HarvCst_{ft} - HaulCstSY_{ft} - HaulCstP_{ft}\Big) - \sum_{m=1}^{M} [\mathrm{Vol}_{m,\,ft} * (HandCst + HaulCstM_m)] \quad (2)$$

where $SYRV_{ft}$ is residual value of logs from forest type, ft, when sorted at the sort yard, $RevM_{m,ft}$ is revenue per hectare from end-user mill m for forest type, ft, calculated as the delivered price for logs at the mill (\$/m^3) multiplied by volume of logs per hectare directed to that mill from the sort yard, $RevPM_{ft}$ is revenue per hectare from the paper mill for forest type, ft, calculated as the delivered price for logs at the paper mill (\$/m^3) multiplied by volume of logs per hectare directed to the pulp mill from the landing and the sort yard, $HaulCstSY_{ft}$ is mean haul cost per hectare to the sort yard from forest type, ft, $Vol_{m,\,ft}$ is the volume in m^3 going from the sort yard to end-user mill, m, originating from forest type, ft, HandCst is the mean sort yard handling cost per m^3 for logs from all forest types, $HaulCstM_m$ is the haul cost per m^3 from the sort yard to end-user mill, m, and M is the total number of end-user mills.

Net Change in Residual Value

To assess whether a sort yard in Ravalli County could increase total surplus in the timber market (difference between total revenue and total cost), the net change in residual value (ΔRV) between the sort yard and sort at landing scenarios was determined as follows (hereafter, ΔRV is referred to as the net benefit of the sort yard):

$$\Delta \mathrm{RV} = \sum_{ft=1}^{5} (SYRV_{ft} - LRV_{ft}) \quad (3)$$

If ΔRV is greater than 0, the sort yard generates positive benefits for society by increasing total surplus in the timber market. This may result in net increases in stumpage prices paid to forest owners but will depend on the level of competition throughout the wood products supply chain and the relative negotiating skills of agents involved in transactions from the forest owner to the final mill destination. However, in assessing the social efficiency (as distinct from the financial performance) of an investment in a sort yard, which party actually benefits from the increase in surplus is irrelevant.[2] Positive ΔRV is also likely to increase the number of treatable hectares that can be profitably treated relative to a traditional sort at landing. If $\Delta \mathrm{RV} < 0$, the sort yard decreases the residual value of forest health restoration treatments to forest owners relative to sorting at the landing.

Sensitivity analyses have been performed to assess the influence of changes in total areas and volume harvested per year, delivered prices of logs (particularly house log prices), green house log volume, haul costs from the forest to the end-user, and sort yard costs on ΔRV. With the exception of house log volume, the level of each of these parameters was incremented and decremented by 10 and 30% from the base levels determined for the analysis. The sensitivity of sort yard net benefit to green house log volume was assessed for volumes between 0 and 100% of projected green (air-dried) house log volume.

Results and Discussion

Tables 4 and 5 report by forest type the estimated annual area harvested, harvest costs, harvested volume by product type, delivered prices by product type, round trip haul costs by product type, and the residual value of logs when sorted at the landing and sorted at the sort yard, respectively. Harvest costs are the same in the sort at landing and sort yard scenarios because the silvicultural prescription for each forest type is the same for both scenarios. Delivered prices are reported for the end user to which the logs were sold in the model. Delivered prices for pulp logs reflect the willingness of the paper mill to pay more for logs as haul distance increases. Weighted average delivered price was calculated by weighting the price paid for each log type in accordance with the contribution of that log type to total harvested volume. Round trip haul costs in Table 5 are the sum of haul cost from the forest to the sort yard and haul cost from the sort yard to the end user. Weighted average harvest, haul, and sort yard cost were calculated by weighting these costs for each log type in accordance with the contribution of that log type to total harvested volume.

In this case study, total harvested volumes under the sort at landing and sort yard scenarios are almost identical. This is not surprising, because the paper mill in the study area will take logs that meet their minimum length down to a top-end diameter of 2.5 inches, providing an outlet for logs that have no other commercial value. Small increases in total harvested volume per hectare in the sort yard scenario relative to the sort at landing scenario reflect differences in residues left at the landing. In the sort at landing scenario, all logs in the sawlog pile are shipped to the single sawmill that pays the highest net delivered price. When all trees are bucked into the particular log specifications of that sawmill, greater waste can occur than in the sort yard scenario, where each log is assessed against the specifications of all mills analyzed in the study.

Total annual residual value in the study area across all forest types with a sort at landing is estimated to be \$5.434 million, compared with \$5.693 million with a sort yard. Thus, the sort yard is estimated to increase the residual value of logs in Ravalli County by \$0.259 million/year (5%) or \$106/harvested hectare. However, the benefit of the sort yard varies substantially by the forest type from which logs are harvested and the available volume of high-value products such as house logs.

Comparison of Tables 4 and 5 indicates that the sort yard increased the residual value of logs harvested in Douglas-fir and dry mixed conifer forest types by facilitating the separation of substantial volumes of green house logs and peeler logs, and by upgrading of pulp logs to stud logs and posts and poles. In contrast, the sort yard decreased the residual value of logs harvested in ponderosa pine, lodgepole pine, and Engelmann spruce and alpine fir forest types. For the ponderosa pine forest type, most logs in the sawlog pile in the sort at landing scenario were also in the sawlog pile at the sort yard. Most of the sawlog volume from the lodgepole pine forest type was upgraded to the post and pole pile at the sort yard because of a small increase in delivered value net of haul costs. In the Engelmann spruce and alpine fir forest type, 7.2 m^3/ha of sawlogs was upgraded to house logs. In

Table 4. Prices, costs, and residual values of logging operations in Ravalli County for the two-pile sort at the landing scenario.

	Forest type				
Item	Douglas-fir	Ponderosa pine	Dry mixed conifer	Lodgepole pine	Engelmann spruce and alpine fir
Areas harvested per annum (ha)	970	572	323	348	234
Volume of timber products					
Sawlog (m^3/ha)	64	49	40	55	22
Pulp log (m^3/ha)	14	24	95	40	55
Total (m^3/ha)	78	72	135	95	77
Delivered prices					
Sawlog (\$/m^3)	66	86	86	86	86
Pulp log (\$/m^3)	40	38	40	43	40
Weighted average (\$/m^3)	61	70	54	68	54
Harvest and haul costs					
Harvest cost (\$/m^3)	21	16	19	20	16
Round trip haul to sawmill (\$/m^3)	23	16	19	22	19
Round trip haul to paper mill (\$/m^3)	12	9	12	14	12
Weighted average harvest and haul (\$/m^3)	42	29	33	38	30
Residual value					
\$/m^3 [a]	19	41	21	29	24
\$/ha [b]	1482	2952	2835	2755	1848
LRV (\$ millions) [c]	1.438	1.689	0.916	0.959	0.432

[a] Residual value in \$/m^3 is weighted average delivered price less weighted average harvest and haul cost.
[b] Residual value in \$/ha is residual value in \$/m^3 multiplied by total harvested volume in m^3/ha.
[c] Total residual value per annum is log residual value in \$/ha multiplied by the number of hectares harvested per annum.

Table 5. Prices, costs, and residual values of logging operations in Ravalli County for the sort yard scenario.

Item	Forest type				
	Douglas-fir	Ponderosa pine	Dry mixed conifer	Lodgepole pine	Engelmann spruce and alpine fir
Areas harvested per annum (ha)	970	572	323	348	234
Volume of timber products removed					
Standing dead house log (m^3/ha)	0	0	1	0	0
Green house log (m^3/ha)	13	4	16	2	7
Peeler log (m^3/ha)	27	8	30	0	0
Sawlog (m^3/ha)	2	45	21	16	14
Posts and poles (m^3/ha)	1	1	16	63	0
Stud logs mill 1 (m^3/ha)	27	8	17	1	5
Stud logs mill 2 (m^3/ha)	3	0	21	4	40
Pulp log from landing (m^3/ha)	4	3	7	6	4
Pup log from sort yard (m^3/ha)	3	4	6	3	5
Total (m^3/ha)	78	72	137	95	77
Delivered prices					
Standing dead house log ($/$m^3$)	175	175	175	175	175
Green house log ($/$m^3$)	118	118	118	118	118
Peeler log ($/$m^3$)	93	93	93	93	93
Sawlog ($/$m^3$)	86	86	86	86	86
Posts and poles ($/$m^3$)	84	84	84	84	84
Stud logs mill 1 ($/$m^3$)	77	77	77	77	77
Stud logs mill 2 ($/$m^3$)	66	66	66	66	66
Pulp log from landing ($/$m^3$)	40	38	40	43	40
Pulp log from sort yard ($/$m^3$)	35	35	35	35	35
Weighted average ($/$m^3$)	82	78	79	76	68
Harvest, haul, and sort yard costs					
Harvest ($/$m^3$)	21	16	18	20	16
Round trip haul cost to sort yard ($/$m^3$)	9	5	9	11	8
Sort yard ($/$m^3$ input to sort yard)	13	13	13	13	13
Round trip haul to log home manufacturer ($/$m^3$)	4	4	4	4	4
Round trip haul to veneer manufacturer ($/$m^3$)	20	20	20	20	20
Round trip haul to sawmill ($/$m^3$)	11	11	11	11	11
Round trip haul to post and pole manufacturer ($/$m^3$)	6	6	6	6	6
Round trip haul to stud mill 1 ($/$m^3$)	20	20	20	20	20
Round trip haul to stud mill 2 ($/$m^3$)	14	14	14	14	14
Round trip haul to paper mill from sort yard ($/$m^3$)	4	4	4	4	4
Round trip haul to paper mill from landing ($/$m^3$)	12	9	12	14	12
Weighted average harvest, haul, and sort costs ($/$m^3$ input volume to sort yard)	57	45	51	50	48
Residual value					
$/$m^3$ input volume to sort yard[a]	24	34	28	26	21
$/ha[b]	1,872	2,448	3,836	2,470	1,617
SYRV ($ millions)[c]	1.816	1.400	1.239	0.860	0.378

[a] Residual value in $/$m^3$ is weighted average delivered price less weighted average harvest and haul cost.
[b] Residual value in $/ha is residual value in $/$m^3$ multiplied by total harvested volume in m^3/ha.
[c] Total residual value per annum is residual value in $/ha multiplied by the number of hectares harvested per year.

all three forest types, there was a substantial volume of pulp logs upgraded to other low-value log types. However, the increase in the weighted average delivered price in these forest types was not sufficient to offset the increase in the weighted average haul and sort yard costs.

These observations highlight the fact that the potential to separate high-value logs at a sort yard is a critical determinant of whether a sort yard can increase the residual value of the forest. It is also clear that there could be a substantial payoff to sort yard operators and forest owners to assess ahead of a sale whether there is a payoff to sorting the logs at a sort yard. Given data used in this study, the residual value of logging operations in Ravalli County can be further increased by sorting logs from Douglas-fir and dry mixed conifer forest types in a sort yard, while sorting logs from ponderosa pine, lodgepole pine, Engelmann spruce, and alpine fir forest types at the landing.

Because merchantable volumes in the sort at landing and sort yard scenarios are virtually identical, the results of our study indicate that a sort yard in Ravalli County is unlikely to reduce the level of in-woods burning of forest residue and the associated particulate matter and carbon emissions. However, it should be noted that a sort yard can potentially provide options for effective marketing of biomass resources. Unmerchantable parts of logs due to size, breakage, or defects that would be otherwise disposed of by open burning can be readily ground into chips or hog fuels at the sort yard for other biomass uses. This may reduce in-woods burning of forest residue, resulting in reduced particulate matter and carbon emissions, as well as saving the cost of burning. In addition, a sort yard may redirect volume away from the pulpwood market. In our analysis, the sort at landing scenario generated 84,223 m^3 of pulp logs/year, compared with 20,172 m^3/year in the sort yard scenario.

This redirection of logs to longer life products does constitute a carbon storage benefit. These additional benefits of a sort yard have not been accounted for in this study.

Figure 3 summarizes the sensitivity of ΔRV to changes in several modeling parameters. ΔRV is highly sensitive to delivered prices for all log types. A delivered log price reduction of 10% is sufficient for a negative ΔRV indicating that sorting at the landing is better under that circumstance. The relatively high sensitivity of ΔRV to house log price is due to the fact that house log price is important in the sort yard scenario but not in the sort at landing scenario for which only sawlogs and pulp logs are marketed.

In our study, average haul distances (and costs) are greater in the sort yard scenario. Consequently, increases in haul costs (e.g., diesel prices) decrease ΔRV, the measure of the relative advantage of the sort yard. However, the directing of logs to various end users to maximize residual value was performed, assuming particular haul costs per kilometer on paved and unpaved roads, and some logs may be optimally redirected to other mills should haul costs rise or fall. Consequently, ΔRV may be underestimated for reduced and increased haul costs. Holding log destination constant, a rise in haul costs of less than 30% would make sorting at the landing more attractive for forest owners.

There is uncertainty about the optimal configuration of sort yards, which affects their costs of operation. In this case study, the simulated sort yard was configured by expert opinion and the Log Sort Yard Cash Flow Analysis model (Bilek 2008) to handle 0.2 million m^3/year, given the size and species distribution of logs expected from forests in the study area. A description of this configuration and detailed accounting of the total (fixed and variable) sort yard handling costs adopted in this study (\$13/m^3 of input volume) can be found in Han et al. (2009). Anecdotal information acquired from managers of log sort yards suggested that \$7/m^3 might be more appropriate, although it is unclear whether this estimate covers total costs of the operation. Net benefits of the sort yard are more sensitive to sort yard costs per unit volume handled than to haul costs or areas harvested, but less sensitive than delivered log prices. An increase in sort yard costs of only 10% is enough to make sorting at the landing a more attractive alternative to forest owners.

Permanent changes in volume handled at the sort yard would be addressed by changing the configuration of the sort yard, which would also affect sort yard handling costs per unit of input volume. Short-term changes, including fluctuations associated with normal business cycles, are likely to be addressed by altering levels of variable factors of production such as labor and energy, which is addressed in the sensitivity analysis of net benefits of the sort yard to change in total area harvested and total volume handled. Change in total area harvested affects the net benefit of the sort yard by changing total delivered log revenue and by changing sort yard costs per unit volume. For example, a decrease in area and volume harvested reduces total delivered log revenue for the sort yard and sort yard variable costs, but increases fixed costs (including the return on capital invested) per unit volume handled at the sort yard. The overall effect is a decrease in the net benefit of the sort yard over the sort at landing scenario. However, even at a 30% reduction in volume, the sort yard still breaks even with the sort at landing scenario. Increases in area and volume harvested improve the performance of the sort yard relative to a sort at the landing, because increases in total delivered log revenue and decreases in fixed costs per unit volume handled at the sort yard outweigh increases in variable costs at the sort yard. Thus, the sensitivity analysis suggests that net benefits of the sort yard are robust against changes in area and volume harvested.

The harvested volume projection included the harvest of 650 m^3 of standing dead house logs and 43,109 m^3 of green house logs per year in Ravalli County. This compares with the annual processing capacity of log home manufacturers in Ravalli County of 106,590 m^3 and actual production of 70,110 m^3 in 2004 (Spoelma et al. 2008) (a conversion factor of 5.7 m^3/1,000 board feet was applied). However, for reasons outlined in Methods, only 50% of this green

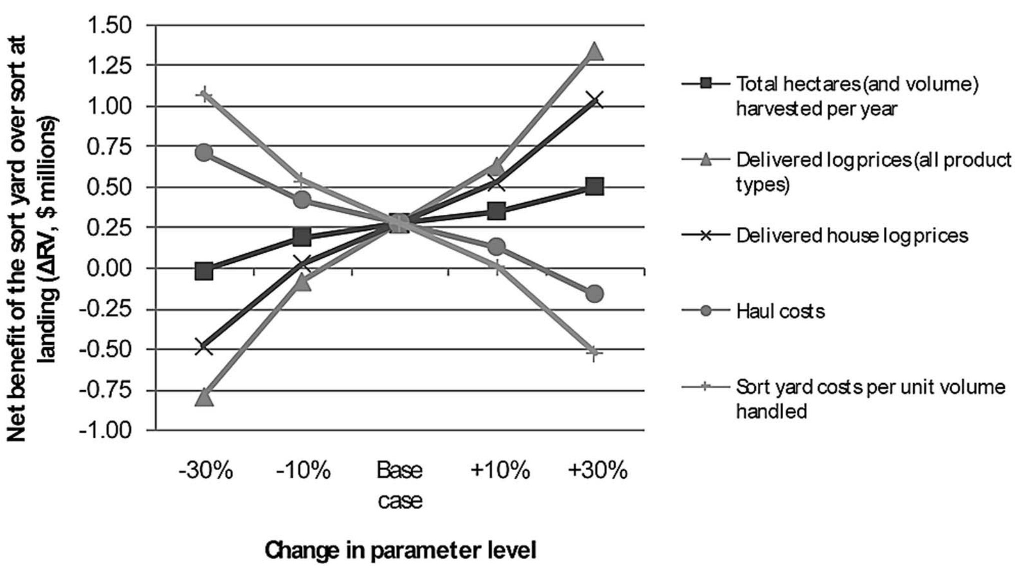

Figure 3. Sensitivity of the net benefit of the sort yard to changes in modeling parameters.

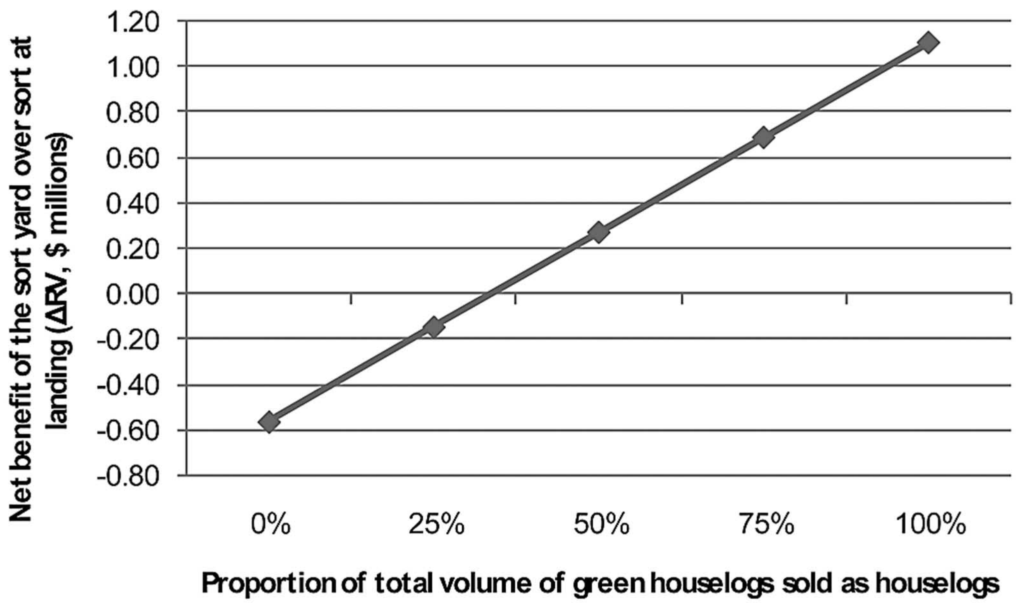

Figure 4. Relationship between sort yard net benefit and the proportion of the projected total volume of green house log volume that can be sold as house logs.

house log volume was assumed to be sold as house log, with the remaining volume being sorted into peeler logs and sawlogs. Figure 4 illustrates how ΔRV changes as this proportion is altered. The sort yard scenario is inferior to the sort at landing scenario if none of the green house log volume can be sold as house logs. However, if 75% of the projected green house log volume can be sold as house logs, then the net benefit of the sort yard is $0.7 million ($286/ha) above the sort at landing scenario.

Conclusions

The analysis suggests that the establishment of a log sort yard in Ravalli County has the potential to increase residual value of forest health restoration treatments to forest owners, improving potential financial returns from treatments and expanding the area that is profitable to treat. However, the benefit of the sort yard varies substantially by the forest type from which logs are harvested and delivered log prices.

There are some notable limitations of this study that will be addressed in future work. First, the assumption adopted in this study that the area treated annually by forest type is proportional to the presence of that forest type within the treatable landscape may result in a harvest volume composition that is substantially different from the composition of harvests in recent years. Second, the sort at landing scenario assumed sawlog and pulp log piles only in all forest types. Given anecdotal information about harvesting operations in the study area, this seemed appropriate. However, on analyzing the cut tree lists by forest type, it became clear that greater residual value from a two-pile sort at the landing could have been obtained by assuming alternative product combinations in the two piles for some forest types. For example, the lodgepole pine forest type could have yielded a greater residual value with post and pole and pulp log piles at the landing. The Engelmann spruce and alpine fir forest type could have yielded a greater residual value with stud log and pulp log piles at the landing. Third, our study did not consider optimal log bucking, which is one of the potential advantages of operating a sort yard. However, the benefit of optimal bucking will vary by timber value, volume processed, and cost of such equipment. Fourth, our study used a variety of data, models, and assumptions to estimate harvest volumes and costs for each forest type. Whereas using models and making assumptions is inevitable when outcomes of future harvest activities are estimated, it should be noted that the results of this study rely heavily on the input data, assumptions, and limitations of each model used in this study. For example, we used R1-VMP spatial data, the FVS model, and FIA data to estimate harvest volumes by forest type. Even though these models and data have been well-documented and widely used in many studies in the United States, the accuracy of such data and models can vary from site to site. We assumed that only ground-based harvesting systems would be used and considered stand polygons located within 600 m of existing roads with a median ground slope of 40% or less as harvestable areas. However, steep areas or areas far from the existing roads can be harvested with alternative harvesting systems. For simplification, we used an average skidding distance of 240 m to estimate harvest costs for all the selected stand polygons. In reality, the average skidding distance per polygon can vary widely, depending on the relative location of the polygon and its access to existing roads.

Despite the limitations, this study provides a methodology to spatially analyze the amount and types of material removed from forest health restoration treatments and assess whether a log sort yard can increase the residual value of the treatments to landowners relative to a traditional sort at landing. By directing logs to their highest value market, sort yards can increase the value of timber harvested, improve the financial viability of health restoration and fuel reduction treatments, and increase the willingness of loggers to bid on timber sales. This approach may facilitate greater implementation of fuel reduction and forest restoration treatments on the landscape to achieve forest management and public safety objectives without the need for taxpayer-funded subsidization.

Endnotes

1. Heinselman (1981) defines fire regime as "the kind of fire history that characterizes an ecosystem," with three elements describing the fire regime: fire type and intensity, size, and frequency.
2. An anonymous reviewer raised a concern that the sort yard could become a monopsonist purchaser of logs from forest owners and a monopolist supplier of logs to mills, maximizing its profit margins while driving down returns to other sectors of the local timber industry. However, unless the local timber industry is regulated in a way that requires all logs to be directed through the sort yard, this is an unlikely outcome. The sort yard will be competing with mills for logs. Loggers will choose to sell their logs to the sort yard (not directly to mills) when it is in their financial interest to do so. Similarly, mills will buy logs from the sort yard (not directly from loggers) when this improves their financial performance.

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